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Dynamic Network and Protection Security of Transmission Systems

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Blackout, Blackout Prevention, Dynamic Security Assessment, DSA, Power System, Protection, Security, Selectivity, PSA, SIGUARD, Stability.

ABSTRACT

During the previous decades, the increase of the consumption of electric energy led to an extension and a spatial expansion of synchronous operated AC systems as well as higher voltage levels. In Europe, technical and economical advantages of combined operation caused the interconnection of adjoining networks. So, the synchronous operated combined network of UCTE with an installed generation capacity of currently more than 860GW was created. Today, as an organisation, the UCTE is integrated in ENTSO-E (European Network of Transmission System Operators for Electricity) (www.entsoe.eu).

In the near future, North Africa will be connected to the ENTSO-E transmission network, using the so-called “Mediterranean Ring“, which will be supported by HVDC (high voltage direct current) links. This will help to implement major solar projects, such as DESERTEC, in the Sahara desert.

In the course of deregulation, privatization and trading of electrical energy, the loadflow in special network areas is extremely increasing. This results in transportation bottlenecks and deterioration in reliability. With a view to global warming and the very necessary reduction of CO₂-emissions, there will be additionally a significant change in used resources and the energy mix. As the transmission and distribution network structures were developed in accordance with the generation and load structures of the past, significant structural and operational changes of the networks are now required.

Large-area outages and blackouts in America and Europe have confirmed that the interconnection of adjoining networks is beneficial in terms of operation and economy, but it also bears the risk of uncontrollable, cascading outages. Especially when those networks are operated close to their thermal limits in certain areas, stability and protection problems will occur.

In the paper, methods for the assessment of the dynamic network security, with regard to the installed protection system, are introduced. Currently, an accordant online system is under development together with European Universities and European Transmission System Operators. Here, the purpose is the observation of the security of the overall system, consisting of primary network and the superimposed interacting protection system including its communication.

The assessment of the security of the installed protection system with its actual characteristics and settings is of special importance.

1 INTRODUCTION

During the previous decades, the increase of the consumption of electric energy led to an extension and a spatial expansion of synchronous operated AC systems as well as higher voltage levels. In Europe, technical and economical advantages of combined operation caused the interconnection of adjoining networks. So, the synchronous operated combined network of UCTE with an installed generation capacity of currently more than 860GW was created. Today, as an organization, the UCTE is integrated in ENTSO-E (European Network of Transmission System Operators for Electricity) (www.entsoe.eu).

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2 TRANSMISSION NETWORK GERMANY

In Germany, the generation of energy undergoes a change including three significant tendencies acc. to Fig. 1:

1. An increase in generation from renewable resources near the point of consumption, feeding directly medium and low voltage distribution networks.
2. An increase in resources-orientated centralized generation, such as onshore and offshore wind farms, solar parks and coal-fired power plants, feeding the high-voltage transmission network.
3. A shutdown of nuclear power plants in load centres.

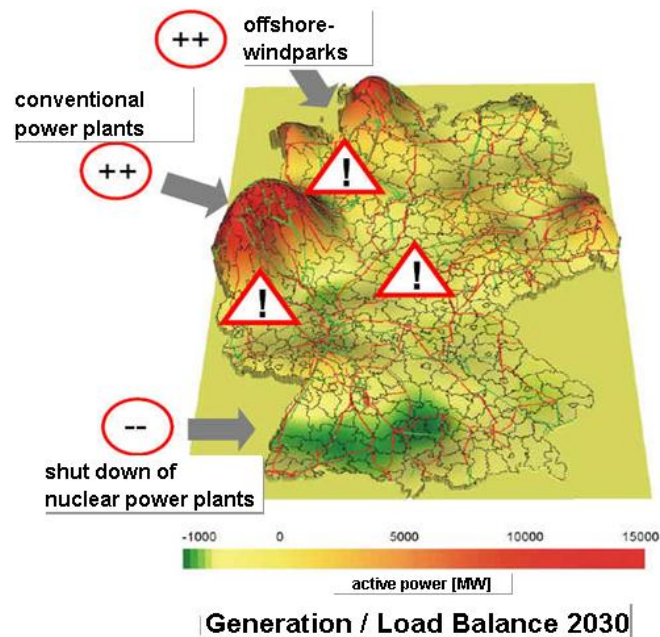


Fig. 1: Regional Load Balance in Germany 2030 Source: CIGRE SC2 C2, RWE, Nov. 19, 2008

In the future, these changes will lead to spatial separation of generation and consumption in the German transmission network. This causes longer transmission ways in a network, which was not designed for this. It is expected that steady-state bottlenecks, dynamic oscillations and protection problems will occur, which have to be detected in advance, and against which countermeasures have to be determined and verified online [1].

3 ASSESSMENT AND IMPROVEMENT OF NETWORK SECURITY WITH SIGUARD®

The measures for the assessing and improving the network security can generally be divided in three time periods, referring to Fig. 2:

Past:

The analysis of already occurred disturbances on the basis of disturbance and fault records allows us to identify weak points as well as wrong protection concepts and settings and to improve them in the future. A wide range of usable software tools is available on the market.

The disadvantage here is, that disturbances must have occurred at least once in order to identify a weak point.

Present:

Today, so-called Phasor Measurement Units (PMUs) are available, which are able to carry out time-synchronized and time-stamped measurements of the voltage and current phasors in the range of 20-100ms, using GPS, the Global Positioning System. The transmitted phasors will be collected and archived in Phasor Data Processors, and are then available for online monitoring of the electromechanical behaviour of the system. This is called “Wide Area Monitoring”. The Siemens Phasor Data Processor is the SIGUARD®-PDP, which is also able to provide further analysis of the phasor measurements.

On the basis of this higher observability, it is possible to design a “Wide Area Protection and Control System” in the future, provided that sufficient fast power electronics equipment (FACTS and HVDC) are available to close the loop.

Future:

With the performance of up-to-date computers, nationwide networks can be dynamically simulated and analyzed with sufficient speed. Hereby, the actual state-estimator results, the actual switching state and the state of the protection system will be used as initial conditions.

So, it is possible to receive a foresighted assessment of the network stability in case of disturbances and contingencies, before these disturbances even occur. This also allows us to determine and verify countermeasures, which can be proposed to the operator. It is the first small step towards an “Autopilot” for network operation.

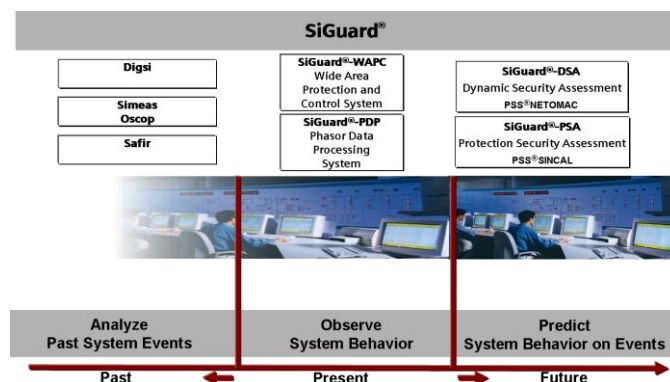


Fig. 2: Measures for assessing and improving the system stability

3.1 Dynamic Security Assessment with SIGUARD®-DSA

Network disturbances such as short-circuits, equipment and generator failures as well as sudden network changes, caused by switching, create electro-mechanical transients [4, 5]. Whether these events do not only endanger the steady-state but also the transient stability must be analyzed beforehand using a so-called “Dynamic Security Assessment, DSA”. To do so, all passive equipment

(wires, cables, transformers, ...) as well as all active, switched or controlled equipment (generators, capacitor banks, FACTS, ...) including their controllers must be simulated.

In order to consider the influences and limits caused by the protection system, e.g. in case of overload or power oscillations, the dynamic simulation software must be able to simulate the protection devices of many different manufacturers including all their characteristics and communications. Also out-of-step protection relays and vector-jump relays must be considered. This is indispensable as the relays have direct impact on the switching condition of the network through the circuit breakers they are assigned to. That is the only way, the danger of cascading outages, as occurred at beginning blackouts, can be identified. A DSA-system, for example the Siemens system SIGUARD®-DSA, must be able to not only assess the dynamic state of the system, but also to determine, rate and visualize the margins to critical states of the system [3]. To do so, an interconnection to existing control systems is essential, in order to provide continuous snapshots of the actual, quasi-steady-state condition of the system as a basis for the dynamic security assessment [10].

If network outages are simulated and possible dynamically critical conditions are found, the DSA-system should be able to find measures and solutions that will keep the system or bring it back in a stable and secure mode. Some examples for such measures are:

- Blocking of transformer tap changers (OLTCs)
- Switching of available reactive power components
- Islanding
- Load shedding
- Generation shedding

The Siemens SIGUARD®-DSA is using the simulation software PSS®NETOMAC [2] as engine. With PSS®NETOMAC it is possible to carry out the dynamic outage simulation faster than in real-time using a standard PC.

At the exemplary project for a nationwide transmission network in North Africa [11,12], where the Siemens DSA-system is already in use, it could be shown, that in the time between two consecutive snapshots of the EMS-system (15 min) more than 2000 dynamic transient stability simulations with a time step of 20ms are possible using a cluster of only 10 PCs. This means that the outage of all equipment of the transmission network could be simulated, if wanted, and the dynamic stability of the network can be assessed.

Analyses of past blackouts showed, that there is always a time period of 20 - 30 minutes between the first critical network outage and the following cascading disconnections. The typical snapshot time step of 15 minutes or less is therefore completely sufficient to identify critical network conditions, to propose countermeasures and therefore to prevent blackouts.

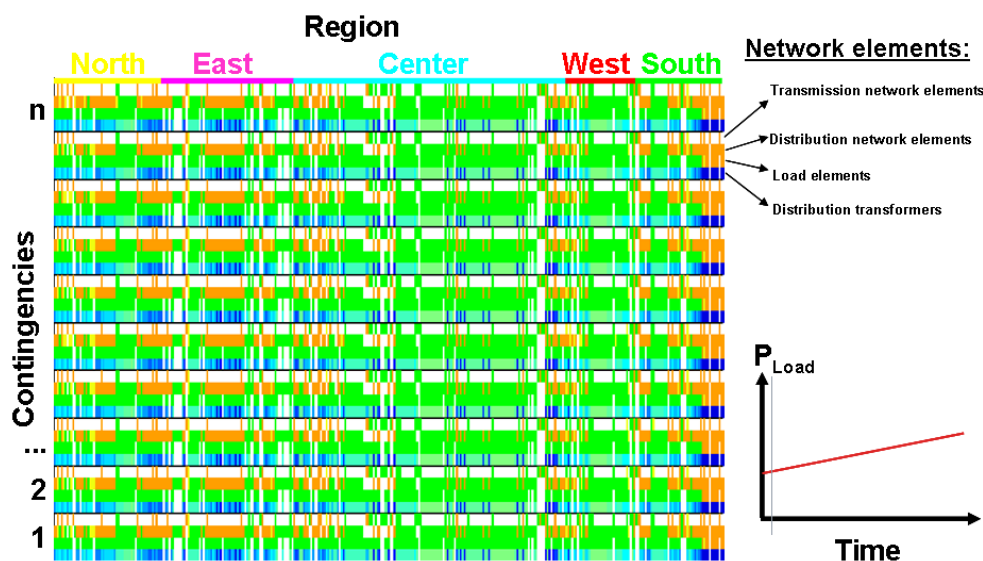


Fig. 3a: Overview over the stability-index dependability of system nodes for different contingencies and a specific load profile

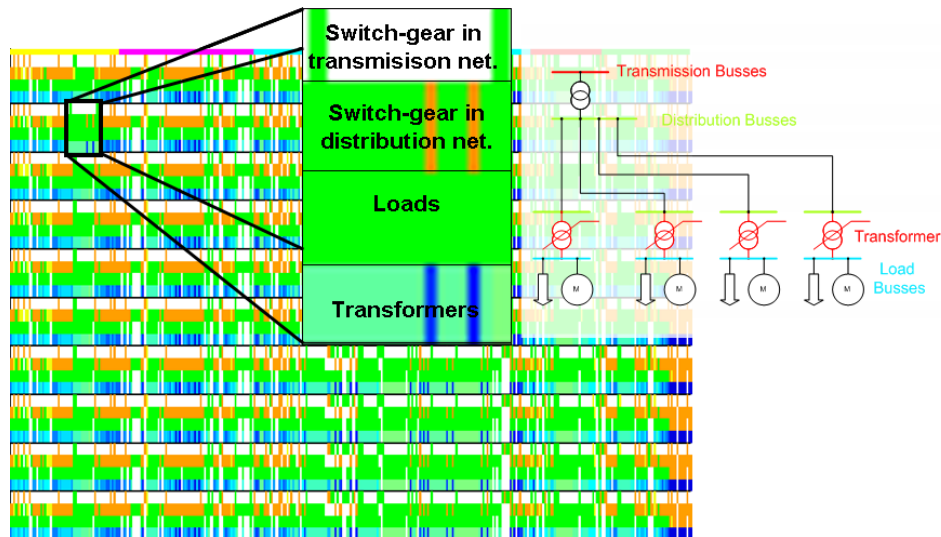


Figure 3b: Zoom for more detailed information

Figure 3 (a and b): Meta level visualization of stability indices for a nationwide power system

Fig. 3a depicts a first suggestion for visualization of system stability indices for n different contingencies (y-axis) over the system nodes (x-axis). The 3rd dimension, the different loading of bus bars is put into the time scale, resulting in a dynamic, time dependent diagram. Using the time as a slider, the indices for a specific load can be visualized and analyzed. An allocation of the coloured results is shown here only roughly according to the regional area. If the operator wishes to get more information about a, as critical coloured area or substation, he can zoom into the “patchwork carpet” and receive all additional information in the respective single-line diagram, as shown in Fig. 3b.

3.2 Protection Security Assessment with SIGUARD®-PSA

Analyses of network disturbances in different countries and continents show, that there was basically no blackout without protection devices involved. Often there are wrong or critical characteristics or settings in use.

Always recurring problems in this matter are:

- Zone 3 trips of distance protection relays. This zone is often used as an overload protection instead of using a thermal model as it is implemented in numerical relays.
- Uncoordinated or non-selective short-circuit or overload protection e.g. cross-border between different system operators
- Too low synchro-check settings so that reconnection is blocked
- Back-up oc-time protection which acts parallel to distance protection or differential protection without additional time delay
- Primary networks are enlarged, extended and reconstructed, without adjusting the protection concept and protection settings.

An important module to limit the enlargement of disturbances and to avoid blackouts is the so-called online or offline “Protection Security Assessment (SIGUARD®-PSA)”. Based on the actual switching scenario of the network, an automated analysis of the selectivity of the overall protection system can be carried out. This requires, of course, the functions of the applied relays, their characteristics and settings as well as the communication between the devices. Using PSS®SINCAL [6] as engine, all possible kinds of faults can be simulated anywhere along lines, on bus bars, in transformers, etc. Pickups and trips of relays are simulated and are evaluated considering selectivity aspects. Results of the online or offline simulation can be alarm lists which can indicate the need of a protection study. It is also possible to use an expert system which proposes improved, selective settings. These improved settings can be verified and documented in the course of another simulation loop before they will be actually set in the relays or sent directly to modern adaptive relays.

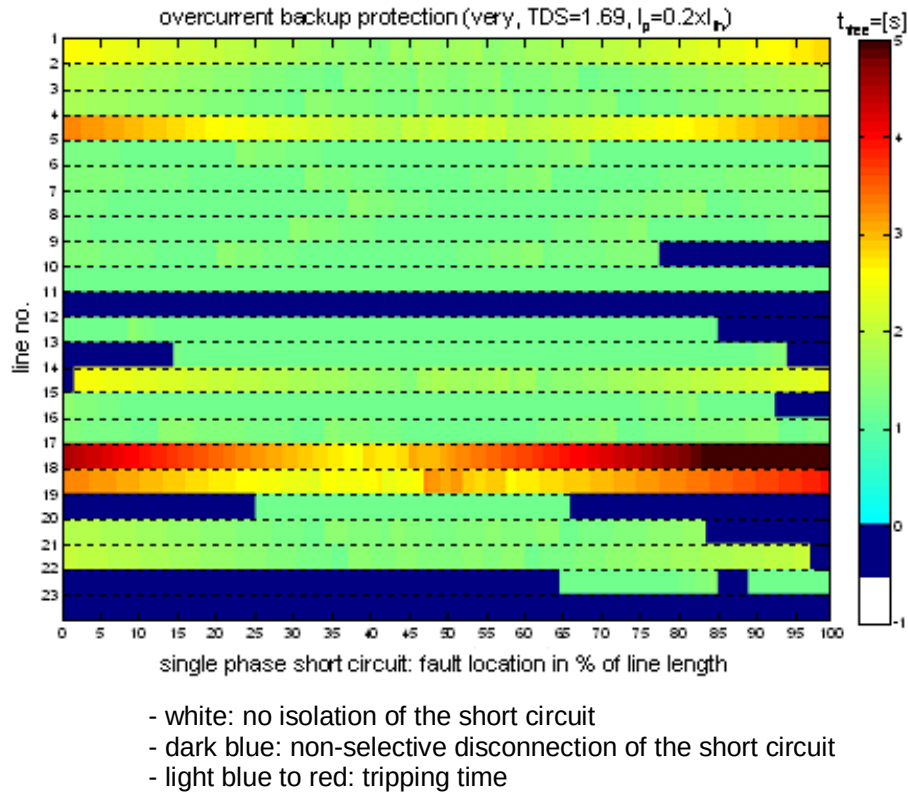


Fig. 4: Fingerprint of a backup protection system in a network with 23 lines

If nationwide power systems are analyzed, which already has been carried out for transmission networks with more than 12.000 relays, the proposed graphical description of the quality within a meta level is absolutely necessary [7, 8] like for the DSA system. Here, a tripartite analysis and referring graphical description has been proven to be useful, divided in:

- Main protection alone
- Back-up protection alone
- Main and back-up protection combined

Figure 4 shows therefore a “Fingerprint” of the back-up over-current time protection system of a small transmission network with 23 lines. In this case, the over-current time protection devices are all parameterized with Inverse-Time characteristics.

For the evaluation of the selectivity and the trip times, a large number of different kinds of faults and fault resistances were simulated, each in the pattern of 1% along the lines and also on the bus bars. Figure 4 shows one of the results, namely for single line-to-ground faults. It is possible to identify very easy the lines on which non-selective trips occurred (dark blue) and the ones with extremely increased trip times (red), without checking of dozens of grading charts. If zoomed into the result diagrams, detailed information regarding the course of the fault clearing can be received for each short-circuit simulation point.

Usually the characteristics and settings of relays will be plotted for the selectivity analysis. By this means, it is only possible to check the selectivity of one sort of protection relays against each other. E.g. either overcurrent or distance protection. By the use of the Fingerprints of SIGUARD®-PSA, where the fault clearing behaviour of the overall protection system will be evaluated and shown, a clear assessment of the quality can be performed regardless of the kind of protection relays.

4 SUMMARY

Deregulation, energy trade and the reduction of CO₂-emissions originate a different usage and a changed operation of transmission systems. High utilization of equipment and high loads in network corridors result in stability and protection problems [9]. In the future, new tools are required to identify critical system conditions beforehand, not only in the steady-state field but also dynamically. Those

tools must be able to inform the operator about the safety margins between the actual point of operation (including possible outages) to voltage and frequency collapse points. Here, the protection system must always be under consideration as its characteristics and settings can reduce those safety distances. When critical system conditions are identified, it must be possible to determine, verify and propose countermeasures.

In parallel the selectivity and speed of the protection system must be assessed to find in an early stage possible so called “hidden faults”.

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