Online Dynamic Security Assessment System for Power System Monitoring and Control

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***Abstract*—In recent years the energy consumption, decentralised feed-in, storage of renewable energies [1] and the power system complexity have grown rapidly worldwide. Hence, some electrical networks are already working at their stability limits because they were not originally designed for today's load. Consequently, the risk of power system instability has greatly increased. Therefore, protecting electrical networks from critical situations such as blackouts has become a very relevant issue in the network operation. The fast evaluation of the current network state, particularly its dynamic state, and the use of appropriate remedial measures in the control rooms play an important role in solving this problem. This paper describes the online Dynamic Security Assessment system for the prevention of power system instabilities and improvement of the electrical network state by applying remedial measures.**

***Index Terms*—contingency; control room; Dynamic Security Assessment (DSA) system; dynamic stability; power grid.**

I. Introduction

The energy demand around the world is increasing by 2% per year according to the American Energy Information Administration (EIA) [2]. Such a rapid increase of the energy demand, utilization of renewable energy sources lead to growth of the power grids and their complexity. Nowadays the electrical networks utilize more energy than they were originally designed to handle [3]. Consequently, the power grids are nearing not only their thermal limits, but more often their dynamic stability limits, which leads to unexpected critical situations in the power grids e.g. blackouts.

Therefore, the dynamic power system stability has recently become a very important topic in the area of the electrical network monitoring. Today the standard control rooms can usually consider only the steady state stability of the power systems, which is no longer enough to provide their security [4].

So-called "Dynamic Security Assessment" (DSA) methodology takes into account the dynamic system stability behavior. Hence, using an online DSA system in the control rooms could improve the observability of the electrical networks, identify dynamic problems and avoid blackouts by using appropriate remedial measures.

In this paper a concept of the online DSA system, its purpose, scope and possible functionalities are considered. Further, input data quality requirements, to provide the accurate instability prevention in the power grid, and deployment of the DSA system are described. In addition, the visualisation of such system on an example of the SIGUARD® DSA system [12] by Siemens AG is introduced.

II. Dynamic Security Assessment (DSA) System

The power system security can be identified from the power flow change and physical, operating and economic limits. The identification of the power system critical limits and instabilities, fast application of correct remedial actions are keys for realizing the power grid security [5]. Hence, Dynamic Security Assessment (DSA) of the power system was developed to perform this task [6].

A. Power system measurements [9]

Power system measurements can be provided by system operating tools, e.g. often used Supervisory Control and Data Acquisition (SCADA), which is based on measuring devices such as Remote Terminal Units (RTU) or Phasor Measurement Units (PMUs). Obtained measurements of the power grid parameters are used to create the converging power flow of the electrical network by so-called State Estimator (SE). This power flow or the power system state can be utilized by DSA system for the evolution of the power system stability.

B. The purpose of a DSA system and its security criteria

The main purpose of a DSA system, e.g. the Siemens SIGUARD® DSA system [12], is to detect critical situations in the electrical network early enough and to help a network operator in the network control room avoid instabilities in the power grid [7].

Usually, a DSA system should consider the following security criteria [5], [8]:

- angle stability,
- frequency stability,
- transient stability,
- voltage stability,
- small-signal stability,

Different phenomena in the power grid, which describe its stability, such as voltage stability, rotor angle, maximum frequency deviation, frequency gradient, frequency recovery time, dynamic voltage, quasi-steady-state voltage, fault ride through, line power flow, load shedding, transformer power flow, power oscillations etc., could be evaluated with a help of so-called indices or indicators [14]. The results could be scaled between 0 and 1, where 0 means that the power system is completely stable regarding the considered phenomenon and 1 means the power system instability, possibly a blackout. SIGUARD® DSA [12] uses e.g. the voltage stability index, angel index, maximum frequency deviation index, frequency gradient index, frequency recovery time index, dynamic voltage index, quasi-steady-state voltage index, fault ride through index, line power flow index, load shedding index, transformer power flow index, small signal stability index etc. to assess the dynamic power system stability.

For example, Angle Index (AI) is often mentioned in literature and is defined as a minimum between 1 and the maximum ratio of the maximum load angle $\delta_{i,max}$ of the i-th generator and the maximum admissible load angle $\delta_{max,adm}$ given by the protection relay (1) [15] [16]. Usually the protection relays of the generators limit the generator load angle (δ_i) to a certain value (e.g. 120°) [16].

$$AI = \min\left\{1, \max_{i=1,\dots NG}\left(\frac{\delta_{i,\max}}{\delta_{\max,adm}}\right)\right\} \qquad (1)$$

where N_G – number of generators.

C. DSA system applications

A DSA system could be used for:

- Network operation (system monitoring, fault analysis, risk assessment, control, remedial action verification, decision support, alarming)
- Day ahead planning (security check of the system dynamic behavior)
- Long-term planning (detection of weaknesses and problems in the power grid and their elimination, planning of the stability limits),
- System model improvement
- market dispatch (optimal utilization of the network equipment, definition of technical constraints for the market)
- Power system reserve determination
- renewable energy sources operating (dispatch determination through the fast evaluation of the network state)
- Asset management (optimal utilization of the network equipment)
- Training for operators, market dispatchers, planners, asset managers, etc.

D. DSA system modes

1) Online mode: In this mode, a DSA System is usually used for the evolution of the dynamic power grid behavior in the control room. The online DSA system assesses the dynamic power system stability in real-time receiving data about the current steady state of the electrical network. Therefore, a dangerous situation in the power grid, e.g. blackouts, must be determined very fast to apply some remedial measures on time and in this way prevent the power system instability.

2) Off-line mode: A DSA system can be also used off-line for different tasks, e.g. long-term planning, system model improvement, training, etc. Such tasks do not need fast decision-making for avoiding critical situations in the power grid, which is very important for the online mode in the control room. In the offline mode, not only models of the real electrical networks can be used but also models of fictitious power grids, e.g. for the training so-called test network model of a nonexistent small power grid is usually chosen.

3) Study mode: In this mode, power network and operational planning studies can be performed by engineers off-line. Furthermore, the dynamic power grid behavior can be easily studied with the DSA system. The network state data for the study mode could be taken from the life operating system.

E. Possible functionalities of a DSA system

1) Power system model size and its element models: A DSA system should be able to work with large network models, which include all network element types, e.g. lines, transformers, bus bars, loads, generators, HVDC, FACTs, tap-changers, etc., and their associated controllers, e.g. Automatic Voltage Regulators (AVR), governors, Power System Stabilizers (PSS), Over Excitation Limiters (OXL), Under-Excitation Limiters (UXL), etc.

2) Power system protection [14]: The power grid model often includes different type of the power system protection. Therefore, contingency simulations in a DSA system should also consider their behavior.

3) Screening: The screening method can help to identify critical contingencies very fast. Main power flow parameters such as voltage, angle and frequency could be used for the screening. Particularly, this function is important for the online mode because in this way the contingency simulation time could be extremely reduced. Therefore, the control room personnel has more time to apply remedial measures by a critical situation and keep the power system stable.

4) Contingencies in a DSA system: A DSA system should be able to simulate different type of contingencies and their combination to prevent possible critical situations in the power grid:

- Different types of short circuits (single-phase-to-ground fault, phase-to-phase fault, double-phase-to-ground fault, three-phase fault, three-phase-to-ground fault)
- Line and generator tripping
- Network element switching (lines, electrical circuit breaker, etc.)
- Overloading of power grid element (transmission lines, transformer, etc.).

5) Contingency screening [14]: The contingency screening could be based on constraint definitions for each contingency and/or historical data of the power system simulations.

6) Plausibility check of the power system model and its states [17]: The power system model plausibility could be automatically tested by a DSA system at the beginning of its integration into the power grid. Furthermore, every new state estimated operating point of the electrical network, provided from the online system, should also be checked for the power flow plausibility by a DSA system before contingency simulations are started. During this procedure, different power flow parameters, e.g. current and voltages of the network bus bars, line angles, generator working points, etc., should be compared with the values from the state estimated operating point.

7) Short-term forecast: An online DSA system should also be able to make the forecast on the power system behavior for a short-term (e.g. from 30 minutes to several hours). In particular, this function is very important for the power systems, which include an unpredictable generation based on e.g. the solar, wind or geothermal energy.

8) Remedial measures in a DSA system: By critical situations in the power grid, a DSA system may be able to propose different remedial actions to the network operator. These actions can improve the current network state or to prevent a blackout, to the network operator. The following remedial measures could be used [4], [10], [11] in the power networks:

a) preventive measures such as:

- Topology changing
- Using the voltage and current tolerance bands
- Generator rescheduling
- Redispatch, etc.

b) corrective measures such as:

- Tap-changer blocking
- Quadrature booster
- HVDC
- Element switching and tripping (e.g. lines, capacitors, circuit breakers, etc.)
- Generation rejection
- Load shedding
- Islanding, etc

9) Result visualisation: Simulation results of a DSA system should be clearl and simple displayed particularly in the online mode. Therefore, the control room personnel has enough time to take some actions by a critical situation.

10) Simulation result archive: A DSA system may be able to save power network simulation results because they could be needed for different analysis in the future.

11) High integration ability: A DSA system should be easily integrable into any online control system e.g. SCADA (Supervisory Control And Data Acquisition).

F. Concept of an online DSA system

An online DSA system must work cyclically. If a new power system state, a so-called snapshot is available, the cycle starts with the simulations of the previously applied contingencies in the parallel time domain on a computation server. Then the simulation results should be evaluated. If some stability problems are found, the online DSA system should display this information immediately and in a very clear way, e.g. the SIGUARD® DSA system [12] uses a traffic light for the simulation result representation. Finally, the online DSA system should also propose some remedial measures, e.g. load shedding, element switching, redispatch etc., to keep the power system stable [9]. Figure 1. shows this cyclic process of the DSA system work.

The control room personnel has enough time to act on the critical situation only if the online DSA system works very fast. To provide its fast work the DSA system needs to use a power system simulation engine for the contingency simulations, which is able to work faster than in real-time to forecast changes in the electrical network state, e.g. PSS®NETOMAC [13].

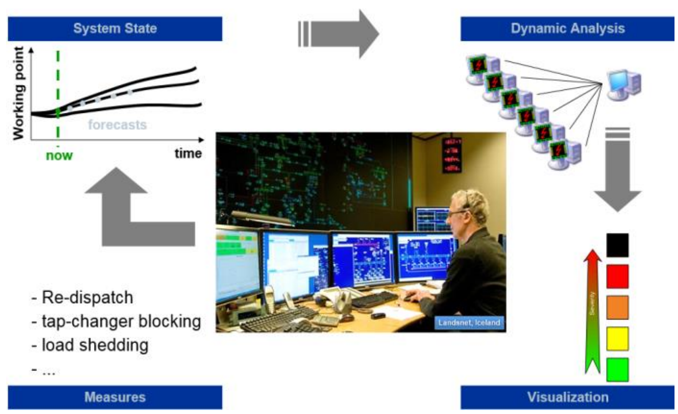

Figure 1. Online DSA system concept [9]

G. Input data quality requirements

A DSA online System can only supply expedient simulation results and propose appropriate remedial measures by a critical situation in the power grid if the input data for the DSA system has high quality. This input data includes:

- Dynamic power system model
- State Estimation from any SCADA system
- Power system states from day-ahead planning
- Power system forecasts (optional)

The dynamic power system model must be done accurately and include the description of all physical phenomena, which are important for the assessment of the dynamic stability. It must be flexible enough and be easily adaptive if some changes are made in the electrical network [9]. Furthermore, it should also be updated very often. The State Estimation of the power system must be done accurately as well and the SCADA system must provide high-quality snapshots. The accuracy of the DSA system work can be guaranteed only if the above-mentioned input data quality requirements are satisfied.

H. Deployment of online DSA system

The deployment of an online DSA system can be realized in different ways depending on the performance, availability and its reliability requirements. The DSA system can be installed on a single server, desktop PC or notebook with some minimum requirements as a simplest deployment way. However, in order to obtain a high performance, high availability and high reliability of DSA online system its components can be deployed on a clustered environment [14].

III. Visualisation

A. *Four-layer result representation*

1) Result representation in the cockpit

To help the control room personnel react very fast to emergencies a main layer of an online DSA system should descriptively show that the electrical network is now reaching its stability limits and that it is in a dangerous state. For example, the cockpit of a DSA system could display the instability risk and how close the power system is to its dynamic stability limits. For this purpose a traffic light approach could be used, which allows the control room operator to notice a network emergency state very quickly and take some remedial actions to keep the power system stability. Figure 2. shows the cockpit of the online SIGUARD® DSA system [12] with such a traffic light approach.

The pre-contingency, post-contingency and measure-contingency curves, which show the power system progress in time, are represented in the cockpit. The pre-contingency curve is based on the power flow simulations of the snapshots, the post-contingency curve - on the dynamic contingency simulations and the measure-contingency curve - on the dynamic simulations of the contingencies with applied remedial measures. The cockpit displays the contingency simulation history, the current working point simulation and the forecast of the power grid state changing.

The traffic light shows the power system moving from the stable state (green color) to blackout (black color). The yellow, orange and red colors indicate that there are some system stability problems.

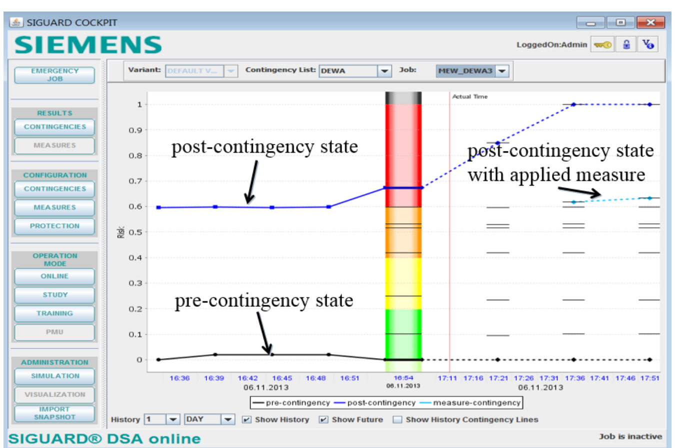

Figure 2. Online DSA system cockpit [14]

Figure 2. shows how the test network, which is used for testing of SIGUARD® DSA system, is moving from the stable state to the power system instability by a critical contingency. In this example, the short circuit on a generator bus bar is able to cause frequency problems in the test network and consequently lead to blackout. By duly automatic applying an appropriate remedial measure, e.g. fast tripping of the affected generator, the test network stays stable. Therefore, the critical network state can be avoided.

2) Detailed analyses of dynamic stability problems

To understand the causes of the dynamic stability problems the operator needs detailed information about contingency simulations of the power system. The following layers in Figure 3. were developed for the detailed analyses.

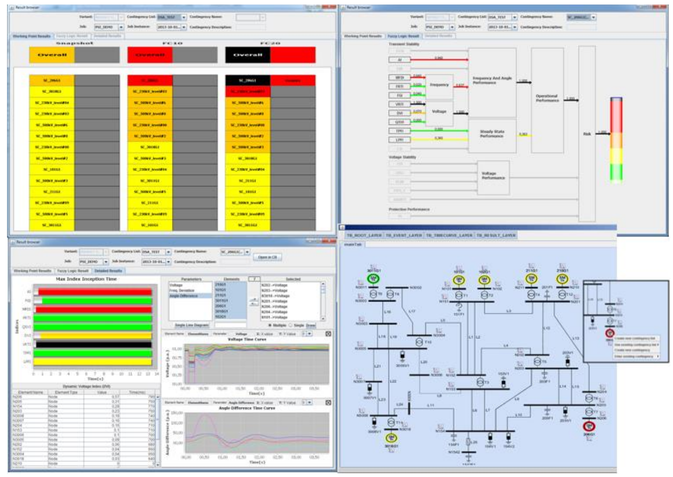

Figure 3. Result Browser layers [14]

With help of the first three layers the critical contingencies, physical phenomena and networks elements involved in the critical situations can be determined. Therefore, the causes of the dynamic stability problem can be analysed in detail, e.g. for the blackout prevention or for the network planning.

In addition, to make the stability analyses process more convenient and faster, a DSA system should be able to display a Single Line Diagram (SLD) of the power system model.

The SLD could also provide the contingency simulation result. Hence, the network elements are colored according to the maximum value of indices that observe these elements. In this way the network elements that causes the stability problems or are affected by a contingency, can be easily identified.

IV. Conclusion

Because of the high energy consumption, power grid complexity [4] [7] and renewable energy utilization [15] is continually increasing on a global level, the assessment of dynamic problems in the electrical networks is becoming very important issue for the secure system operation. In order to avoid some power system instabilities caused by dynamic problems, the evaluation of the dynamic of the power system in the control room must occur faster than real-time [4]. This gives the control room staff enough time to apply some remedial measures to protect the power system from blackouts.

The main security criteria functionalities, capabilities and applications of an online DSA system that is able to perform this task are introduced in this paper. Further, the concept of an online DSA system, its deployment and the input data quality requirements are described. In addition, its possible visualisation is presented, using as an example the SIGUARD® DSA system [12].

The SIGUARD® DSA system [12] is easily compatible with SCADA systems and can be installed in the control rooms for the dynamic security assessment (DSA) of the power systems. It is also able to forecast the electrical network dynamic behavior when the power system moves towards the critical state and alarm the network operator about it early enough. Finally, this online DSA system can recommend different remedial measures to avoid critical situations in the power grid.

The DSA system can be used for a day ahead and long-term planning in power grids as well. Its visualization can give a detailed view of dynamic problems in the power network, which can help the experts to analyse the reasons of the dynamic instabilities of the power grid.

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