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STABILITY ASSESSMENT IN A POWER SYSTEM CONTROL CENTRE

OCENE STABILNOSTI V NADZORNEM CENTRU VODENJA ELEKTROENERGETSKEGA SISTEMA

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Abstract

This paper presents a conceptual picture of new stability control possibilities in power system control centres. A potential future state of power system operations and control, with regard to stability assessment, is described and compared to the present state. New technologies have raised the possibility of developing much faster and more widespread stability control that can enable the safe operation of the grid closer to its limits.

Povzetek

Članek predstavlja konceptualno sliko novih možnosti nadzora stabilnosti v nadzornem centru elektroenergetskega sistema. Opisana je primerjava med prihodnjim in sedanjim stanjem na področju poslovanja in nadzora, povezano z oceno stabilnosti. Nove tehnologije so odprle hitrejše možnost razvoja in nadzora širokega področja stabilnosti, ki lahko omogoči varno delovanje omrežja v področju skrajnih mej.

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1 INTRODUCTION

To maintain interconnected power systems in a stable dynamic state, tight control and protection along with the intelligent and diligent operation of such systems are necessary. The general public often take operating details for granted; a catastrophic failure usually happens before power system stability becomes a topic of discussion. Power system faults mostly occur due to natural phenomena, beyond human control. However, if power systems are expected to recover automatically and to continue delivery power, they have to be well designed. If so, very little inconvenience will be experienced by customers. Achieving this is hardly possible without high costs in terms of manpower and equipment. The result of an open market economy is that power systems are forced to operate much closer to their limits of stability; therefore, the decisions of operating personnel must be based on an accurate, online system information and simulations. The current practice of extensive offline simulation of a comprehensive set of possible system operating conditions is good for training purposes but is less useful in real time power system operation situations. As a side effect of liberalized transmission access, networks have to accommodate MW transfers that can be quite different from those for which their transmission networks were originally planned. This is mainly because of the possibility for parallel flows to occur, which is often the case with energy transactions across multi-area systems. Low bus voltages and significant network loadings can occur. The risk of such deteriorated operating conditions, causing blackouts due to instability, increases when a large amount of MW is transferred across a stability-constrained transmission corridor. Furthermore, there are other causes, such as a major disturbance occurring, or even if an otherwise insignificant topology change (such as a minor line trip) happens in a system already operating near its maximum load ability limit. The abovementioned facts highlight the need to compute stability limits for the current and next-day operations processes, thereby foreseeing whether the transmission loading progresses and it is projected to maintain in secure operating reliability limits.

2 STABILITY ASSESSMENT IN THE SCADA/EMS

2.1 SCADA/EMS

The main function of the control centre is real time data acquisition from the entire power system so that the operator can monitor its operation. Manual operation of controls, such as changing transformer taps or opening or closing circuit breakers is also a significant part of a control centre's function. These functions are all together known as Supervisory Control and Data Acquisition (SCADA), and the control centre is often referred to as SCADA.

Most of the SCADA functions are executed in real time. The monitoring of data generated by a real-time process is a typical example of real-time activity. However, the information generated in SCADA system can also be used in other ways that do not qualify as real time. A data warehouse can be created from historical data and used for post-analysis.

Together with advances in information technology, the computational power of the control centres has grown, and consequently more functions have been added. The most prominent one recently added has been the state estimator. It calculates the real time steady state model of the network. This model can thus be used for two kinds of real time calculations. One, known as security analysis, can study the effects of disturbances (contingencies) and can alert the operator if the post-contingency conditions violate limits. The other, usually using a set of analysis tools known as optimal power flow, can be used to suggest better operational conditions to dispatchers. The abovementioned advanced analytical tools provide better operational guidance to the operator and can provide more efficient operation than the old SCADA systems could. Those functions are now known as Energy Management Systems (EMS).

2.2 Real-Time Stability Assessment Possibilities

There are at least three ways to distinguish on-line security assessment, [2]:

- Distinguishing computer analysis and simulation of contingencies from direct monitoring of the current operating point,
- Distinguishing the criteria of types of phenomena: thermal overload, voltage stability problems, or angle stability problems,
- Differing between preventive countermeasures because of a potential disturbance threat and corrective countermeasures that follow the occurrence of the actual disturbance.

The transient stability problem is, unfortunately, far too demanding on computers for true real-time performance, especially if using the conventional time-step simulation method. The outcome of transient stability calculations depends on the initial state, but there is also an issue of the critical dependency on the duration and the location of the fault in the network. Accordingly, determination of system stability requires immense computational effort even for medium-sized networks. Another issue arises regarding the representation of injections in tie lines by SCADA/EMS models. On the border line, the internal network model, and the external system, the incoming power flows (imported power) are usually shown as generated powers being injected into the internal network. Since the abovementioned generators are not actually generators, some other way must found to represent them in the stability calculations. One way of solving this issue is to introduce dynamic equivalents to the model.

The capability of a power system to retain its stability in the presence of slow deviations in the total demand is another type of stability. Practically, an operator needs to know how much additional load can be handled by the transmission system starting from the current state if the load and, consequently, generation and imports would be increased progressively. This can be referred to as steady state stability. Large disturbances caused by faults, loss of equipment, and so on are not part of the transient stability problem. The limit of steady state stability corresponds to the maximum load; moreover, a wheeled power system is able to cope in the current system configuration without collapsing. Imbalances in increases of transmission capacity and growth in the use of electrical power bring many power systems close to limit of stability. Large transfer capacities make power systems more flexible and robust than those lacking the ability to accommodate certain power transfers. One indicator of power system security is certainly the system's transfer capacity.

Real-time cognition and the monitoring of the steady state (voltage) stability limit is highly valuable for the system operator. For that information to be usable as a simple indicator, a limit should be set in terms of a "distance" to instability; specifically, the indicator answers the question about how far the current system is from the defined limit. Voltage control is always a local control, but one must be aware that controlling the voltage at one node affects the neighbouring nodes.

2.3 Voltage Stability

Voltage stability is considered to be the ability of a power system to maintain voltages in acceptable ranges at all buses in an observed power system under normal conditions and after disturbances occur. Voltage stability assessment is becoming increasingly complicated as power systems are strengthened. To substantiate that, it should be noted that voltages do not indicate the proximity to voltage collapse point in heavy loading conditions or even in heavily compensated systems. In previous decades, transient angle stability has very rarely been a reason for the restriction of power transfers due to stronger power systems and the development of new equipment technology. Nevertheless, over the past 20 years, the power system blackouts occurring throughout the world have been voltage collapses in most cases.

Voltage instability progress is rather slow, so the dynamic security analysis techniques do not yield satisfying results in voltage collapse detection. Accordingly, separate software is required for voltage security analysis. The continuation of power flow programs use a special technique to obtain a convergence of the power flow solution near voltage collapse conditions and, therefore, are the main off-line tool used to study voltage conditions in networks. This ensures a method for determining the limits in order to avoid voltage collapse. Using these kinds of techniques online has been described in other articles [15], [16]. It has been stated that the static and dynamic security assessment tools provide much information about voltage trends in real time system under contingencies, and that they should be used as a basis for voltage collapse prediction. The static security assessments, for instance, calculate voltages for each contingency, and a voltage collapse limit alert is triggered if there are voltages that are particularly low. If there is no convergence in power flow studies for a contingency, it may be an indication of voltage collapse and continuation of the power flow should be performed.

One problem that exists on online security monitoring is finding the distance of an operating point from stability. Such a measure may be qualitative or quantitative. A qualitative measure does not give the exact megawatt margin but a number, i.e. a stability index that can be interpreted as a degree of stability. For quantitative evaluation, the exact active power value of deviation to stability with respect to a credible scenario is known. Displaying the exact active power value can be computationally highly intense, so the focus is generally in generating a precise voltage stability index. In online applications, these indices are tended to be kept in a way that simplifies their calculation from the online measurements available. If on-line analysis is not possible, the offline study results must be translated into operating limits and indices that are easy to monitor and understand by the operating personnel. The basis of the online security assessment is usually offline computed security limits, such as transfer limits at interconnections. The data warehouse holds the security limits, and the data monitored online is compared for the closest match in the database. Operators commonly recognize these security limits as a security boundary.

The uncertainty of offline security assessments that are typically done months in advance of actual operation is minimized with the use of emerging technologies of online security assessment. The security assessment involves the simulation of the potential contingencies and effects on power systems online, i.e. closest to real time as possible. The study mode of security assessment is useful for determining power transfer capabilities, but the user has to be aware of some conservative assumptions made by the offline system.

If new conditions occur that are potentially not well understood, real-time assessment can immediately assure ongoing operation in a secure state. The first step in comprehensive security assessment is voltage security assessment. It can be done via power flow simulation; since voltage security encompasses localized problems, it is simpler than inter-area dynamic security assessment. Currently, voltage criteria very frequently limit power transfer in power companies. On-line security assessment requires static state estimation, which is difficult to perform in large power systems.

The monitoring of reactive power is an essential part of voltage stability assessment actions. If reactive power sources are near their limits, then voltages are insecure even if voltage magnitudes are within acceptable ranges. Reactive power reserves and high and low reactive power outputs are sensitive indicators of non-secure voltage situations.

Emergency control of voltage stability has the primary goal of halting the progress of an unstable scenario before it progresses toward a voltage collapse. Therefore, timing is critical, i.e. time to detect the instability and time to start applying the emergency control is crucial.

There are a diversity of measures for voltage stability control in emergency conditions, including reactive device switching, tap changer control, generation rescheduling, and load shedding.

3 MODERN CONTROL CENTER

The common current technology of monitoring and control may be summarized thusly, [8]:

a. Contingency screening is the basis of the security assessment, which is mainly a steady state power flow analysis.

b. Local information is mostly the basis of the protection and control system. In recent papers, [11], Special Protection Schemes have been described in the global impact sense. Offline studies are used to adjust control strategies, so generally the coordination of different protection and control systems is limited.

c. State estimation output is the basis of the monitoring system. It is subject to a considerable delay at the scale of tens of seconds to minutes. Usually, it is based on the local control area information. Interaction with neighbouring system is limited in most cases.

In order to eliminate these limitations, control centres built in the future are expected to make the most of wide-area information for online, measurement-based real-time security assessment, which would ensure the implementation of an automatic and decentralized control strategy.

Monitoring systems in control centres currently depend on a state estimator that is based on data collected via remote terminal units and SCADA. Future control centres should obtain the system level information from the state measurement module based preferably on a Phasor Measurement Unit (PMU). From the state measurement based on a PMU, higher efficiency is expected than at present since synchronized phasor signals give the state variables, specifically voltage angles. Data collected from Remote Terminal Units (RTU) is not synchronized, and a major effort must be made in order for bad data to be detected and the topology to be checked; therefore, the present state estimation requires more running time and is less robust. In the future, state measurements should replace state estimates.

An innovative technology called “on-line pre-decision” is the future of stability control in power systems. Decision making will be provided in five minutes as a result of online decision-making technology. Using this system will enable the calculation of the decision table to be formed online, and necessary suggestions can also be given to the grid dispatching operators together with instructions.

3.1 True Stability Margin Monitoring

If there is possibility of using state variables from state measurement, displaying the true system stability measures in real time is more feasible. Usually, only voltage magnitude is displayed, and that is insufficient information for the determination of the voltage stability margin. “As the system is more stressed and voltage collapse is a recurring threat, the voltage magnitude is no longer a good indicator of voltage stability. Hence, a true indicator of voltage stability margin is needed for better monitoring”, [7]. Most of the current technology relies on monitoring frequencies on a small area. The frequency and phase of all power generation units must keep their synchronism within narrow limits in order to keep the power grid stable. If the generator frequency falls below 50 Hz, it will rapidly heat in its bearings and eventually destroy them. Therefore, at that point, frequency protection detects frequency variations and sends a command to the circuit breakers and trips a generator out of the system. Even small frequency changes can be indicators of instability in the grid. In order to enable identifying the fault in remote locations, and to prepare for possible instability, the frequency in the wider area and its change must be monitored and traced. Using the proposed technology together with the assistance of the wide-area GIS data would make displaying the voltage stability margin and trends of changes in frequency in real time on the top layer of the actual wide-area GIS map possible. Current technology mostly relies on simulations and visualizations of local measurements. In the future, a measurement-based stability margin monitoring system will greatly aid operators in the prediction and identification of potential real-time operation problems.

3.2 Dynamic Security Assessment

After outages, a static security assessment checks for limit violations, but with assumes that the power system is in a steady state in the post-outage time. Since outages are usually the results of an accidental short-circuit that causes the isolation of the short-circuited elements by protective systems, the power system may experience significant outing in the voltages and power flows during such disturbances, [10]. If a severe enough disturbance occurs, these swings may cause generators to become unstable. In that case, widespread outages would occur instead of a single outage. Those short circuits or contingencies that cause instabilities are identified by the dynamic security assessment. No contingencies should make the system unstable if it is operated within its limits and properly planned. Nevertheless, in real-time operation, the power system happens to end up in conditions that were not foreseen when the planning was done. It is important to analyse whether such contingencies can make the system unstable. The stability calculations are even more computationally intensive and time consuming than the power flow calculations, so the online checking of stability in hundreds of possible contingencies is an exhausting task. Dynamic security assessment has become a reality thanks to the continuous falling of the price-performance ratio in information technology. Running a static security assessment has led to some new techniques as well as new algorithms, all of which have been very useful in developing dynamic security assessment tools. Contingency screening based on the concept of rapidly isolating the worst contingencies is also applicable for dynamic security. The task is to isolate the few unstable contingencies among most of the stable ones. A rapid approximate method is needed via contingency screening in order to determine the stability of the system. One common and accurate method is the time domain solution performed over sufficiently long time periods that allow the trajectories to depict stable or unstable behaviour. The approximate method calculates the time domain solution for a short time just beyond fault clearing and then projects the stable or unstable behaviour from these trajectories by performing other calculations. There are various techniques that are used: transient energy and their margins, signal energy, different coherency measures and the equal area criterion, [10]. Ranking the contingencies in order to determine the worst cases is possible via these measures. The traditional time domain solution can be used to accurately determine the stability of the system once the worst cases are determined. The abovementioned techniques work quite well for systems that are at high risk for instabilities caused by a lack of synchronizing power. These instabilities can be detected using fewer calculations because they occur very quickly, within a second or so. Those instabilities that occur after several oscillations because of negative damping are difficult to detect without detailed and longer simulation or by using modal analysis. Online dynamic security assessment is still not available for these kinds of systems, and conservative operating limits calculated offline are, unfortunately, the only answer. When the dynamic security assessment detects instabilities (although those are rare cases), the operator, once alerted, needs to take preventive action. When a contingency occurs, the rush of instability is very fast, so the possibility of the operator to take manual corrective action is rather slim. Sometimes, the operator may be able to trip special protection devices to shed load or generation, which will ensure stability. A common case is the modification of the generating pattern, which the operator uses as the available preventive action. Because this increases the cost of operation, methods to quickly calculate the minimum changes required to maintain stability for a particular contingency are being explored. The simplest way known to do this is by recalculating the power flow limits on a certain transmission corridor.

4 WIDE-AREA STABILITY AND VOLTAGE CONTROL

There is a synergy between on-line security assessment and wide-area controls. Wide-area stability controls are presently utilized mainly as so-called special protection systems. They can be also referred as remedial action schemes. These schemes are about the direct detection of severe outages. Detection is followed by transferring commands for generator tripping or other discrete feed-forward stabilizing actions. Using such controls is commonly based on direct monitoring, i.e. system conditions observed by control centre operators and/or dispatchers; the system conditions for arming such tripping are determined by off-line simulation and analysis. These controls only operate for predetermined outages, in comparison to response-based controls. It is realistic to expect more sophisticated wide-area stability controls in the future. While local stability controls are normally used and generally preferred, there are opportunities for using more advanced wide-area or centralized controls. Superior observability is the driving force behind using remote signals, [2]. Centralized controls can take action based on a large information base, and they are often a switching action.

4.1 Wide-Area Protection System for Stability

The modern power system and its stability characteristics are becoming increasingly complicated along with the increase of transmission distance, growth of loads and the composite structure of HVAC and HVDC systems. There are advanced systems that are made for the purpose of protecting the power system from blackout, and they also can significantly improve the stability of the power grid. The main defence lines of that system are:

a. Fault Clearing. It is based on accurate and fast protective relays whose job is to ensure that the fault can be quickly cleared, thereby ensuring the stability of power system. There are reliable and high-speed protection products that can ensure that the fault is quickly cleared before the system loses the stability, thanks to innovative protection elements that can significantly reduce the pickup time to trip the fault.

b. Load Shedding and generator shut-down is used in severe contingencies for emergency control. Rising of the load and generation unbalance will provoke the wide-area protection to take some intervention, such as generator shut-down or load-shedding, to ensure stability. If a stability loss in the power system is detected after the serious fault is cleared, wide-area protection and the control system calculate the power flows and generate corresponding control strategies. Control commands are then sent to the executing device so that prompt intervention can be made in order to maintain the stability of the system.

c. Out-Of-Step Islanding is local corrective control for extremely severe contingencies. If the above-described fault clearing and load shedding cannot maintain the power system's stability, then the third line of defence will be activated in order to avoid the collapse and minimize the load loss. This third line includes control devices such as out-of-step protection and frequency-voltage to maintain the system stability. The theory behind the out-of-step model of system protection is avoiding any element in power system that may trip while stable swings are on. When synchronicity is lost between two areas of same power system, or two interconnected systems, these areas must be detached as soon as possible. This is performed automatically in order to avoid equipment damage and the shutdown of major portions of the power system, [14]. Uncontrolled circuit breakers trips while the power system is in an out-of-step state can cause equipment damage and potential danger for utility personnel. With this method, it can be concluded that controlled manipulations of indispensable power system elements are necessary in order to prevent equipment damage and severe wide-area power outages, as well as to minimize the negative effects of the disturbance.

4.2 The Future

The merging of information and control can definitely be considered to be the future in on-line security assessment and wide-area control. One distinct challenge is the development of wide state estimation on interconnections. Rapidly developing information-age technology is crucial in meeting this challenge. This includes advanced systems such as integrated substation and power plant control and protection, advanced sensors, phasor measurements, communications through fibre optic and WAN and LAN technologies. In control centre-based centralized control, where a large measurement and information database is available, new control technologies such as intelligent automated controls may be applicable.

5 CONCLUSION

Adequate planning and proper operational procedures with smart decision making are crucial for maintaining the security of the power system. Current technology and a vision of the future are discussed, and a comparison between those two is given. Modern technology, specifically in terms of improvements in computers, communications and controllers, is already being used in power systems in many ways. By combining these technologies, it is possible to develop wide-area controls for power systems, which enable controlling stability better and, consequently, increasing transmission limits. New control technologies, i.e. intelligent controls, may be applied for control centre-based centralized control where large amounts of measurement and information data base are available. Steady-state contingency analyses are generally the best that the present on-line analyses in control centres typically perform. The reach of those analyses is analysing each credible contingency event by using contingency power flow studies and identifying line flow violations. Future control centres are expected to have online time domain-based analysis. That would imply the ability to perform voltage stabilization and transient angular stability in real time.

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