An Improved On-line Contingency Screening for Power System Transient Stability Assessment

This paper presents a contingency screening method and a framework for its on-line implementation. The proposed method carries out contingency screening and on-line stability assessment with respect to first-swing transient stability. For that purpose, it utilizes the single machine equivalent method and aims at improving the prior developed contingency screening approaches. In order to determine vulnerability of the system with respect to a particular contingency, only one time-domain simulation needs to be performed. An early stop criteria is proposed so that in a majority of the cases the simulation can be terminated after a few hundred milliseconds of simulated system response. The method's outcome is an assessment of the system's stability and a classification of each considered contingency. The contingencies are categorized by exploiting parameters of an equivalent one machine infinite bus system. A novel island detection approach, appropriate for an on-line application since it utilizes efficient algorithms from graph theory and enables stability assessment of individual islands, is also introduced. The New England and New York system as well as the large-scale model of the Continental-European interconnected system are used to test the proposed method with respect to assessment accuracy and computation time.

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Scopus rating (2013): SJR 0.433 SNIP 0.854 CiteScore 1.07
Detecting Topological Errors with Pre-Estimation Filtering of Bad Data in Wide-Area Measurements

It is expected that bad data and missing topology information will become an issue of growing concern when power system state estimators are to exploit the high measurement reporting rates from phasor measurement units. This paper suggests to design state estimators with enhanced resilience against those issues. The work presented here include a review of a pre-estimation filter for bad data. A method for detecting branch status errors which may also be applied before the state estimation is then proposed. Both methods are evaluated through simulation on a novel test platform for wide-area measurement applications. It is found that topology errors may be detected even under influence of the large dynamics following the loss of a heavily loaded branch.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric power components, Electric power systems, Technical University of Denmark
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2017
Super-Positioning of Voltage Sources for Fast Assessment of Wide-Area Thévenin Equivalents

A method for superimposing voltage sources is sought optimized by using a sparse triangular solver and multiprocessing. A revision to the method is suggested which exploits Schur's complement of the network admittance matrix and optimal re-use of computations. The algorithm is implemented and parallelized for shared memory multiprocessing. The proposed algorithm is tested on a collection of large test systems and performance is found to be significantly better than the reference method. The algorithm will thereby facilitate a speed-up of methods relying on Thévenin equivalent representation such as the Thévenin equivalent method for contingency assessment.

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BFI (2014): BFI-level 1
Scopus rating (2014): SJR 3.105 SNIP 3.799 CiteScore 7.77
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BFI (2013): BFI-level 1
Scopus rating (2013): SJR 3.175 SNIP 4.831 CiteScore 9.88
ISI indexed (2013): ISI indexed no
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Energy Optimization for Distributed Energy Resources Scheduling with Enhancements in Voltage Stability Margin

The need for developing new methodologies in order to improve power system stability has increased due to the recent growth of distributed energy resources. In this paper, the inclusion of a voltage stability index in distributed energy resources scheduling is proposed. Two techniques were used to evaluate the resulting multiobjective optimization problem: the sum-weighted Pareto front and an adapted goal programming methodology. With this new methodology, the system operators can consider both the costs and voltage stability. Priority can be assigned to one objective function according to the operating scenario. Additionally, it is possible to evaluate the impact of the distributed generation and the electric vehicles in the management of voltage stability in the future electric networks. One detailed case study considering a distribution network with high penetration of distributed energy resources is presented to analyse the proposed methodology. Additionally, the methodology is tested in a real distribution network.

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Scopus rating (2011): SJR 0.41 SNIP 0.709 CiteScore 0.92
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.232 SNIP 0.521
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.253 SNIP 0.42
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Scopus rating (2003): SJR 0.286 SNIP 0.523
Scopus rating (2002): SJR 0.4 SNIP 0.257
Scopus rating (2001): SJR 0.264 SNIP 0.646
Fault Tolerant Emergency Control to Preserve Power System Stability

This paper introduces a method for fault-masking and system reconfiguration in power transmission systems. The paper demonstrates how faults are handled by reconfiguring remaining controls through utilisation of wide-area measurement in real time. It is shown how reconfiguration can be obtained using a virtual actuator concept, which covers Lure-type systems. The paper shows the steps needed to calculate a virtual actuator, which relies on the solution of a linear matrix inequality. The solution is shown to work with existing controls by adding a compensation signal. Simulation results of a benchmark system show ability of the reconfiguration to maintain stability.
Improved Thévenin equivalent methods for real-time voltage stability assessment

An improved Thévenin equivalent method for real-time voltage stability assessment that uses wide-area information from synchrophasors is proposed. The improvements are a better modeling of the limited synchronous generators, and a processing that anticipates the effect of field current limiters, before the latter are activated. Several study cases using detailed dynamic simulations of the Nordic test system have been used to assess the performance of the proposed improvements. Their effectiveness is analyzed and, based on the results, their possible application in combination with the sensitivity-based voltage stability assessment method is explored.

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Publication date: 2016
On-Line Generation and Arming of System Protection Schemes

This paper presents a new method to automatically generate system protection schemes in real-time, where contingencies are filtered using a method providing N– 1 system snapshots. With future power systems consisting largely of renewable distributed generation with time-varying production, highly fluctuating conditions throughout the day will be the result. This makes off-line design of extensive defense plans for power systems infeasible, forming the motivation for the presented method. It relies on the real-time identification of which disturbances that threatens a power systems integrity. The method is based on a recently proposed method of calculating post-contingency Thevenin equivalents, which are used to assess the security of the post-contingency condition. The contingencies that violate the emergency limits are contained by pre-determining event-based remedial actions. The instability mechanisms threatening the system are individually treated, such that appropriate controls are allocated. The procedure is illustrated through a case study using the Nordic32 benchmark system.

Real-Time Countermeasures Preventing Power System Instability by using PMU data from RTDS simulation

This paper presents an innovative approach to apply wide-area control actions in real-time and prevent emerging instability. A software platform has been further developed, which utilizes Real Time Digital Simulator (RTDS) technology to prevent scenarios leading to power system instability. The software platform receives phasor measurement unit (PMU) data at a high repetition rate for full system observability. The PMU data serves as input for methods capable of analyzing the steady state torque balance for each individual generator and to determine available power reserves and possible remedial actions. The capabilities of the software platform were demonstrated by testing the methods on the Nordic32 test system and the results show that the methods can determine an active power re-dispatch and apply the countermeasures in realtime and prevent aperiodic rotor angle instability.

Real-time remedial action against aperiodic small signal rotor angle instability
This paper presents a method that in real-time determines remedial actions, which restore stable operation with respect to aperiodic small signal rotor angle stability (ASSRAS) when insecure or unstable operation has been detected. An ASSRAS assessment method is used to monitor the stability boundary for each generator in real-time. The ASSRAS boundary represents the condition when a generator reaches the maximum steady state active power injection. The proposed control method exploits analytically derived expressions for the ASSRAS boundary and other characteristic curves in the injection impedance plane to determine an active power redispatch among selected generators to restore stable and secure operation. Since the method is purely based on analytically derived expression, the computation of the remedial actions is fast and well suited for real-time operation. The method was tested on the IEEE 14-bus and the Nordic32 test systems where results show that the method can efficiently determine the required active power redispatch to avoid an imminent instability.
Unweighted Betweenness Centrality for Critical Fault Detection for Cascading Outage Assessment

This paper analyses the possible use of unweighted betweenness centrality instead of weighted betweenness centrality, for critical fault detection for assessment of cascading failures. As unweighted betweenness centrality is significantly faster to compute, the possible use of this will significantly improve the computation speed. The method is tested on four IEEE test systems, and the study finds that the unweighted analysis is not a good substitute if the method is only used naively, but it is possible to make graph modifications, and improve the unweighted analysis.

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Source-ID: 126813556
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Thévenin equivalent based static contingency assessment

The present invention relates to a method for static security assessment of a power system and a real time static security assessment system for assessing a power system, the power system having a plurality of generators, the plurality of generators being represented in the network by a plurality of voltage controlled nodes, wherein the method for static
security assessment of the power system comprises receiving information of a present state of the power system, determining a Thevenin equivalent for each voltage controlled node, determining for each voltage controlled node on basis of the determined present state of the power system and determining a first representation of the network based on the determined Thevenin equivalents, determining a modified representation of the network, wherein the modified representation is a representation of the network having at least one contingency, wherein at least one Thevenin equivalent of at least one voltage controlled node is modified due to the at least one contingency, the modified network representation being determined on the basis of the modified Thevenin equivalents, calculating voltage angles of the modified Thevenin equivalents, and evaluating the voltage angles to determine whether the network having at least one contingency admit a steady state. Also a method of providing information on a real time static security assessment of a power system is disclosed.

Convex Relaxation of Power Dispatch for Voltage Stability Improvement

A method for enhancing the voltage stability of a power system is presented in this paper. The method is based on a stability-constrained optimal power flow approach, where dispatch is done such that a maximum L-index is minimised for all load busses in a transmission grid. It is shown that optimal dispatch is obtainable with enhanced margins for voltage stability using a semidefinite relaxation of the optimal power flow problem, and that this problem can be formulated as a semidefinite program with a quasi-convex objective. Numerical tests are performed on the IEEE-30 bus and BPA systems. The feasibility of the method is demonstrated through demonstrating that improved voltage stability margins are obtained for both systems.
Critical machine cluster identification using the equal area criterion
The paper introduces a new method to early identify the critical machine cluster (CMC) after a transient disturbance. For transient stability assessment with methods based on the equal area criterion it is necessary to split the generators into a group of critical and non-critical machines. The generators in the CMC are those likely to lose synchronism. The early and reliable identification of the CMC is crucial and one of the major challenges. The proposed new approach is based on the assessment of the rotor dynamics between two machines and the evaluation of their coupling strength. A novel coupling coefficient is derived and a cluster identification algorithm is developed. The algorithm determines the CMC based on the impact of the fault on the derived coupling coefficient of individual generator pairs. The results from two cases are presented and discussed, where the CMC is successfully determined just after fault clearance.

Derivation and application of sensitivities to assess transient voltage sags caused by rotor swings
The paper introduces an approach to investigate voltage sags, which are caused by large generator rotor swings following a transient disturbance. Therefore, the method exploits sensitivities derived from the algebraic network equations. These provide information on the impact of a generator on the voltage magnitude at a load bus and the effect of load variation on the generator’s power injection. It is shown that these sensitivities give valuable information to identify critical generator–load pairs and locations for applying preventive control measures.
This paper presents a method to determine suitable countermeasures against emerging aperiodic small disturbance rotor angle (ASD) instability. The method utilizes stability indicators, computed in real time, to define a criterion for ASD stability. Sensitivities of these stability indicators are then determined and used to identify the most influential nodes for countermeasures. To increase the computational speed, only nodes visited by a self-propagating graph, rooted at the vulnerable

\[
\begin{align*}
\text{Early Prevention Method for Power System Instability} \\
\text{This paper presents a method to determine suitable countermeasures against emerging aperiodic small disturbance rotor angle (ASD) instability. The method utilizes stability indicators, computed in real time, to define a criterion for ASD stability. Sensitivities of these stability indicators are then determined and used to identify the most influential nodes for countermeasures. To increase the computational speed, only nodes visited by a self-propagating graph, rooted at the vulnerable}
\end{align*}
\]
generator, will have their sensitivities calculated. The steady state voltages after a given counter measure are then
determined, using a grid transformation coefficient (GTC) and a numerical, iterative solution to an equation system. The
stability criteria can then be assessed to evaluate the sufficiency of a suggested counter measure. The method is
demonstrated on a synthetic 8-bus network and a 464-bus model of the Western Denmark transmission grid. The method
successfully demonstrates its ability to efficiently identify and evaluate counter measures for a large, practical system.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric power systems,
Energinet.dk
Authors: Dmitrova, E. (Ekstern), Wittrock, M. L. (Intern), Jóhannsson, H. (Intern), Nielsen, A. H. (Intern)
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Scopus rating (2009): SJR 1.94 SNIP 2.723
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.537 SNIP 2.448
Web of Science (2008): Indexed yes
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Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.233 SNIP 2.316
An approach to evaluate the HVDC interconnections models to be used in real-time voltage stability assessment is proposed. The existing models for the HVDC interconnections, that are based on voltage source converter, were studied selecting the ones that are suitable for its application in thevenin equivalent methods for voltage stability assessment. The proposed methods to evaluate the validity of the models by using synthesized PMU measurements from simulations and from PMUs connected to the Danish system. Wide-area measurements are used to estimate the HVDC model parameters which are needed to calculate a distance to the instability boundary. The parameters are benchmarked according to their expected uncertainty and its impact in the Thevenin equivalent methods is evaluated. The results show the used pre-processing procedure for the real PMU measurements and simple criterion for the evaluation of the parameter validity. The parameters calculated for all the selected models are between the expected uncertainty values for a time window of at least 2 cycles.

Evaluation of HVDC interconnection models for considering its impact in real-time voltage stability assessment

This article characterizes experimentally the relation between phase and magnitude error from Phasor Measurement Units (PMU) in steady state and study its effect on real-time stability assessment methods. This is achieved by a set of...
laboratory tests applied to four different devices, where a bivariate Gaussian mixture distribution was used to represent the error, obtained experimentally, and later include it in the synthesized PMU measurement using the Monte Carlo Method. Two models for including uncertainty are compared and the results show that taking into account the correlation between magnitude and phase error reduces significantly the uncertainty in the calculated voltage stability indexes for all the study cases.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric power systems, Ken M Consulting
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**Relations**

Projects:
Improved method for considering PMU’s uncertainty and its effect on real-time stability assessment methods based on Thévenin equivalent

**Investigation of Suitability of Cascading Outage Assessment Methods for Real-Time Assessment**

This paper investigates the suitability of assessment methods for cascading outages for real-time assessment. A total of ten assessment methods for cascading outages are investigated, and for all of the investigated methods a complexity assessment is performed to assess the suitability of the method to real-time assessment. The investigation revealed that two of the methods are of special interest for further study on real-time assessment of cascading outages. These are the betweenness centrality model, based on network topology, and the manchester model, based on AC power flow.
Thevenin Equivalent Method for Dynamic Contingency Assessment

A method that exploits Thevenin equivalent representation for obtaining post-contingency steady-state nodal voltages is integrated with a method of detecting post-contingency aperiodic small-signal instability. The task of integrating stability assessment with contingency assessment is challenged by the cases of unstable post-contingency conditions. For unstable postcontingency conditions there exists no credible steady-state which can be used for basis of a stability assessment. This paper demonstrates how Thevenin Equivalent methods can be applied in algebraic representation of such bifurcation points which may be used in assessment of post-contingency aperiodic small-signal stability. The assessment method is introduced with a numeric example.

Wide-Area Emergency Control in Power Transmission

This thesis concerns the development of new emergency control algorithms for electric power transmission systems. Diminishing global resources and climate concerns forces operators to change production away from fossil fuels and towards distributed renewable energy sources. Along with the change on production side measures must be taken on the demand side to maintain power balance. Due to these changes, the operating point of the power system will be less predictable. Traditionally, emergency controls are designed off-line by extensive simulations. The future power system is expected to fluctuate more, thus making the behaviour less predictable, suggesting the need for new intelligent wide-area emergency control algorithms. The fluctuating nature of the future power system calls for new methods of calculating remedial actions that are able to adapt to changing conditions. As part of this thesis convex relaxations are used to compute remedial actions when an emergency condition is detected, and the method is assessed using a set of benchmark systems. An optimal power flow approach is suggested to reconfigure a power system, and methods are introduced to be able to recover from an emergency condition and reach a secure stable equilibrium. In order to contain fast instability mechanisms, event-based emergency controls can be necessary, and this thesis also presents a contribution to real-time generation of event-based emergency control. By the use of contingency screening with post-contingency stability-margin information, system protection schemes are automatically generated and armed, and it is
shown that, by examination of the physical phenomena behind the security threat, emergency controls can be properly allocated. Power systems can exhibit low-frequency oscillations due to the inertia of synchronous machines affecting each other through electric power transfers. Today, dedicated controllers are applied to cope with such oscillations. However, faults can affect the behaviour of these controllers, or even separate them. The thesis presents a novel method that – without particular knowledge on existing controllers – reconfigures the close-loop system to guarantee stability in the case of faults. This is achieved through a stability-preserving reconfiguration design using absolute stability results for Lure type nonlinear power systems. It is implemented using a wide-area virtual actuator approach, and relies on the solution of a linear matrix inequality. The developed methods enables emergency control for real-time stabilization that adapts to changing conditions in the future power system. The results contribute to the development of a self-healing power system, where the power system automatically responds to system disturbances.

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Organisations: Department of Electrical Engineering, Automation and Control, Center for Electric Power and Energy, Electric power systems
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Source-ID: 119519810
Publication: Research › Ph.D. thesis – Annual report year: 2015

Wind farms generation limits and its impact in real-time voltage stability assessment
This paper proposes a method to consider the impact of the wind farms maximum current limits on real-time voltage stability assessment. The approach is based in a multi-port equivalent of the system which makes possible to assess the effect of each wind farm limit on the stability boundary, the approach indicates the distance to the limit activation and the effect of each load in such a limit. The wind farm control schemes includes voltage control and it is represented as a constant current at its limit. A criteria to select the critical bus bar, based on the generator transformation coefficients, is presented. This methodology is tested in a platform that produces synthesized PMU measurements from time-domain simulations and critical boundary for the wind-farm limits are shown. The methodology is also tested for synchronous machines and its parallel structure is exploited when implemented in a High Performance Computing environment. A computational time under 2ms shows that the method is suitable for real-time applications.

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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric power systems
Authors: Perez, A. (Intern), Jóhannsson, H. (Intern), Østergaard, J. (Intern)
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Relations
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Wind farms generation limits and its impact in real-time voltage stability assessment
Source: PublicationPreSubmission
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2015
Computation of Steady State Nodal Voltages for Fast Security Assessment in Power Systems

Development of a method for real-time assessment of post-contingency nodal voltages is introduced. Linear network theory is applied in an algorithm that utilizes Thevenin equivalent representation of power systems as seen from every voltage-controlled node in a network. The method is evaluated by comparing with results from time domain simulations and power flow calculations using Newton-Raphson’s method. It is concluded that the developed method performs better than Newton-Raphson’s method in reproducing results from time domain simulations. Discussion includes considerations for further development for facilitating treatment of composite loads.

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Computation of Steady State Nodal Voltages for Fast Security Assessment in Power Systems
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

Early Prediction of Transient Voltage Sags caused by Rotor Swings

The paper investigates various methods to predict voltage sags at load buses caused by large generator rotor swings and following a transient disturbance. Three different prediction methods are proposed, which all use real-time measurements from PMUs. One of the methods uses a slightly extended version of the E-SIME method. The other two methods use Measurements and process them by recursive least square estimation. It is shown that the prediction method employing E-SIME allows the earliest detection of a critical voltage sag with satisfactory accuracy.

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Relations
Projects:
Early Prediction of Transient Voltage Sags caused by Rotor Swings
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2014
Evaluation of enhancements to Thevenin equivalent based methods for real-time voltage stability assessment

The possibilities offered by the use of Phasor Measurement Units (PMU) in real-time monitoring provide interesting ways to ensure secure operation of power systems. This paper studies the specific case of voltage stability and the possible improvements to the Thevenin equivalent methods, which is applied generally with local measurements. This paper uses the PMU measurements to calculate the grid transformation coefficients to obtain wide-area information. This is achieved by studying the generator's electromagnetic force estimated using values in the coefficient transformation matrix. The improvements are tested in a small system and a through comparison with traditional Thevenin equivalent methods is carried out.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Authors: Perez, A. (Intern), Jóhannsson, H. (Intern), Østergaard, J. (Intern)
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Equivalent circuits, Phasor measurement units, Voltage Stability, Power system stability, Real-time assessment, Long term dynamics
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Relations
Projects:

The thesis concerns the development of tools and methods for on-line dynamic security assessment (DSA). In a future power system with low-dependence or even independence of fossil fuels, generation will be based to a large extent on noncontrollable renewable energy sources (RES), such as wind and solar radiation. Moreover, ongoing research suggests that demand response will be introduced to maintain power balance between generation and consumption at all times.

Due to these changes the operating point of the power system will be less predictable and today's stability and security assessment tools may no longer be feasible, since they are generally based on extensive off-line studies. A core component of an efficient on-line dynamic security assessment is a fast and reliable contingency screening. As part of this thesis a contingency screening method is developed and its performance is assessed on a set of test cases. The developed method reliably assesses first-swing transient angular stability of a power system in its current state with respect to a given set of contingencies. In order to ensure fast performance of the screening method, first a review of existing transient stability assessment (TSA) methods was carried out and their computational complexity was investigated. This allowed to identify the single machine equivalent (SIME) method as the potentially fastest assessment method and, hence, well suited for on-line DSA. Means for further performance improvement of the SIME method are investigated such as the reduction of the degree of model detail used in time-domain simulation, which results in a recommendation for the required model detail for synchronous generator. A challenging task when using the SIME method is to early and reliably determine the critical machine cluster, which is the group of generators likely to lose synchronism.

Therefore, a novel approach to identify the critical machine cluster is proposed in the thesis. This approach uses a new coupling coefficient, which is a measure of the coupling strength of a pair of generators, and a simple clustering algorithm to identify the critical group of generators. In order to determine a system to be transient secure, it is not sufficient to solely assess if all synchronous generator remain in synchronism, it is also required that the bus voltages remain within acceptable limits. A transient disturbance and the following angular divergence of a group of generators can cause critical voltage sags at certain buses in the system. In this thesis assessment of such voltage sags using two types of sensitivities, which are derived from the algebraic network equations, is proposed. These sensitivities are derived after an in-depth study of the mechanism causing the voltage sags. The first sensitivity type is called load voltage xii sensitivity and allows identifying which bus voltages are affected by a change in rotor angle of a particular generator. The second proposed type is called generator power sensitivity, which provides information on the effect of load variation on the generator's power injection. It is shown that the derived sensitivities can give valuable information to identify critical generator-load pairs as well as locations for applying preventive or remedial control measures. Furthermore, the development of a method for early prediction of critical voltage sags is described. The method's performance is compared to other prediction approaches. The results show that the proposed method succeeds in early, accurately and consistently
predicting critically low voltage sags. An efficient on-line DSA not only identifies unstable or insecure operation, but also proposes preventive or remedial control actions to restore stability and security in the system. In this thesis a further development of a method for determining real-time remedial action against aperiodic small signal rotor angle instability is described. A real-time aperiodic small signal rotor angle stability assessment method is employed to monitor the respective stability boundary and to compute the respective stability margin of each generator in the system. In case that the stability margin of a particular generator falls below a pre-defined security threshold, the proposed method analytically determines power generation re-Dispatch solutions, which restore stable and secure operation in the system. The effectiveness of the method is presented on two test cases in two different test systems.

General information
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Relations
Projects:

Sensitivity based Assessment of Transient Voltage Sags caused by Rotor Swings
The paper introduces an approach to investigate voltage sags, which are caused by large generator rotor swings following a transient disturbance. Therefore, the method exploits sensitivities derived from the algebraic network equations. These provide information on the impact of a generator on the voltage magnitude at a load bus and the effect of load variation on the generator's power injection. It is shown that these sensitivities give valuable information to identify critical generator-load pairs and locations for applying preventive control measures.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, University of Liege
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Relations
Projects:
Sensitivity based Assessment of Transient Voltage Sags caused by Rotor Swings

New challenges are arising in managing power systems as these systems become more complex due to the use of high levels of distributed generation, mainly based on renewable energy sources, and due to the competitive environment within the power sector. At the same time, the use of Phasor Measurement Units (PMUs) provides more information and enables wide-area monitoring with accurate timing. One of the challenges in the near future is converting the high quantity and quality of information provided by PMUs into useful knowledge about operational state of a global system. The use of real-time simulation in closed-loop is essential to develop and validate new real-time applications of wide-area PMU data.
This paper presents a simulation platform developed within the research project Secure Operation of Sustainable Power Systems (SOSPO). The SOSPO simulation platform (SOSPO-SP) functions in a closed-loop, integrating new real-time assessment methods to provide useful information to operators in power system control centers and to develop new control methodologies that handle emergency situations and avoid power system blackouts.

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BFI (2013): BFI-level 1
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Web of Science (2013): Indexed yes
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Scopus rating (2012): SJR 1.038 SNIP 3.259 CiteScore 5.56
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Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.875 SNIP 2.514 CiteScore 4.08
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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.615 SNIP 2.072
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.99 SNIP 2.3
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.012 SNIP 2.59
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**Relations**

Projects:
Stabiliser Fault Emergency Control using Reconfiguration to Preserve Power System Stability

Stabiliser faults in multi-machine power systems are examined in this paper where fault-masking and system reconguration of the nonlinear system is obtained using a virtual actuator approach. Phasor Measurement Units, which can be integrated in wide-area transmission grids to improve the performance of power system stabilisers, are utilised when reconguring remaining stabilisers after one has been inoperable by a local failure. A stability-preserving reconguration is designed using absolute stability results for Lure type systems: The calculation of the virtual actuator that relies on a solution of a linear matrix inequality (LMI) is detailed in the paper. Simulation results of a benchmark transmission system show the ability of the fault-tolerant reconguration strategy to maintain wide-area stability of a power system despite failure in a stabiliser.

General information
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Organisations: Department of Electrical Engineering, Automation and Control, Center for Electric Power and Energy, Siemens
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Stabiliser Fault Emergency Control using Reconfiguration to Preserve Power System Stability
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SW-platform for R&D in Applications of Synchrophasor Measurements for Wide-Area Assessment, Control and Visualization in Real-Time

The Danish research project "Secure Operation of Sustainable Power Systems (SOSPO)" is currently being conducted in a collaboration by a group of partners from academia and industry. The focus of the project is on how to achieve secure operation of the power grid as large scale thermal power plants, supplied by fossil fuel, are phased out in favor of non-controllable renewable energy sources like wind and solar energy. In particular, the SOSPO project aims to develop real-time stability and security assessment methods as well as wide-area control methods to re-establish stable and secure operation when a critical operation has been identified. An important part of the SOSPO project is the development of a SW-platform that enables testing and demonstrations of the various methods for wide-area assessment, control and visualization the project delivers. In order to test the methods under realistic conditions, the future system scenarios are represented in a real-time grid simulator that is an integrated part of the platform. The SW-platform provides structured access to any model parameter as well as access to real-time phasor measurement unit (PMU) and remote terminal unit (RTU) snapshots. Having such structured access to relevant data greatly eases the implementation process of new methods. The SW-platform is facilitated by PowerLabDK at the Technical University of Denmark, which is a new state-of-the-art experimental laboratory for technology development, testing, training and demonstration of technologies within electric power and energy. More specifically, the SW-platform exploits the Intelligent Control Lab facilities in PowerLabDK, which provides access to a powerful Real-Time Digital Simulator, a SCAD A system, a full scale experimental power system control room with a video wall and an IBM Blade center for the implementation of the SW-platform and the wide-area methods developed in SOSPO. This paper provides insights into the details of the SOSPO
Technical Resource Potential of Non-disruptive Residential Demand Response in Denmark

Denmark has one of the most aggressive renewable energy strategies in the world; however, large penetrations of fluctuating renewable energy resources will pose new problems in the Danish power system. Demand response (DR) has the potential to mitigate these problems by providing a new source of flexibility. This paper estimates the technical resource potential of residential DR in Denmark. We focus on DR that is non-disruptive to the consumer, meaning that DR actions harness inherent load flexibility and are not noticeable by the consumer. We build on existing methodologies for computing DR technical resource potentials, and use real data from Denmark. We find that country-wide load flexibility is on the order of GWs and GWhs, and will increase drastically over the next 20 years due to electrification of space heating systems and vehicles. However, we also find that flexibility is time-varying on timescales of hours to months, and this variability will become more pronounced with electrification.

General information
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Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric power systems , Eidgenössische Technische Hochschule, Technical University of Denmark, Swiss Federal Institute of Technology
Authors: Mathieu, J. (Ekstern), Rasmussen, T. B. (Intern), Sørensen, M. (Ekstern), Jóhannsson, H. (Intern), Andersson, G. (Ekstern)
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Relations
Projects:
Technical Resource Potential of Non-disruptive Residential Demand Response in Denmark
Uncertainty in real-time voltage stability assessment methods based on Thevenin equivalent due to PMU's accuracy

This article studies the influence of PMU's accuracy in voltage stability assessment, considering the specific case of Thévenin equivalent based methods that include wide-area information in its calculations. The objective was achieved by producing a set of synthesized PMU measurements from a time domain simulation and using the Monte Carlo method to reflect the accuracy for the PMUs. This is given by the maximum value for the Total Vector Error defined in the IEEE standard C37.118. Those measurements allowed to estimate the distribution parameters (mean and standard deviation) of the studied voltage stability indices and grid transformation coefficients which have applications in voltage stability assessment. The obtained distributions have a direct impact in the number of samples needed for estimating system parameters and compromise between time-scale and uncertainty in those estimations is shown.

Wide-Area Assessment of Aperiodic Small Signal Rotor Angle Stability in Real-Time

This paper presents the details of a new real-time stability assessment method. The method assesses a particular mechanism of stability: each generator's capability to generate sufficient steady state electromechanical torque. The lack of sufficient steady state torque causes aperiodic increase in rotor angle and a loss of synchronism, referred to as aperiodic small signal instability. The paper provides the theoretical background of the method and an analytical assessment criterion. Furthermore, a mathematical mapping of the generators' operating points that enables informative visualization of multiple operating points is derived in the paper. Finally, results from timedomain simulation of instability scenarios in the Nordic32 test system are presented and results used for testing the assessment method. The results illustrate the method's capability to efficiently identify the location of the emerging problem and to quantify margins to stability boundary.
This paper introduces the concept of prosumption control where intelligent loads and distributed generation are aggregated and controlled to improve power system security. It is expected that intelligent load and generation units can respond to control / market signals and thus present an opportunity of available resources for changing the operating point (OP) of a system to one that is more secure. A prosumption pattern is then a signal to prosumers to shift their demand in time. This makes it possible to temporarily change the distribution of the power demand. A prosumption pattern is balanced, such that frequency can be maintained by other smart grid technologies. To find a prosumption pattern which can improve security, it is necessary to determine sensitivities of stability indicators such that beneficial load permutations can be identified. After introducing prosumption control and patterns, stability indicators for aperiodic small signal angular stability (ASSA) are examined, while the concept of prosumption is described. The methodology presented is shown to be able to assess the margin to instability and to predict how this margin can be affected if a load is changed in the grid. The resulting sensitivities are described and their suitability to be used to search for a prosumption pattern is evaluated.

An implementation and test platform for wide area stability assessment methods
This paper presents a software platform developed in MatLab with the purpose of supporting research, Development and testing of wide area algorithms for stability assessment and control. The development and testing process of algorithms exploiting real time wide area data from Phasor Measurement Units (PMU) can be very time consuming, especially if the testing procedure is not carried out in a systematic and automatic manner. The test platform overcomes this problem by automatically importing system model parameters, topology and simulation output from a time domain simulation of an instability scenario and automatically generating synthetic PMU snapshots of the system conditions. To demonstrate the platform's potential for supporting research and development of wide area algorithms, a method to detect voltage instability is implemented and tested, giving results consistent with results from literature.
Coordination of system needs and provision of services

This paper addresses a challenge associated with large scale deployment of distributed energy resources (DER) to provide system services in future sustainable power systems; namely how to prioritize conflicting interests in a service provided by a DER. For that purpose, different services utilizing the DER in a future system are identified as well as potentially conflicting interests between services. A scheme is suggested for how conflicting interests should be prioritized based on considerations regarding the nature of the service and the system operating state at the time of the service request. Examples are provided for illustrating the functionality of the scheme.

Early Prevention Method for Power Systems Instability

In the scope of this work, a method capable of fast identification of the proper countermeasure, that prevents emerging instability, has been developed. The focus is placed on the prevention of aperiodic small signal angular instability by means of manipulations applied to load nodes (nodes containing no voltage sources). The main functionality of the early prevention method is to deliver control solution allowing escape from instability on the basis of data obtained by PMU measurements. The developed algorithm performs identification of the optimal node for countermeasure application and defines which amount of countermeasure would be sufficient to bring a critical generator to the stable operation.

The early prevention method is addressing the possibility of near real time analysis, utilizing computationally efficient algorithms. The method is providing efficient countermeasure matching a given operational conditions and predicts the resulting stability margins for the new steady state, while avoiding time consuming time domain simulations. The method has been validated on the Western Danish power system model, containing 464 buses. The case study of aperiodic small signal angular instability was created. Utilizing synthetic PMU data, the early prevention method proposed a location and an amount of the countermeasure which will prevent instability; the prediction of the resulting stability margins corresponding to application of the suggested countermeasure was carried out. The predicted effect of the suggested countermeasure application is in a good agreement with the results obtained by RMS dynamic simulation. Developed method enables adaptive preventive control for near real-time stability maintenance. The achieved results are opening promising perspective for power system's evolution to self-curing systems, for which the human factor involved in control, will keep diminishing.
This paper presents a method for a fast determination of the grid nodes where countermeasures, in the form of changes in nodal admittance, would provide greatest impact on the stability margin for a specific generator that is facing the risk of instability. The sensitivity of the stability criteria for aperiodic small signal angular stability to the change in nodal admittance is used as a factor quantifying impact that the node has on the stability of a critical generator. In order to lower the number of nodes which are processed through sensitivity analysis, a self-propagating graph with discrete steps is applied. The suggested method is tested on the IEEE 30 bus test system and on the 1648 bus US west coast test system where the results show that the number of nodes processed through sensitivity analysis are well reduced compared to the full sensitivity analysis, illustrating the potential of the developed approach for the fast identification of the optimal nodes for countermeasure application.

General information
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Graph theory, Power systems, Sensitivity analysis, Stability
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 Relations
Projects:
Early Prevention of Instability-Use of Self Propagating Graph for the Fast Search for Optimal Grid Nodes to Apply Countermeasures
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

Fast assessment of the effect of preventive wide area emergency control
This paper describes an approach to quick assessment of the effect that a suggested countermeasure would have on the system generators stability margins in respect to aperiodic rotor angle small signal stability. The approach ensures that computational demanding simulations can be avoided to determine whether the suggested counteraction is sufficient to avoid system instability during severely critical operating conditions. The fast assessment of the effect that a countermeasure has on system stability provides an important decision support for the control room personnel in emergency situations. The validity of the suggested approach is proved on the 8 bus test system and IEEE30 bus test system.
In this paper, it is investigated how detailed the model of a synchronous machine needs to be in order to assess transient stability using a Single Machine Equivalent (SIME). The results will show how the stability mechanism and the stability assessment are affected by the model detail. In order to identify the transient stability mechanism, a simulation with a high-order model was used as reference. The Western System Coordinating Council System (WSCC) and the New England & New York system are considered and simulations of an unstable and a stable scenario are carried out, where the detail of the machine models is varied. Analyses of the results suggest that a 4th-order model may be sufficient to represent synchronous machines in transient stability studies.

Impact of Model Detail of Synchronous Machines on Real-time Transient Stability Assessment

In this paper, it is investigated how detailed the model of a synchronous machine needs to be in order to assess transient stability using a Single Machine Equivalent (SIME). The results will show how the stability mechanism and the stability assessment are affected by the model detail. In order to identify the transient stability mechanism, a simulation with a high-order model was used as reference. The Western System Coordinating Council System (WSCC) and the New England & New York system are considered and simulations of an unstable and a stable scenario are carried out, where the detail of the machine models is varied. Analyses of the results suggest that a 4th-order model may be sufficient to represent synchronous machines in transient stability studies.

Influence of current limitation on voltage stability with voltage sourced converter HVDC

A first study of voltage stability with relevant amount of Voltage Sourced Converter based High Voltage Direct Current (VSC-HVDC) transmission is presented, with particular focus on the converters' behaviour when reaching their rated current. The detrimental effect of entering the current limitation on the Power-Voltage (PV) curves at a load bus is exemplified on a three-bus system, proposing a method to model the converters in current limiting mode through ideal
current sources. The influence of the current magnitude and angle on the reduced stability margin is analysed and results show that, when the current limit is reached, despite the detrimental effect brought about by an increased equivalent transmission impedance, the loss of stability margin can be minimised by proper control of the converter.

**General information**

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Authors: Zeni, L. (Intern), Jóhannsson, H. (Intern), Hansen, A. D. (Intern), Sørensen, P. E. (Intern), Hesselbæk, B. (Ekstern), Kjær, P. C. (Ekstern)
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**Relations**
Projects:
Influence of current limitation on voltage stability with voltage sourced converter HVDC

**Method of determining remedial control actions for a power system in an insecure state**

A method of determining remedial control actions for a power system in an insecure state is provided. The power system has a plurality of generators injecting power into a network and each generator has a generator injection impedance and a stability boundary in the injection impedance plane. A system safety boundary is calculated based on a predetermined network operating safety margin for each generator, the generator injection impedance is compared with the safety boundary and it is determined whether each generator is safe or unsafe. A remedial control action is determined comprising a scheme for re-dispatching power generation for each unsafe generator to thereby establish a secure operating condition for the power system. A new safe operating point in the impedance plane for each unsafe generator may be determined, and a distance between the generator injection impedance and the new safe operating point is calculated under the assumption of constant voltage magnitude for each unsafe generator. The unsafe generator operation is remedied by reducing power generation of the unsafe generator.

**General information**

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Main Research Area: Technical/natural sciences

**Relations**
Projects:
Method of determining remedial control actions for a power system in an insecure state
Real-Time Thevenin Impedance Computation

Stable and secure operation of power systems becomes increasingly difficult when a large share of the power production is based on distributed and non-controllable renewable energy sources. Real-time stability assessment is dependent on very fast computation of different properties of the grid operating state, and strict time constraints are difficult to adhere to as the complexity of the grid increases. Several suggested approaches for real-time stability assessment require Thevenin impedances to be determined for the observed system conditions. By combining matrix factorization, graph reduction, and parallelization, we develop an algorithm for computing Thevenin impedances an order of magnitude faster than previous approaches. We test the factor-and-solve algorithm with data from several power grids of varying complexity, and we show how the algorithm allows realtime stability assessment of complex power grids at millisecond time scale.

Suitability of voltage stability study methods for real-time assessment

This paper analyzes the suitability of existing methods for long-term voltage stability assessment for real-time operation. An overview of the relevant methods is followed with a comparison that takes into account the accuracy, computational efficiency and characteristics when used for security assessment. The results enable an evaluation of the run time of each method with respect to the number of inputs. Furthermore, the results assist in identifying which of the methods is most suitable for realtime operation in future power system with production based on fluctuating energy sources.
System security assessment in real-time using synchrophasor measurements

The increasing amount of renewable power from wind and solar generation causes higher fluctuation in power generation and in general increased distances between generation and load. Both aspects influence the system stability of electricity transmission in a negative way. Therefore, additional measures to ensure stable and secure operation of the system are necessary. Time stamped synchrophasor measurements lay the foundation for development of new real-time applications for security and stability assessment. The paper provides overview of existing solutions for synchrophasor based security assessment and sheds light on ongoing research activities that focus on exploiting wide-area synchrophasor measurements for real-time security assessment of sustainable power systems. At last, an mathematical mapping enabling informative visualization of the system state in respect to aperiodic rotor angle stability is described and analyzed in detailed.

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Abstract Wide Area Monitoring IEEE PES Copenhagen_2.pdf
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Relations
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Wide-Area Assessment of Aperiodic Small Signal Rotor Angle Stability in Real-Time
This paper presents the details of a new real-time stability assessment method. The method assesses a particular mechanism of stability: each generator’s capability to generate sufficient steady state electromechanical torque. The lack of sufficient steady state torque causes aperiodic increase in rotor angle and a loss of synchronism, referred to as aperiodic small signal instability. The paper provides the theoretical background of the method and an analytical assessment criterion. Furthermore, a mathematical mapping of the generators’ operating points that enables informative visualization of multiple operating points is derived in the paper. Finally, results from time-domain simulation of instability scenarios in the Nordic32 test system are presented and results used for testing the assessment method. The results illustrate the method’s capability to efficiently identify the location of the emerging problem and to quantify margins to stability boundary.

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Web of Science (2016): Indexed yes
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BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.831 SNIP 3.577 CiteScore 5.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.939 SNIP 4.35 CiteScore 6.33
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.177 SNIP 3.516 CiteScore 5.84
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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Scopus rating (2011): SJR 1.725 SNIP 3.254 CiteScore 5.34
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Web of Science (2011): Indexed yes
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Scopus rating (2010): SJR 1.949 SNIP 2.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.94 SNIP 2.723
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.537 SNIP 2.448
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.242 SNIP 2.521
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.233 SNIP 2.316
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.582 SNIP 2.547
Scopus rating (2004): SJR 1.036 SNIP 2.843
Scopus rating (2003): SJR 2.669 SNIP 2.652
Scopus rating (2002): SJR 2.271 SNIP 2.337
Scopus rating (2001): SJR 1.708 SNIP 1.837
Scopus rating (2000): SJR 1.169 SNIP 3.37
Scopus rating (1999): SJR 0.418 SNIP 1.408

Original language: English

Power system measurements, Power system monitoring, Power system stability, Generators, Impedance, Real-time systems, Rotors, Stability analysis, Steady-state

Electronic versions:
approved_IEEE_Tran_final.pdf

DOIs:
10.1109/TPWRS.2013.2271193

Relations

Projects:
Wide-Area Assessment of Aperiodic Small Signal Rotor Angle Stability in Real-Time
Addressing the security of a future sustainable power system: The Danish SOSPO project

Current power systems have been undergoing in depth changes by the increasing use of renewable generations. At one hand, the grid is progressively more interconnected in order to collect the renewable generation from geographically dispersed places meanwhile reduce the risks of intermittency; on the other, the power is increasingly generated at relative low voltage networks which in turn gives rise to new challenges in the conventional system design. The high governmental objective of greenhouse gas reduction provokes accelerating adoption of the renewables. The effect of this has to be carefully evaluated to secure the operation from both transmission and distribution levels. The Danish SOSPO project is launched from 2012 targeting at the system security assessment in the control room for the future scenarios. Methods will be developed in this project to counteract with the future challenges, and a testing platform will be developed in the laboratory for algorithm testing and demonstration.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Automation and Control
Authors: Yang, G. (Intern), Jóhannsson, H. (Intern), Lind, M. (Intern), Garcia-Valle, R. (Intern), Blanke, M. (Intern), Nielsen, A. H. (Intern), Østergaard, J. (Intern)
Number of pages: 5
Publication date: 2012

Host publication information
Title of host publication: Conference proceedings of the 9th IET International Conference on Advances in Power System Control, Operation and Management
Publisher: Institution of Engineering and Technology
ISBN (Print): 9781849197434
Main Research Area: Technical/natural sciences
Conference: 9th IET International Conference on Advances in Power System Control, Operation and Management (ASPCOM 2012), Hong Kong, Hong Kong, 18/11/2012 - 18/11/2012
Renewable energies, System security, Control room application, Visualisation
DOIs: 10.1049/cp.2012.2164

Relations
Projects:
Addressing the security of a future sustainable power system: The Danish SOSPO project

Assessment of the impact that individual voltage source has on a generator's stability

This paper presents an approach for splitting equivalent Thévenin voltage into components induced by each voltage source in the reduced grid. Thévenin equivalent representation of the system is sometimes used for stability assessment of a given generator, where the Thévenin voltage is one of the key variables affecting the stability conditions. Thévenin voltage is formed by components induced by each voltage source in the grid, while depending on topology and system parameters, the impact of these components on the equivalent Thévenin voltage $E_{th}$ might vary considerably. This paper demonstrates how the impact of individual voltage source to the $E_{th}$ might be defined utilizing system admittance matrix. Knowledge about alternation of $E_{th}$ while applying changes to either admittance matrix or generators’ excitation and torque gives promising perspective for determination of effective countermeasures aimed on instability prevention. Suggested approach for $E_{th}$ decomposition is applied to the IEEE 30 bus test system.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Authors: Dmitrova, E. (Intern), Jóhannsson, H. (Intern), Nielsen, A. H. (Intern)
Number of pages: 6
Publication date: 2012

Host publication information
Title of host publication: Proceedings of 10th International Power and Energy Conference, IPEC 2012
Main Research Area: Technical/natural sciences
Conference: The 10th International Power and Energy Conference (IPEC 2012), Ho Chi Minh City, Viet Nam, 12/12/2012 - 12/12/2012
Early prevention of instability - search for optimal grid nodes for applying countermeasures

This paper proposes a method for automatically determining which nodes in a given grid would have the largest contribution to an improvement of stability margins when wide-area control actions, in form of load changes, are applied to the nodes. The assessment of the influence each node in the grid has on the stability of the given generator is based on sensitivity analysis. The sensitivity of the stability criteria for aperiodic small signal angular stability to the corresponding change in the nodal admittances used to generate a prioritized candidate list over possible nodes for preventive countermeasures application. The suggested method is tested on an 8 bus test system and IEEE 30 bus test system; the obtained results show that the proposed approach identifies the system nodes having the highest potential for improvement of critical stability margins.

Identification of Critical Transmission Limits in Injection Impedance Plane

In this paper, equations are derived that describe the mapping of critical boundaries and characteristic lines from the three dimensionalPQV-surface into the two-dimensional injection impedance plane (load impedance plane for both positive and negative resistance). The expressions derived for the critical and characteristic lines in the impedance plane form the basis for a new phasor measurement based situational awareness method, which uses the results in this paper to identify critical operational boundaries in real time and to visualize the system operating conditions in an informative way. The situational awareness method will be described in a later paper, where this paper focuses on the derivations of some system characteristics in the injection (or load) impedance plane. The critical lines from the PQV-surface that are mapped into the impedance plane are the ones representing the conditions where the partial derivatives of the variables P,Q and V in respect to each other become zero. In addition to the mapping of the critical lines, some characteristic lines are mapped as well. These include the mapping of the lines of constant P,Q,V and d from the PQV-surface into the impedance plane. All of the mapped critical and characteristic lines appear as circles in the impedance plane.
Investigation of the Adaptability of Transient Stability Assessment Methods to Real-Time Operation

In this paper, an investigation of the adaptability of available transient stability assessment methods to real-time operation and their real-time performance is carried out. Two approaches based on Lyapunov’s method and the equal area criterion are analyzed. The results allow to determine the runtime of each method with respect to the number of inputs. Furthermore, it allows to identify, which method is preferable in case of changes in the power system such as the integration of distributed power resources (DER). A comparison of the performance of the analyzed methods leads to the suggestion that matrix reduction and time domain simulation are the most critical operations.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Image Analysis and Computer Graphics
Authors: Weckesser, J. T. G. (Intern), Jóhannsson, H. (Intern), Sommer, S. (Intern), Østergaard, J. (Intern)
Number of pages: 9
Publication date: 2012

Host publication information
Title of host publication: IEEE PES Innovative Smart Grid Technologies Conference Europe
Publisher: IEEE
ISBN (Print): 9781467325974
Main Research Area: Technical/natural sciences
Conference: 3rd IEEE PES Innovative Smart Grid Technologies (ISGT) Europe Conference (IEEE PES ISGT Europe 2012), Berlin, Germany, 14/10/2012 - 14/10/2012

Assessment of Power Systems

General information
State: Published
Organisations: Electric Energy Systems, Department of Electrical Engineering
Authors: Jóhannsson, H. (Intern)
Publication date: 2011

Publication information
Patent number: 111681113.6 - 2207
Date: 30/05/2011
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 281894
Development of Early Warning Methods for Electric Power Systems

This thesis concerns the development of methods that can provide, in realtime, an early warning for an emerging blackout in electric power systems. The blackout in E-Denmark and S-Sweden on September 23, 2003 is the main motivation for the method development. The blackout was caused by occurrence of two severe system disturbances within a time interval of five minutes. Following the second disturbance where initial oscillations had damped out, a period of approximately 80s with slowly decaying voltage magnitude was observed, before a system blackout was experienced. It was of interest to develop methods, that could, in such situations, give an early warning for the emerging blackout. After investigation of data and plots taken from the time of the blackout, it was decided to focus the development on assessment of aperiodic small signal stability. In order to assess the system generators aperiodic small signal stability, expressions for stability boundaries were algebraically derived in the injection impedance plane. A method for detecting aperiodic small signal stability was established, which was based on one of the derived boundaries. The method carries out an element-wise assessment of the system aperiodic small signal stability where each generator is assessed specifically by using the value of its injection impedance and its corresponding system Thevenin impedance. For the purpose of obtaining distance-to-instability information, the generators operating point were visualized in the injection impedance plane. A mapping of the different operating points into a normalized injection impedance plane was derived, which enabled a visualization of multiple operating points on the same screen. Such visualization provides system operators a new mean of graphically assessing the system conditions in respect of aperiodic small signal stability and enables a quick identification of critical generators. The assessment method was implemented in an algorithm, that could effectively determine the required information for carrying out the stability assessment. The algorithm received a PMU-snapshot of the system conditions as an input and determined the injection and Thevenin system impedances I for all system generators. A test bench software was written for the purpose of testing the developed algorithm. A large scale test of the assessment method was carried out where a simulation of the blackout in E-Denmark and S-Sweden September 23, 2003 was used as a test case scenario. The simulation results were used to generate a synthetic PMU-snapshots of the system conditions which were used as an input to the assessment algorithm. The test results showed that the loss of aperiodic small signal stability of one machine was detected approximately 54s before the simulated blackout was experienced. The developed assessment method was therefore capable of providing, in real-time, an early warning for the occurrence of the emerging simulated blackout almost a minute before it occurred.

Real-Time Stability Assessment based on Synchrophasors

In this paper, an overview is provided of a new method that in real-time provides an early warning for an emerging blackout that are characterized by a slowly increasing angular separation between sub-groups of system generators. Such angular separation between subgroups of generators can eventually cause in very sharp decline in system voltages at intermediate locations between the two groups as the angular separation approaches 180°. In order to receive an early warning for the occurrence of such type of blackouts, the boundaries of the system generators aperiodic small-signal stability are suggested to be monitored. For that purpose, method for real-time assessment of aperiodic small-signal rotor angle stability is presented. The approach is based on an element-wise assessment of individual synchronous machines where the aim is to determine the maximum steady state power that each synchronous generator can inject into the system. The limits for maximum injectable power represent the boundary for aperiodic small signal stability. The concept of the proposed method is tested on two different systems. The results show that the method is capable of accurately detecting when a given machine crosses the stability boundary. The method can as well provide in real-time a margin to the machines stability boundary, which can be used as an early warning for an impending system stability problem.
High Performance Algorithms Enabling Real-Time Security Assessment of Sustainable Electric Power Systems

Department of Electrical Engineering
Period: 15/05/2017 → 14/05/2020
Number of participants: 4
Phd Student:
Hildebrandt, Christina Berndt (Intern)
Supervisor: Jóhannsson, Hjörtur (Intern)
Sommer, Stefan Horst (Intern)
Main Supervisor: Nielsen, Arne Hejde (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Modelling of renewable energy under stressed power system stability conditions

Department of Wind Energy
Period: 15/11/2016 → 14/11/2019
Number of participants: 5
Phd Student:
Sarkar, Moumita (Intern)
Supervisor: Altin, Müfit (Intern)
Hansen, Anca Daniela (Intern)
Jóhannsson, Hjörtur (Intern)
Main Supervisor: Sørensen, Poul Ejnar (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Voltage Stability in RES based power systems

Department of Electrical Engineering
Period: 15/05/2016 → 14/05/2019
Number of participants: 3
Phd Student:
Karatas, Bahtiyar Can (Intern)
Supervisor: Jóhannsson, Hjörtur (Intern)
Main Supervisor: Nielsen, Arne Hejde (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Security Assessment of Renewable Power Systems

Department of Electrical Engineering
Center for Electric Power and Energy

Electric power systems

Department of Wind Energy

Integration & Planning
Period: 01/04/2016 → 31/03/2020
Number of participants: 5
Acronym: SARP
Project participant:
Sørensen, Poul Ejnar (Intern)
Phd Student:
Karatas, Bahtiyar Can (Intern)
Sarkar, Moumita (Intern)
Hildebrandt, Christina Berndt (Intern)
Project Coordinator:
Jóhannsson, Hjörtur (Intern)

Relations
Related projects:
Voltage Stability in RES based power systems
Modelling of renewable energy under stressed power system stability conditions
Secure Operation of Sustainable Power Systems
High Performance Algorithms Enabling Real-Time Security Assessment of Sustainable Electric Power Systems

Early Warning for Cascarding Outages in Electric Power Systems

Department of Electrical Engineering
Period: 01/11/2013 → 31/12/2016
Number of participants: 6
Phd Student:
Petersen, Pauli Fríðheim (Intern)
Supervisor:
Jóhannsson, Hjörtur (Intern)
Main Supervisor:
Nielsen, Arne Hejde (Intern)
Examiner:
Wu, Qiuwei (Intern)
Repo, Sami Petteri (Ekstern)
Terzija, Vladimir (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Static Security Assessment and PMU Data Validation

Department of Electrical Engineering
Period: 01/08/2013 → 12/04/2017
Number of participants: 6
Phd Student:
Møller, Jakob Glarbo (Intern)
Supervisor:
Jóhannsson, Hjörtur (Intern)
Main Supervisor:
Østergaard, Jacob (Intern)
Examiner:
Pinson, Pierre (Intern)
Huang, Zhenyu Henry (Ekstern)
Hug-Glanzman, Gabriela (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansierede - Virksomhed
Project: PhD

Wide-Area Prosumption Modelling and Control
Department of Electrical Engineering
Period: 01/03/2013 → 12/04/2017
Number of participants: 6
Phd Student:
Wittrock, Martin Lindholm (Intern)
Supervisor:
Jóhannsson, Hjörtur (Intern)
Main Supervisor:
Nielsen, Arne Hejde (Intern)
Examiner:
Sørensen, Poul Ejnar (Intern)
Erlich, István (Ekstern)
Glavic, Mevludin (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Real-Time Assessment of Voltage Stability (tentative)
Department of Electrical Engineering
Period: 15/01/2013 → 30/09/2016
Number of participants: 6
Phd Student:
Perez, Angel (Intern)
Supervisor:
Jóhannsson, Hjörtur (Intern)
Main Supervisor:
Østergaard, Jacob (Intern)
Examiner:
Træholt, Chresten (Intern)
Chow, Joe H. (Ekstern)
Uhlen, Kjetil (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Offentlig finansiering
Project: PhD

Emergency Control in Power Transmission
Department of Electrical Engineering
Period: 01/11/2012 → 20/01/2016
Number of participants: 7
Phd Student:
Pedersen, Andreas Søndergaard (Intern)
Supervisor:
Jóhannsson, Hjörtur (Intern)
Tabatabaeipour, Mojtaba (Intern)
Main Supervisor:
Blanke, Mogens (Intern)
Examiner:
Niemann, Hans Henrik (Intern)
Erlich, István (Ekstern)
Stoustrup, Jakob (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Secure Operation of Sustainable Power Systems
Funded by the Danish Council for strategic research (DSF)

The project period spans four years, starting in January 2012. The total budget for the project is approximately 30.2 million DKK, which covers among others the funding of 5 PhD and 3 PostDoc positions. The project is managed by prof. Jacob Østergaard, head of Centre for Electric Technology.

The SOSPO project focuses on a critical, difficult and not yet treated problem regarding how secure operation of future sustainable power systems (based on wind and solar energy) can be ensured.

The research in the SOSPO project focuses on methods that enable system stability and security assessment in real-time and on methods for automatically determining control actions that regain system security when an insecure operation has been detected.

Centre for Electric Technology
Department of Electrical Engineering
Electric Energy Systems
Automation and Control
Center for Electric Power and Energy
Electric power systems
Eidgenössische Technische Hochschule
Lund University
Chalmers University of Technology
Energinet.dk
Siemens
Ken M Consulting
Period: 01/01/2012 → 31/12/2015
Number of participants: 13
Stability sustainable power system
Acronym: SOSPO
Number of related Ph.D. students: 5
Project participant:
Nielsen, Arne Hejde (Intern)
Garcia-Valle, Rodrigo (Intern)
Yang, Guangya (Intern)
Lind, Morten (Intern)
Blanke, Mogens (Intern)
Zhang, Xinxin (Intern)
Phd Student:
Weckesser, Johannes Tilman Gabriel (Intern)
Wittrock, Martin Lindholm (Intern)
Møller, Jakob Glarbo (Intern)
Perez, Angel (Intern)
Pedersen, Andreas Søndergaard (Intern)
Project Manager, academic:
Østergaard, Jacob (Intern)
Jóhannsson, Hjörtur (Intern)

Relations
Publications:
Wide Area Prosumption Control and Sensitivities of Aperiodic Small Signal Stability Indicators
Early Prevention Method for Power Systems Instability
Uncertainty in real-time voltage stability assessment methods based on Thevenin equivalent due to PMU’s accuracy
Sensitivity based Assessment of Transient Voltage Sags caused by Rotor Swings
Impact of Model Detail of Synchronous Machines on Real-time Transient Stability Assessment
Evaluation of enhancements to Thevenin equivalent based methods for real-time voltage stability assessment
Suitability of voltage stability study methods for real-time assessment
Evaluation of HVDC interconnection models for considering its impact in real-time voltage stability assessment
Wide-Area Assessment of Aperiodic Small Signal Rotor Angle Stability in Real-Time
Computation of Steady State Nodal Voltages for Fast Security Assessment in Power Systems
Wide-Area Assessment of Aperiodic Small Signal Rotor Angle Stability in Real-Time
Real-Time Thevenin Impedance Computation
Improved method for considering PMU’s uncertainty and its effect on real-time stability assessment methods based on Thevenin equivalent
Identification of Critical Transmission Limits in Injection Impedance Plane
System security assessment in real-time using synchrophasor measurements
Fast assessment of the effect of preventive wide area emergency control
Critical machine cluster identification using the equal area criterion
Convex Relaxation of Power Dispatch for Voltage Stability Improvement
Investigation of Suitability of Cascading Outage Assessment Methods for Real-Time Assessment
Early prevention of instability - search for optimal grid nodes for applying countermeasures
Addressing the security of a future sustainable power system: The Danish SOSPO project
Improved method for considering PMU’s uncertainty and its effect on real-time stability assessment methods based on Thevenin equivalent
Early Prevention of Instability-Use of Self Propagating Graph for the Fast Search for Optimal Grid Nodes to Apply Countermeasures
Thevenin Equivalent Method for Dynamic Contingency Assessment
Technical Resource Potential of Non-disruptive Residential Demand Response in Denmark
Wind farms generation limits and its impact in real-time voltage stability assessment
Investigation of the Adaptability of Transient Stability Assessment Methods to Real-Time Operation
Early Prediction of Transient Voltage Sags caused by Rotor Swings
An implementation and test platform for wide area stability assessment methods
Assessment of the impact that individual voltage source has on a generator’s stability
SW-platform for R&D in Applications of Synchrophasor Measurements for Wide-Area Assessment, Control and Visualization in Real-Time
Influence of current limitation on voltage stability with voltage sourced converter HVDC
Method of determining remedial control actions for a power system in an insecure state
Stabiliser Fault Emergency Control using Reconfiguration to Preserve Power System Stability
Derivation and application of sensitivities to assess transient voltage sags caused by rotor swings
Early Prevention Method for Power System Instability
Real-Time Stability Assessment based on Synchrophasors
Documents:
SOSPO Public Fact Sheet 2013
**On-line Dynamic Security Assessment in Power Systems**

Department of Electrical Engineering  
Period: 01/09/2011 → 07/05/2015  
Number of participants: 6  
Phd Student:  
Weckesser, Johannes Tilman Gabriel (Intern)  
Supervisor:  
Jóhannsson, Hjörtur (Intern)  
Main Supervisor:  
Østergaard, Jacob (Intern)  
Examiner:  
Pinson, Pierre (Intern)  
Glavic, Mevludin (Ekstern)  
Kundur, Prabha (Ekstern)  

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.  
Project: PhD

**Methods for Early Warning and Early Prevention of Voltage Instability**

Department of Electrical Engineering  
Period: 01/06/2010 → 26/11/2013  
Number of participants: 7  
Phd Student:  
Dmitrova, Evgenia (Intern)  
Supervisor:  
Jóhannsson, Hjörtur (Intern)  
Jóhannsson, Hjörtur (Intern)  
Main Supervisor:  
Nielsen, Arne Hejde (Intern)  
Examiner:  
Træholt, Chresten (Intern)  
Makarov, Yuri V. (Ekstern)  
Samuelsson, Olof (Ekstern)  

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.  
Project: PhD

**EcoGrid DK: 50% wind power in the Danish Electric Power System**

The object of the EcoGrid.dk research programme is to develop new long term technologies and market solutions for power systems with an increased share of distributed generation and renewable energy sources while maintaining the reliability of supply. The programme will focus on the identification and evaluation of new architectures and structures for the power system and development of new solutions for enhanced customer participation and pioneering concepts of system control and operation. The EcoGrid programme will cover research and development activities within related areas, and the programme will initiate and coordinate these activities. EcoGrid.dk will look for global solutions with reference to the Danish power system and the new Danish energy policy the objective of which is at least 30% renewable energy in the overall energy system in 2025, and indications that wind power can cover 50% of electricity demand in 2025.

Department of Electrical Engineering  
Centre for Electric Technology  
Period: 01/05/2007 → 01/07/2008  
Number of participants: 13  
wind power, electric power system, architectures, market, measures  
Acronym: EcoGrid  
Project ID: 55486
Project participant:
Nyeng, Preben (Intern)
Xu, Zhao (Intern)
Chandrashekhara, Divya K (Intern)
Poulsen, Bjarne (Intern)
Horstmann, Jørgen Peter Frederik (Intern)
Chen, Yu (Intern)
Jóhannsson, Hjörtur (Intern)
Saleem, Arshad (Intern)
You, Shi (Intern)
Garcia-Valle, Rodrigo (Intern)
Vlachogiannis, Ioannis (John) (Intern)

Project Manager, organisational:
Østergaard, Jacob (Intern)
Lind, Morten (Intern)

Financing sources
Source: Forsk. Private danske - Andre
Name of research programme: Forsk. Private danske - Andre
Amount: 666,000.00 Danish Kroner

Development of PMU-based early Warning Detection System for the Electric Power System

Department of Electrical Engineering
Period: 01/04/2007 → 24/08/2011
Number of participants: 6
Phd Student:
Jóhannsson, Hjörtur (Intern)
Supervisor:
Østergaard, Jacob (Intern)
Main Supervisor:
Nielsen, Arne Hejde (Intern)
Examiner:
Bruun, Erik (Intern)
Andersson, Göran (Ekstern)
Kundur, Prabha S. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU, Samfinansiering
Project: PhD

Activities:

Real-Time Stability Assessment based on Synchrophasors: IEEE PowerTech 2011
Period: 20 Jun 2011
Hjörtur Jóhannsson (Speaker)
Department of Electrical Engineering
Electric Energy Systems
Centre for Electric Technology

Description
Place: Trondheim

Related external organisation
Udvikling af nye metoder for realkidsstabilitetsovervågning af elforsyningssystemer: PMU/WAMS seminar hos Energinet.dk
Period: 1 Jan 2011 → …
Hjörtur Jóhannsson (Speaker)
Department of Electrical Engineering
Electric Energy Systems
Centre for Electric Technology

Related external organisation

Unknown external organisation
Activity: Talks and presentations › Conference presentations