A Memory-Efficient Parallelizable Method for Computation of Thévenin Equivalents used in Real-Time Stability Assessment

This paper introduces a factor-solve method, which efficiently computes Thévenin equivalents for all buses in the power system. A range of real-time stability assessment methods rely on Thévenin equivalents, and it is therefore essential that these can be determined fast and efficiently. The factor-solve method has runtime for computing Thévenin voltage that scales linearly with system size resulting in runtime of only a few milliseconds even for systems with several thousand buses. The computations only need the sparse admittance matrix for the power system and a sparse factorization resulting in low memory requirements, and furthermore Thévenin impedances can be determined in parallel. The factor-solve method is compared to a reference method, which uses coefficients for super-position to determine the Thévenin equivalents. The reference method is shown to have dissatisfying runtime and complexity. The factorsolve method is tested, parallelized and analysed, which shows a considerable speed-up in computations of Thévenin equivalents enabling them to be computed in real-time.
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 6.6 SJR 3.315 SNIP 3.386
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BFI (2014): BFI-level 2
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Web of Science (2011): Impact factor 2.678
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
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Scopus rating (2010): SJR 1.708 SNIP 2.759
Web of Science (2010): Impact factor 2.355
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.622 SNIP 2.675
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.309 SNIP 2.45
Web of Science (2008): Indexed yes
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Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.147 SNIP 2.259
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.41 SNIP 2.482
Scopus rating (2004): SJR 0.938 SNIP 2.807
Scopus rating (2003): SJR 2.078 SNIP 2.607
Scopus rating (2002): SJR 1.404 SNIP 2.284
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Evaluation of Factorization Methods for Thévenin Equivalent Computations in Real-Time Stability Assessment

Thevenin equivalents are used by a range of power system stability indicators, such as the L-index for voltage stability and the aperiodic small signal rotor angle stability indicator. This paper investigates the effect of using different factorization methods for computing coefficients for wide-area Thevenin equivalents. Direct and incomplete factorization methods are compared with respect to runtime, accuracy and amount of fill-in. The paper introduces a proof that the block triangular form of bus admittance matrices will have no non-zero entries in the off-diagonal. KLU factorization is found to perform almost twice as fast as the standard LU factorization with no cost of accuracy. It is, however, shown that the largest computational workload is associated with dense matrix multiplications. An incomplete method reduces the fill-in of coefficient matrices at the cost of accuracy in Thevenin voltages. It is shown, that inaccuracies are amplified as the L-index approaches the stability limit.

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Historical Data Analysis for Extending Dynamic Line Ratings Across Power Transmission Systems

Dynamic Line Rating (DLR) consists in an innovative way to operate power systems, which allows for higher power flows on transmission lines depending on weather conditions. Extending the application of DLR technology from one to numerous lines across a larger transmission power system presents challenges with respect to the scalability due to the large amount of data required. Firstly, a modified overhead line thermal model and the use of historical weather data are considered in this paper to preliminary assess the margin for increased rating of transmission lines. Secondly, spatial correlation of line ratings are analyzed and a comparison of various rating approaches, which rely on different combinations of weather variables, is presented. The resulting probability distributions of line ratings are compared with constant seasonal ratings highlighting the trade-off between those solutions that yield a large increase in rating at a cost of high volatility, against simpler approaches which are more conservative and require less information. The results reported are based on actual data of the western section of the Danish power transmission system.

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10.1109/PMAPS.2018.8440449
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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Contributors: Møller, J. G., Jóhannsson, H., Østergaard, J.
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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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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.

**General information**

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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 Thévenin 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.

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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 Thévenin 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 Thévenin 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 Thévenin 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 Thévenin equivalents, calculating voltage angles of the modified Thévenin 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.

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Contributors: Jóhannsson, H., Møller, J. G.
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Priority number: EP20140163623
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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.

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.

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 Thevenin 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.

Policies and Initiatives for Carbon Neutrality in Nordic
Policies and initiatives promoting carbon neutrality in the Nordic heating and transport systems are presented. The focus within heating systems is the promotion of HPs (heat pumps) while the focus within transport systems is initiatives regarding EVs (electric vehicles). It is found that the conversion to HPs in the Nordic region relies on both private economic and national economic incentives. Initiatives toward carbon neutrality in the transport system are mostly concentrated on research, development and demonstration for deployment of a large number of EVs. All Nordic countries have plans for the future heating and transport systems with the ambition of realizing carbon neutrality.
Projects:

**Static Security Assessment and PMU Data Validation**
Møller, J. G., PhD Student, Department of Electrical Engineering
Østergaard, J., Main Supervisor, Department of Electrical Engineering
Jóhannsson, H., Supervisor, Department of Electrical Engineering
Pinson, P., Examiner, Department of Electrical Engineering
Hug-Glanzman, G., Examiner
Huang, Z. H., Examiner
Samfinansierede - Virksomhed
01/08/2013 → 12/04/2017
Award relations: Static Security Assessment and PMU Data Validation
Project: PhD

**SOSPO: 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. Østergaard, J., Project Manager, Department of Electrical Engineering, Electric Energy Systems
Jóhannsson, H., Project Manager, Department of Electrical Engineering, Electric Energy Systems
Nielsen, A. H., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Garcia-Valle, R., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Yang, G., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Lind, M., Project Participant, Automation and Control, Department of Electrical Engineering
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Weckesser, J. T. G., PhD Student, Department of Electrical Engineering, Electric Energy Systems
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Project: Research