power can lead to collapse of the AC voltage at one or the other converter terminal which further contributes to destabilization of the system, or propagation of high AC voltages throughout the network and possible damage to the equipment insulation. This phenomena is mostly observed when the reactive power at the HVDC terminals are limited by the capacity of AC system. In order to assure proper operation of the DC link and minimize voltage fluctuations throughout the network, it is best to maintain the converter AC bus voltages constant during the modulation period.

The contribution of this paper is the development of a predictive control scheme to enhance the converter bus voltages for HVDC systems with real power modulation capability. The AC voltage fluctuations as a consequence of DC power modulation is anticipated and an attempt is made to prevent this voltage fluctuations. The proposed control strategy is a coordinated and centralized scheme. It predicts the needed value of shunt reactive power at each converter AC bus for a given value of the DC modulation power prior to dispatch of the control command to the converter stations. Thus, upon prediction of the reactive power at each converter station necessary provisions are made in computation of the HVDC and SVC control signals to minimize the converter voltage fluctuations.

In order to maintain the converter bus voltages at a pre-set value during the modulation period it is proposed that the needed value of reactive power at HVDC terminals be predicted, and the control signals for coordinated modulation of real and reactive powers be computed prior to dispatch of the control command to proper locations. In process of predicting the required values of reactive power at rectifier and inverter, use is made of the conventional power flow technique. However, certain modifications are needed to maintain a constant voltage at converter buses, and to reflect the generator dynamics.

To represent the converter buses by constant voltages, they are modeled as voltage regulated buses with an infinite reactive power limit in the power flow algorithm. The voltage magnitude of these buses are dictated by the pre-disturbance values of the rectifier and inverter AC bus voltages. To include the generator dynamics, the characteristics of generator terminal buses are modified in the power flow algorithm. A generator terminal bus is modeled as a connecting load bus with a zero specified value of real and reactive power. The generator direct axis transient reactance (x_d') is used to create a new voltage regulated bus which is connected to the generator terminal bus by this reactance. The voltage magnitude of this bus is computed based on the generator loading condition, following arrival of each measurement vector. The magnitude of real power at the voltage regulated buses are computed with use of the generation shift factors.

A nine-bus system is used for the purpose of simulation. The system consists of two synchronous generators, three transformers, an embedded two terminal HVDC link, seven AC transmission lines, an infinite bus, and a load bus.

Simulation results demonstrated a significant improvement in converter voltage profiles due to proper coordination in modulation of real and reactive powers. The inverter AC voltage is essentially maintained constant and an improvement in voltage profile of the rectifier is observed, although its value is not maintained constant. The reason for not being able to have a flat voltage profile is due to the two approximation introduced in the predictive algorithm.

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Extended Equal Area Criterion Justifications, Generalizations, Applications

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Since the beginning of its development [1, 2], the *extended equal area criterion* (EEAC) has shown interesting possibilities for on-line *transient stability assessment* (TSA). A very important advantage is the algebraic expressions it provides for the calculation of critical clearing times and stability margins. This makes the conventional TSA particularly easy, while furnishing analytic sensitivity tools.

This paper consists of three main parts, relative to the following three objectives:

(i) to systematically state the main hypotheses and key conditions underlying the EEAC, justify the former and suggest means to guarantee the latter;
(ii) to scan all possible types of instability likely to arise in practice and devise means to treat them;
(iii) to extract essential information out of a large body of simulations.

The first part of this paper is composed of Sections 2, 3 and 4. Section 2 restates the essentials of the EEAC, summarizes the basic formulation, then scrutinizes an important assumption underlying it and proposes means of justification. Sections 3 and 4 deal with accuracy aspects. Section 3 discusses the critical machine(s)' identification; means to draw up an appropriate list of candidate critical clusters are suggested, and the multimachine critical cluster is modelled. Section 4 explores the possible sources of errors, decomposes them into two types, then proposes means to reduce them to the extent possible.

The second part investigates and brings out an important generalization of the EEAC: that of treating any type of instability. Means to identify second swing instability in an extremely easy way are proposed along with appropriate formulation for their calculation. Notice that this is the first time that a direct method succeeds in tackling stability beyond the first swing. Examples on realistic power systems are quoted, where existing second swing instability phenomena have long been masked.

The third part of the paper reports essential information extracted out of over two thousand exhaustive simulation results, performed on 10 different power systems, under various operating conditions. The accent is put on the cases which do not work satisfactorily enough in order to get further in-depth understanding and to bring out appropriate improvements.

The above three objectives are reached at the expense of negligible additional computing effort which, according to the conclusion of [2], is much lower than that of the most efficient direct methods.

Computational efficiency together with good accuracy make the EEAC mature enough, i.e. ready for real world applications.

Discusser: S. C. M. de Oliviera

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Bad Data Identification in Power System State Estimation Based on Measurement Compensation and Linear Residual Calculation

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The most reliable way of removing erroneous data from a state estimation solution is to successively eliminate measurements with the largest normalized residual value until the remaining measurements satisfy a criteria of an error-free measurement set.

This, however, requires reestimation and recomputation of normalized residuals after the removal of each measurement which is computationally prohibitive for the on-line implementation. In addition, due to the effect of interacting bad data, some of the eliminated measurements may be valid data that should be used in a state estimation solution.

The presented method addresses both of these issues. By employing special techniques, the measurement compensation and linear residual calculation, the vector of normalized residuals following the elimination of the suspected measurements is obtained without reestimation.

Measurement compensation is a technique of removing the desired measurements, not by physically eliminating them from the measurement set but by changing their values in such a way that the resulting state estimator solution would be the same (assuming a linear model) as if the measurement were actually eliminated. Measurement compensation equivalences a change in the measurement topology to a change in the measurement vector.

Linear residual calculation complements the compensation by allowing an accurate computation of a change in the residual vector from a known change in the measurement vector and the subsequent calculation of new values of measurement residuals, objective function and normalized residuals. The terms of the residual sensitivity matrix required for the compensation and linear residual calculation are efficiently obtained using an expanded Jacobian matrix technique which takes advantage of the available factors of the gain matrix and properties of elementary triangular matrices.

The method performs bad data identification in two phases. In phase 1, measurements with the largest absolute normalized residual are successively added to the suspected measurement list and eliminated through compensation. Following each elimination, a new vector of normalized residuals is obtained using the linear residual calculation.

Once the remaining measurements are free of gross measurement errors, the estimated errors of the eliminated measurements become available in the method as a by-product of the measurement compensation. In phase 2 of the method, the final identification is performed by comparing normalized estimated errors of the suspected measurements against the statistically derived thresholds. Eliminated data deemed valid is returned to the measurement set and the final state estimation solution is then obtained without the refactorization of the gain matrix.

The method has been tested on a number of networks utilizing a variety of bad data configurations. Test results area reported for the IEEE 30-bus system and a 481-bus network of a midwestern utility. The 30-bus network tests demonstrate the identification by the method of single, multiple non-interacting and multiple interacting bad data while the large network test illustrates its computational performance.

Discusser: K. A. Clements

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A Flexible AGC Algorithm for the Hellenic Interconnected System

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For a number of years, the problem of Automatic Generation Control (AGC) has been one of the most accentuated topics in the operation of autonomous and interconnected systems. The solution of this problem has been one of the first practical applications of the decentralized control of large scale dynamic systems. The development of modern computers facilitated the design of all-digital AGC systems. The computerized AGC can incorporate the traditional Load Frequency Control (LFC), which is designed to match the generation to the varying system demand, and an Economic Dispatch (ED) program that distributes the generation among the generating units so that the total system cost is minimized.

The paper describes an AGC algorithm developed for the Hellenic Interconnected system. The algorithm consists of a flexible LFC scheme with four operating modes that depend on the magnitude of the measured area control error (ACE), and an approximate ED that is based on a predetermined table of the economic loading of units. The approximation in the ED is due to present computer hardware limitations and a precise on-line full scale optimal operation program can be applied as well.

The developed LFC algorithm includes the three well known types of control (Flat Frequency, Flat Tie-Line and Biased Frequency) and employs the integral control principle which means that the calculated additional generation demand ΔG in each control period is added to the current set point of the system generating units. The incorporated four modes of operation define four respective system operating regions, namely a dead-band, a normal operating region and two distinct emergency regions. When the required additional generation ΔG has an absolute value greater than the dead-band limit $G_{\min}$ and less than the first emergency threshold ΔG_{em1}, the system is in the normal operation mode and priority is given to the economic operation rather than to the speed of response. Therefore, the calculated ΔG in each control period is distributed among the available generators according to their participation factors. However, the scheduled generation is not necessarily picked up in one control period because of a finite rate of increasing or decreasing the generators output.

When the absolute value of the ACE exceeds the emergency threshold ΔG_{em1}, a quick response is much more