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POWER SYSTEM VOLTAGE STABILITY MARGIN IDENTIFICATION USING LOCAL MEASUREMENTS

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ABSTRACT

Voltage stability investigation is of a great importance for long-term electric load expansion as well as power system operation. This paper presents a new algorithm for identification of voltage instability in a specified load bus in a power system. The proposed algorithm is based on the linear Kalman filtering algorithm and the maximum power transfer principle. The proposal technique is used to identify Thevenin's equivalent circuit at a bus for different loading conditions, either when the total system loads change at the same rate (long-term voltage stability problem) or when a load on a certain bus changes. The proposed algorithm uses the real measurements at the bus in question to calculate the load impedance. These measurements are the load voltage and current. Thus, it can be implemented on-line on the control centers to investigate the voltage stability. The proposed algorithm is implemented to the standard IEEE 30-bus system.

INTRODUCTION

Voltage stability and system security are of great concern to planning engineers in the electric power industry. Owing to several widespread system blackouts throughout the world, resulting from voltage collapse, the problem of voltage stability has attracted continuous interest of researchers in the last two decades. presents an approach using fuzzy set theory for voltage and reactive power control of power systems. This approach takes both voltage security enhancement and loss reduction into account, where the violation level of buses voltage and controlling ability of controlling devices are transferred into fuzzy set notation by using a linear model. coordinates excitation and unified power flow control (UPFC) to improve power system transient and voltage stability. A robust approach is used to deal with uncertainties caused by parameter variations and the inclusion of UPFC controller.

Simulation results show that the coordinated excitation and UPFC control is effective for transient enhancement. Modal analysis has been widely employed in voltage stability studies. Literature shows that monitoring the largest eign value/singular value as a function of load increase may drive one to incorrect conclusions, since these values present a sharp variation at the bifurcation point. It applies the center manifold theorem to calculate some linear indices for voltage collapse analysis with the help of critical bus identification. It introduces the concept of interface flow margin in terms of steady-state voltage stability. The interface flow margin is available to determine the secure limit of the interface flow under a fixed load condition. It develops a voltage security assessment tool based on fast time domain simulation engine. Its main features are the simulation of voltage stability phenomena and slow dynamics, the computation of different kinds of security margins, the suggestion and the validation of corrective actions. Several analysis methods are available for long-term voltage stability.

The V-Q curve power flow method is widely used by utilities and has some advantages. Long-term dynamic simulation with proper modeling, however, is clearly the most accurate simulation method. Results from the V -Q method can be misleading. The same is true of other power flow program based analysis employing conventional modeling. Results from these power flow methods may be pessimistic, causing an over-design or overly conservative operation. A risk-based approach to security assessment for a voltage stability constrained power system is provided.

The risk calculation provided accounts for both future uncertainties on the system and the sequence associated with voltage collapse and violation of limits. Effects of the generator excitation current limit, the on-load tap changer (OLTC) and load dynamics on voltage stability are analyzed in state space. It presents a data-processing method to estimate the proximity to voltage collapse. The method employs only local measurements-bus voltage and load current-and calculates the strength of the transmission system relative to the bus. The collapse occurs when the local load approaches this value. The voltage stability of a system is determined by the dynamic characteristics of both the OLTC and the load.

The reactive power allocation is used to control the voltage stability, where a method of determining the best location for shunt compensation is presented. The method is based on the sensitivities of the change in reactive power flow with respect to the change in reactive power injection. The linear programming optimization technique is used to find the amount of shunt compensation, where the objective is to minimize the risk of voltage collapse. A weighted least square minimization of the voltage deviation is applied to put more weight on important load buses, i.e. it is acceptable to have relatively high or low voltages at connecting buses. This method does not solve exact load flow equations, and therefore it avoids inversion of full system size matrix.

The load ability of electrical networks considers whether operating points are feasible under physical constraints and its study has long been an integral part of power systems planning and operation. In the planning phase, load ability analysis can be used to determine the need for shunt compensation, new transmission lines, reserves, and other system additions. In the operation phase, a load flow solution can be used to find stability margins in preventing voltage collapses caused by large load variation and saddle-node bifurcation. As more renewable resources are integrated into the aging electrical infrastructure and systems operate closer to their limits, characterizing the load ability of power systems is becoming increasingly important. The most well-known example of a load ability limit is the power-voltage (PV) curve for a 2-bus system, where the maximum loading occurs at the tip of the curve.

For larger systems, visualizing and computing the load ability boundary becomes more difficult. A typical approach is to increase the load on all buses by the same factor from a given base load until a power flow

LITERATURE REVIEW

W. Taylor (1994) Voltage stability margin is essential to be known in advance to avoid voltage collapse and system blackout. This paper presents a new technique for determining the voltage stability margin, so that a corrective decision is taken in the proper time. The proposed algorithm is based on recursive least error square to measure the Thevenin's impedance at the bus in question as the busload changes. The proposed technique utilizes the past measurements together with the recent local measurements, bus voltage and load current, to predict Thevenin's impedance. The voltage instability occurs at a point where the load impedance equals Thevenin's impedance. Prior to this point the voltage margin can be predicted using the proposed technique. The method is tested on the IEEE 30 bus system for a single bus-load change, short-term voltage stability, and when the buses loads change with the same rate, long-term voltage stability study. Unlike the other techniques the proposed algorithm has the ability to estimate digitally the Thevenin's impedance at the load bus in question.

T. Van Cutsem, L. Wehenkel, et al (1993) Following a review of the difficulties associated with the measurement and interpretation of statistics of the small-scale motion, the evidence for and against local isotropy is assessed in the light of measurements in a turbulent plane jet at moderate values of the Reynolds and Péclet numbers. These measurements include spatial derivatives with respect to different spatial directions of the longitudinal velocity fluctuation and of the temperature fluctuation. Relations between mean-square values of these derivatives suggest strong departures from local isotropy for both velocity and temperature. In contrast, the locally isotropic forms of the vorticity and temperature dissipation budgets are approximately satisfied. Possible contamination of the fine-scale measurements by the anisotropic large-scale motion is assessed in the context of the measured structure functions of temperature and of the measured skewness of the streamwise derivative of

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temperature. Structure functions are, within the framework of local isotropy, consistent with the average frequency and amplitude of temperature signatures that characterize the quasi-organized large-scale motion. Conditional averages associated with this motion account, in an approximate way, for the skewness of the temperature derivative but make negligible contributions to the skewness of velocity derivatives. The degree of spatial organization of the fine structure is inferred from conditional statistics of temperature derivatives.

R. Diao, K. Sun, V. Vittal et al (2009) The probability density functions (PDFs) of sea level and geostrophic relative vorticity are examined using satellite altimeter data. It is shown that departures from a Gaussian distribution can generally be represented by two functions, and that the spatial distribution of these two functions is closely linked to the skewness and kurtosis of the PDF. The patterns indicate that strong jets tend to be identified by a zero contour in skewness coinciding with a low value of kurtosis. A simple model of the statistics of a meandering frontal region is presented which reproduces these features. Comparisons with mean currents and sea surface temperature gradients confirm the identification of these features as jets, and confirm the existence of several Southern Ocean jets unresolved by drifter data. Diagnostics from a range of idealized eddying model simulations show that there is a strong, simple relationship between kurtosis of potential vorticity and effective diffusivity. This suggests that kurtosis may provide a simple method of mapping mixing barriers in the ocean.

K. Vu, M. M. Begovic, D. Novosel et al (1999) In this paper, we present a novel approach for Arabic Text-Independent Writer Identification and Verification. Given that the handwriting of different people is often visually distinctive, we propose a global approach based on texture analysis, where each writer's handwriting is regarded as a different texture. This allows us to apply a texture classification method mainly based on a set of new proposed features extracted from Grey Level Run Length (GLRL) Matrices. The efficiency of the proposed approach is demonstrated experimentally by the classification of 650 handwriting documents collected from 130 different Arabic writers. Comparisons with Grey Level Co-occurrence Matrices (GLCM) technique demonstrate that the GLRL matrices contain more discriminatory information and that a good method of extracting such information is of great importance for successful classification.

I. Smon, G. Verbic, F. Gubina (2006) In forensic science different unique bio-metric information of humans are being used to analyses forensic evidence like finger print, signature, retina scan etc. The same can be used applied on handwriting analysis. The Automatic Writer Identification and Verification

(AWIV) is a study which combines forensic analysis field and computer vision and pattern recognition field. This paper presents a survey of literature on the offline handwritten writer identification/verification with the type of data, features and classification approaches attempted till date in different languages and scripts. The analysis of the approaches has been described for further enhancement and adaptation of these techniques in different languages and scripts.

B. Milosevic, M. Begovic (2003) An existing design of conductivity probe for the measurement of void fraction has been developed and tested. Calibration checks showed that the time averaged output of the instrument was close to linear over the whole range of void fraction, with a tendency to overestimate the true value. Computer modelling of the probe's response to different void distributions supported the calibration results. Two meters were used to examine the dynamic variation of void fraction in air water flows in a vertical 32 mm diameter tube. Flow patterns ranging from bubbly to annular were observed. Examination of the void fraction traces and their probability distribution functions enabled the identification of six flow regimes: discrete bubble flow, spherical cap bubble flow, stable slug flow, unstable slug flow, churn flow and annular flow. The locations of flow regime transition boundaries on a flow pattern map, deduced from this objective analysis, are in agreement with the data of other workers. The unstable slug flow regime corresponds to a region some workers have identified as churn flow, it provides explanations for some of the apparent anomalies concerning the location of the slug to churn flow boundary. Cross-correlation of the signals from the two probes has provided statistical data on the lengths of slugs and Taylor bubbles which suggested modifications to the previous theories enabling the entry to and exit from the unstable slug flow regime to be predicted.

B. Leonardi, V. Ajjarapu (2011) This paper evaluates the performance of edge-based directional probability distributions as features in writer identification in comparison to a number of nonangular features. It is noted that angular features outperform all other features. However, the nonangular features provide additional valuable information. Rank-combination was used to realize a sparse-parametric combination scheme based on nearest-neighbor search. Limitations of the proposed methods pertain to the amount of handwritten material needed in order to obtain reliable distribution estimates. The global features treated in this study are sensitive to major style variation (upper- vs lower case), slant, and forged styles, which necessitates the use of other features in realistic forensic writer identification procedures.

METHODOLOGY

The Thevenin's equivalent circuit at any load bus is given in Figure 1. The measured

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value at the load bus is the voltage amplitude, the load active and reactive power, and accordingly the load power factor and the load bus angle with respect to the slack bus. In this figure the following symbols are used Z1 h is the Thevenin's equivalent impedance at a certain loading condition seen by the load bus in question.,

Z1 h = Rth + jXth,

v;h is the The venin's voltage at a certain loading condition seen by the load bus under consideration

$$V_{th} = a + jb$$

I_L is the load current $= I_a + jI_r$

V_L is the load voltage $V_L = c + jd$

Z_L is the load impedance magnitude $= \frac{|V_L|}{|I_L|}$

Z_L is the load impedance magnitude $= \frac{|V_L|}{|I_L|}$

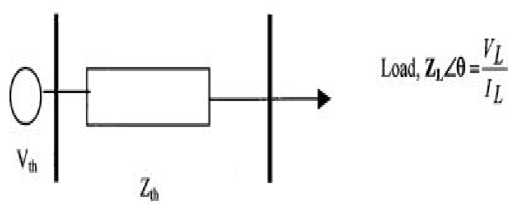

Figure Thevenin's equivalent circuit at bus

At maximum power transfer, the point beyond which a voltage collapse occurs, the load impedance magnitude is equal to the Thevenin' s impedance magnitude.

$$|Z_L| = |Z_{th}|$$

Applying KVL to the equivalent circuit at bus I gives

$$V_{th} = V_i + I_L Z_{th}$$

Where Vth is the Thevenin's equivalent voltage seen by bus i, v; is the voltage of bus i, it can be measured on line for on line identification or from the load flow analysis for long-term identification. h is the load current connected to bus i. It is also measurable quantity for on-line application. Or can be calculated from the load power and load voltage. Finally, Zth is the Thevenin's equivalent impedance seen by bus i. Equation can be written in rectangular form as:

$$a + jb = (c + jd) + (I_a + jI_r)(R_{th} + JX_{th})$$

The real parts of the above equation give,

$$a = c + I_a R_{th} - I_r X_{th}$$

While the imaginary part gives:

$$b = d + I_r R_{th} + I_a X_{th}$$

$$\begin{bmatrix} c \\ d \end{bmatrix} = \begin{bmatrix} 1 & 0 & -I_a & I_r \\ 0 & 1 & -I_r & -I_a \end{bmatrix} \begin{bmatrix} a \\ b \\ R_{th} \\ X_{th} \end{bmatrix}$$

The above equation is valid at any load bus on the system. In vector form, equation can be written at any load j as:

$$Z_j = H_j X + \zeta_j$$

For on-line voltage stability identification, j may by the loading condition at the bus in question for every hour, since the voltage and current and hence the load impedance are measurable quantities.

RESULTS

Test cases both with and without enforcement of reactive power limits are considered. We use the IEEE test cases [36] and large test cases representing the Great

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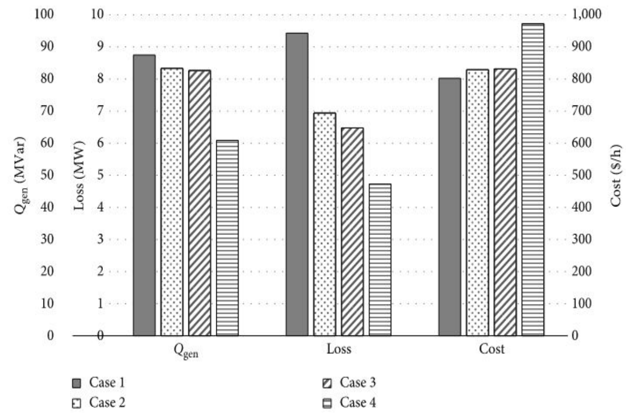
Britain (GB) and Poland (PL) power systems as well as other European power systems from the PEGASE project. These large test cases were pre-processed to remove low impedance lines as described in order to improve the solver's numerical convergence. A 1 × 10−3 per unit low-impedance line threshold was used for all test cases except for PEGASE-1354, PEGASE-2869, and PEGASE-9241 which use a 3 × 10−3 per unit threshold. The power injection direction is specified with uniformly changing active and reactive power injections at constant power factor: Pk (η) = Pk0 η and Qk (η) = Qk0 η, where Pk0 and Qk0 are the test cases' specified power injections.

The relaxations were solved using a computer with a quad-core 2.70 GHz processor and 16 GB of RAM. The "solver time" results do not include the typically small problem formulation times. The continuation power flow (CPF) in MATPOWER [38], modified to consider reactive-power limited generators, is used to obtain a lower bound on the voltage stability margin. In order to maintain consistency between the CPF and convex relaxations, we do not limit the slack bus reactive power output.4 Solution times for the CPF method are not provided for the results in this section due to a strong dependence on implementation details (e.g., selected step sizes, tolerances, and methods for identifying reactive power limit violations). We note that commercial continuation codes are tractable for large systems. The upper bounds provided by the convex relaxations are reported as a relaxation gap calculated as the percent difference from the nose point identified by the CPF. Thus, the relaxation gap is determined by both the CPF's lower bound and the relaxation's upper bound.



Graph Variable comparisons for the IEEE 30-bus test system.

This study is focused on incorporating the static line voltage stability indices into the conventional OPF formulation with the goal of enhancing static voltage stability margin and reducing power losses of the system. The IEEE 30-bus, 57-bus, and 118-bus test systems are used to assess and verify the performance and effectiveness of the proposed control approaches. The detailed data are as follows:

(i)The IEEE 30-bus test system includes six generators installed at buses 1, 2, 5, 8, 11, and 13. There are four transformers at lines 6–9, 6–10, 4–12, and 27–28 and 41 transmission lines. The total loads are 283.4 MW and 126.6 MVar. The network data are given.

(ii)The IEEE 57-bus test system consists of seven generators located at buses 1, 2, 3, 6, 8, 9, and 12; 15 transformers; 80 transmission lines; and 42 loads totaling 1250.8 MW and 336.4 MVar, respectively. The detailed data are taken.

(iii)The IEEE 118-bus test system has 54 generators, 9 transformers, and 186 transmission lines. The active and reactive power load demand of the system is 4242 MW and 1439 MVar, respectively. The complete data of these networks are given.

The results of this study are generated using a program developed in MATLAB. The power flow and continuation power flow processes are accomplished with the help of MATPOWER. The simulation results were generated to investigate the proposed control approaches for all the aforementioned test systems. Since the performance evaluation of the proposed VSC-OPF approach based on the line voltage stability indices is the main purpose of this study. Four different cases will be individually considered as part of the objective function in each system. The details of these cases are as follows:

(i)Case 1: the minimization of the generation cost is the objective function as shown in equation. The coefficients of generation cost are defined as. This study uses the results of this case as the base case to compare the performance with proposed approaches.

(ii)Case 2: the minimization of the total sum of FVSI in equation is used as the objective functions. The lower the value of FVSI, the better the overall system voltage stability.

(iii)Case 3: the minimization of the total sum of L_{mn} in equation is formulated as the objective functions of the OPF problem to enhance the voltage stability.

(iv)Case 4: the minimization of the total sum of LVSI in equation is formulated as the objective functions similar to Cases 2 and 3.

System Performance

This section is to investigate the system performance of proposed approaches. For this study, the continuation power flow is used to determine the maximum loadability of the power system. The nose point of the P-V curve represents the maximum loadability; when the system reaches this point, any further increase in the active power transfer will lead to voltage collapse. The system performance of the IEEE 30-bus test system is shown. The comparisons of reactive power generation, transmission loss, and generation cost are indicated in Figure. It is clear that reactive power generation and transmission loss are significantly reduced with the objective functions of the minimization of the total sum of stability indices compared with the minimization of generation cost (Case 1). The reactive power generation of Case 1 is 87.46 MW, whereas Case 2, Case 3, and Case 4 perform better outcome with 83.33, 82.63, and 60.81 MVar, respectively. Case 4 is able to reduce 49.90% of loss compared with Case 1. Cases 2 and 3 also reduce the loss to 26.39% and 31.37%, respectively.

CONCLUSION

The new method is based on an N+1 buses equivalent system, whose parameters are estimated directly from synchronized measurements obtained at the boundary buses of the load area. For each tie line, the method calculates the transfer limit and margin against voltage instability analytically from that estimated equivalent system. The new method has been demonstrated in detail on a 4-bus system and then tested by case studies on a 140-bus

NPCC system model. Compared to a traditional TE-based method for measurement-based voltage stability monitoring, the new method has two apparent advantages. First, the new method offers detailed limit and margin information on individual tie lines so as to identify the tie line and boundary bus with the smallest margin as the location where voltage instability more likely initiates. Second, as demonstrated on the 4-bus system, before the voltage collapse point, the total tie-line flow limit from the new method is more accurate than the limit from the TE-based method.

The latter fluctuates more and is not as flat as the former because the TE-based method does not model the weak or strong connection between boundary buses. The above second advantage makes the new method more suitable for online monitoring and early warning of voltage instability, and the first advantage can help the system operator to identify the location where voltage instability more likely initiates and accordingly choose more effective control resources, e.g., those having shorter electrical distances to the tie line with the smallest margin. Future work is recommended on techniques to quickly determine the VCA. The proposed method can be extended to online voltage security assessment by considering a set of credible contingencies and by monitoring the smallest margin at any given time, voltage stability control based on the proposed new method will be studied.

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