Study Committee C2

Power system operation and control

Paper 10565_2022

Nonparametric identification of events in the Western Siberia power system based on big data processing of PMU

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Motivation

- **The events in the power system**, leading to pre-emergency, emergency and post-emergency modes, corresponding to voltage, current and frequency values overpassing beyond the permissible continuous limits in the power system **are understood as an abrupt change in the mathematical model of the normal (operating) mode**. As **the violation of the normal mode** develops, the controllability of the power system sharply decreases, which **can lead to various serious consequences**.
- To prevent this situation, **it is necessary to detect such an event as soon as possible**, regardless of its scale, place and cause of occurrence. The **solution** to this problem is possible to achieve through the **use of space-distributed and time-synchronized Phasor Measurement Units.**

Method/Approach

- Known **methods for detecting damage and abnormal modes** of power systems **can be** conditionally **divided into two groups: parametric** (model) **and non-parametric** (modeless, based on data, signals, knowledge, rules, etc.). Parametric methods directly or indirectly use the parameters of mathematical models of power systems and their elements. The **methods of the second group use only vector measurement data**.
- **The application of parametric methods requires complete observability of the power system**, they are characterized by insufficient robustness. In contrast to parametric methods, in the **methods based only on the data of the synchronized vector measurements (SVM), a priori information about the parameters of the model of the power system is not required**.
- The mathematical model of the normal operation of the energy system is described by a linear discrete dynamic system with many inputs and many outputs (multi input multi output - MIMO) in the state space in the form

where A,B - matrices of own dynamics and control efficiency; x - vector of states of the power system of n_x dimension, v - vector of input actions of n_y dimension, k = 0,1, …- discrete time

$\begin{bmatrix} X \end{bmatrix}$ - condition, when an abnormal mode in the power system occurs

$\varepsilon = \left\| X_{k+1} \begin{bmatrix} X_k \\ V_k \end{bmatrix}^{\perp} \right\|_R$ - as a criterion for detecting an abnormal mode in the power system we can take the norm the abovementioned condition, calculated for each moment of time

Method/Approach

- **Algorithm for detecting an abnormal mode in the power system:**
- **Step 1.** For each time instant k, a measurement matrix is compiled

$\begin{bmatrix} X \end{bmatrix}_k \begin{bmatrix} \quad \mathbf{x}_{k+} \end{bmatrix}$

the width of which must be sufficient to meet the conditions of step 2

- **Step 2.** A nontrivial right zero divisor of the measurement matrix satisfying the orthogonality condition

$\begin{bmatrix} X \end{bmatrix}_k \begin{bmatrix} X \end{bmatrix}_k^{\perp}$

is determined

$\begin{bmatrix} X \end{bmatrix}_k \begin{bmatrix} \quad \mathbf{x}_{k+} \end{bmatrix}^{\perp} \mathbf{x}_k$

- **Step 3.** A matrix of measurements

is compiled and the value of the criterion is determined in Step 2

$\left\| \quad \right\| \left\| X \right\|_k^{\perp}$

A sharp increase in the ε value will correspond to the occurrence of a abnormal mode of the power system, and the **moment ε deviates from zero will coincide with the time of its occurrence**. Thus, the speed of the abnormal mode detection algorithm is determined by the sampling rate of the signals and coincides with the time interval between two successive measurements

- The permutation of time instants in criterion

converts the method from the mode o

f controlling the occurrence (identification of the fact) of an event to the mode of predicting the possibility of an event occurring cigre | PARIS 2022

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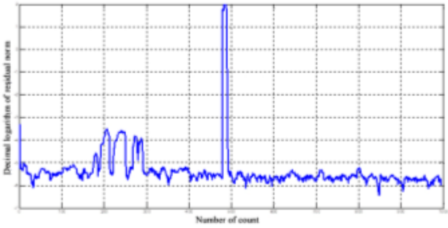
continued

Experimental setup & test results

- The equivalent model of the power system of Western Siberia used in the research corresponded to the mode of the winter maximum load. The model contained **27 nodes and 35 non-transformer branches**, **32 transformer branches** and **17 impedance branches** (transformer and non-transformer), implemented into the scheme to replace the branches formed as a result of the model equivalent in the **RastrWin software package** and containing negative active and/or reactive resistances. The total number of equations describing this power system was more than 200.
- **SVM virtual devices were installed in the nodes of the power system model, as well as at the receiving ends of overhead lines**. Emergency situations were modeled by load surges and short circuits in non-transformer branches with successful and unsuccessful automatic reclosing (AR).



Discussion

- **An explicit burst of criterion indicates a short circuit** in the power system with a successful automatic reclosure, which occurred **at the time instant k = 493 counts**. The ordinate axis in Fig. 1 is given on a logarithmic scale, from which it follows that **at the moment of the onset of a non-normal regime**, the **value of the criterion increased by 5-6 orders of magnitude**. This result was obtained by processing the measurements (readings) of the phase angle received by the SVM device installed at the receiving end of the 500 kV overhead line. In this case, the short circuit occurred at a great distance from the SVM device in the adjacent 220 kV line. Further, as can be seen from the diagram in Fig. 1, a post-emergency mode is established in the power system.
- The performed modeling in reverse time confirmed the validity of criterion for predicting events in the energy system. The value of the criterion changed abruptly several steps before the actual event occurred.

Conclusion

- As a result of the research carried out, an **algebraic method of nonparametric identification** (detection) **and prediction of abnormal modes in the power system in real time has been developed**
- **The method does not require a priori information about the parameters of the mathematical model of the power system**, does not imply a direct solution to the prediction problem, doesn't use statistical calculations, doesn't require its preliminary training or long-term adjustment
- **The numerical algorithm** that implements the method **is based on the algebraic criterion of compatibility (solvability) of the linear matrix equation of the problem of identifying the mathematical model of the power system**
- **The efficiency** of the method **does not depend on the parameters of the power system model**, and, consequently, on errors in their determination