Study Committee B5

PROTECTION AND AUTOMATION

Paper 373_2022

Development of stability monitoring, emergency control and relay protection issues based on online analysis of dynamic properties of power systems

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Motivation

- development of new methods for monitoring and operation the regime of the power system based on the PMU data in the context of the introduction of DER and changes of power system dynamic
- development of adaptive automation based on detection of oscillatory structures and calculation of their energy online
- creation of local emergency automation to prevent stability violations based on emergency mode parameters (the "AFTER" principle)
- clarification of requirements for synchrophasor technology for using PMU data in the tasks of emergency automation and relay protection

Method/Approach

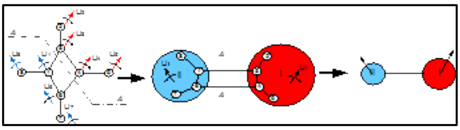
- the method of analysis of oscillatory movements of synchronous machines with the decomposition of oscillation energy into kinetic and potential is tested
- algorithms have been developed:
  - ❑ identification and analysis of oscillatory structures based on PMU data
  - ❑ calculation of the oscillation energy and dynamics of oscillation energy
- a predictive model of stability disturbance has been developed based on monitoring the excess of limits of kinetic energy fluctuations determined by the depths of potential pits for mutual oscillations

Objects of investigation

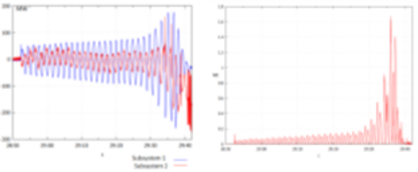
- development of requirements for the algorithm of control action selection based on the "AFTER" principle implemented on the PMU data
- development of requirements for the synchrophasor technology for use in SIPS
- implementation and testing of the control action selection algorithm based on the "AFTER" principle for the selected power system model
- development of principles for the application of automation for the prevention of stability violations based on PMU data as part of the existing emergency management structure

Experimental setup & test results

- development of algorithms for calculating the kinetic energy of own and mutual motion of subsystems based on PMU data

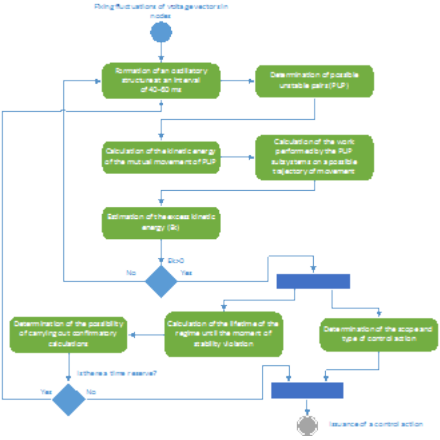


Representation of the oscillatory structure



Kinetic energy of own and mutual motion of two subsystems

The algorithm for selecting the control actions of SIPS based on PMU data



Formation of the oscillatory structure:

- determination of frequency deviations (Δf) from Fnom and the nature of these deviations: accelerating (Δf>0) and the braking (Δf<0) voltage phasor in nodes of power system;
- grouping of power system nodes into subsystems with identical character of voltage phasor motion;
- formation of possible unstable pairs of subsystems, provided that one subsystem in each pair is accelerated, the other is slowed down relative to the center of inertia of the system (the base vector);
- calculation of the rate of deviation of the voltage phasor from the center of inertia at each node;
- calculation of the deviation of the velocity of mutual motion for each pair of subsystems and the mutual moment of inertia;
- calculation of kinetic energy of the mutual motion for each two subsystems

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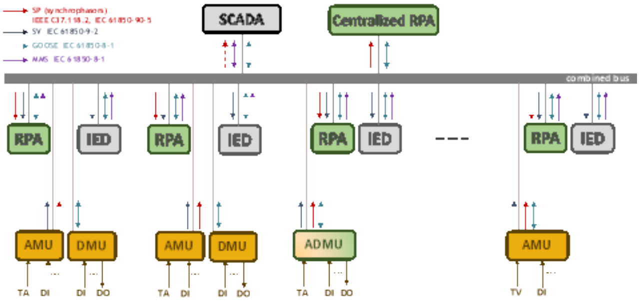
Using of MU for increasing of observability

One of the main condition – availability and large-scale development and implementation of AMU (analog measurement unit), SAMU (stand-alone MU), DMU (digital MU) as sources of synchrophasor. Using AMU, SAMU, DMU allows to use PMU data in SIPS and centralized relay protection and automation.

Due to the information exchange between RPA devices (primarily the current and voltage synchrophasors and GOOSE messages), it becomes possible to improve the quality indicators of the functioning of RPA devices and simplify the implementation of protections with absolute selectivity of buses, transformers, lines, etc., as well as simplify the implementation of centralized RPA devices.



Centralized PACS at the substation

Kinetic energy calculation

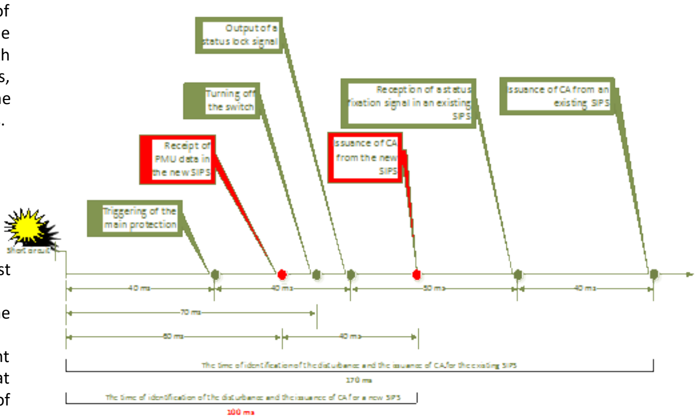
the kinetic energy of mutual motion is defined as

$$K = \frac{1}{2}\left(\frac{J_1 J_2}{J_1 + J_2}\right)\Delta\Omega_{12}^2,$$

J1 – the total moment of inertia of the first (accelerating) subsystem;

J2 – the total moment of inertia of the second (braking) subsystem;

ΔΩ12 – deviation of the displacement velocity of the voltage vector that determines the mutual motion of subsystems 1 and 2.



Time diagram of the choice of control actions for the new and existing SIPS

Conclusion

- the possibility of using the PMU data for emergency management tasks was confirmed;
- the development of synchrophasor technology allows the use of PMU data in SIPS;
- russian companies produce high-quality PMU and AMU at an affordable price, which makes it possible to seriously expand the installation of PMUs at facilities and use PMU data for emergency automation and relay protection;
- the value of kinetic energy of the pair relative to the center of inertia of the system was estimated;
- the instability between the subsystems was predicted based on the analysis of mutual movement on a possible trajectory violation of stability can be recorded when assessing the excess of kinetic energy, defined as the difference between the kinetic energy acquired by the pair at the initial moment of movement, and the work performed by the pair on a possible trajectory of movement aimed at returning to a stable equilibrium position;
- clarification of the requirements for characteristics of the data collection system and server equipment and performance and stability of algorithms.

The main advantages of the SIPS according to the "AFTER" principle:

- calculation of the control actions only after the occurrence of a disturbance during 100 ms;
- fixation of disturbances of any level and nature and reduction of calculation time and selection of control actions;
- the choice of places for the implementation of control actions, taking into account the current circuit-mode conditions.

Research results:

- predicting the occurrence of a stability disorder;
- calculation of the control actions to prevent a stability violation (performed when a disturbance occurs);
- the choice of control actions is performed after any disturbances regardless of the type of stability maintained.