ANNOTATION

to the thesis for the degree of Doctor of Philosophy (PhD)
6D071800 - "Electrical power engineering"
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The theme of the thesis "Identification and damping of low-frequency oscillations along the «North-South» transit of Kazakhstan's NEN using Smart Grid technology"

In the dissertation work, research results on the identification of low-frequency oscillations (LFOs) dangerous for stability in the power system of Kazakhstan and the development of algorithms for their damping are given. The algorithms are directed at the calculation of correct parameters for the adjustment of system stabilizers of the generator's excitation system. Also, the architecture of the Wide Area Damping System (WADS) for identification and damping of oscillations in real-time, using synchronized vector measurements of the Wide Area Monitoring System (WAMS), is developed.

Relevance of the study.

Today, the development of power systems in the world has reached a very high level, as a result of which the dynamic properties of systems have become more complex, and the issues of stability preservation come to the forefront. One of the main problems of oscillatory stability violation is electromechanical power oscillations in the power system called LFOs. The leading causes of LFOs are the occurrence of power unbalance in systems interconnected by long transmission lines, mechanical mass oscillations, changes in synchronous operation of a generator or a power plant in a power system due to the parameters of AVRs and power system stabilizers (PSSs) of the excitation system not being set correctly.

Extensive research has led to the classification of LFOs into various types, including torsional, local, inter-area, and control modes oscillations. The analysis of recorded emergency events in power systems worldwide has revealed that the most frequent cause of power system outages is oscillations with frequencies ranging from 0.1 to 0.7 Hz. Consequently, these LFOs are widely recognized as the most dangerous in international practice.

Identification of LFOs and detection of dangerous oscillations are of paramount importance. Accordingly, it was necessary to create an effective system for monitoring and identifying LFOs in the power system. The emergence of synchronized phasor measurement technologies in online mode allows the creation of a control system for the steady-state and transient process of the power system – WAMS, making it possible to predict dangerous modes leading to stability violations, including the control of oscillatory stability.

Studies of oscillatory stability were conducted using WAMS in the Kazakhstan grid, which showed the presence of undamped inter-area LFOs with natural frequencies of 0.3 - 0.4 Hz and duration of oscillations of up to 4-5 minutes.

The analysis of several recorded events is given, and the largest amplitude of power fluctuations along the overhead 500 kV power line "North-South" transit of the Kazakhstan grid was ±150 MW.

The impact of the identified LFOs significantly limits the capacity of Kazakhstan's power grids and can also lead to major system accidents in post-emergency modes when the transit operates at maximum permissible limits. Also, an increase of Renewable Energy Sources (RES) integration can lead to the deterioration of the power system's dynamic properties and, accordingly, offers new challenges to maintain stability.

Weak damping of LFOs in the power system of Kazakhstan, as well as the risk of deterioration of the situation when integrating a large amount of RESs, show the need to damp dangerous modes of oscillations and thus increase the stability of the system. The main and most effective equipment is the PSS as part of the synchronous generator excitation system. At the same time, it is necessary to adjust the PSS parameters correctly because incorrect adjustment of parameters can worsen the generator response to electromechanical power fluctuations and, consequently, lead to the risk of stability violation. There are several analytical and optimization algorithms for tuning the parameters of the PSS in the excitation system, and the applicability of heuristic and artificial intelligence algorithms continues to be investigated. Therefore, in the conditions of electric grids with long transmission in Kazakhstan, as well as considering the expected volume of RES integration, it is necessary to develop a new algorithm for adaptive tuning of PSS parameters.

The purpose of this work is to develop an algorithm for adaptive tuning of PSS on generators for effective damping of LFOs over the interconnected transmission system under conditions of grid scheme changes and RES integration.

To achieve the objective, the following tasks are required:

- The existing methods of monitoring and identification of LFO in developed power systems of other countries were reviewed, and the recorded accident events caused by LFO were analyzed;
- Carry out identification and analysis of low-frequency oscillations in the Kazakhstan grid according to WAMS data.
- Review existing methods and algorithms for tuning PSS parameters. Analyze the effectiveness of the proposed approach using the residue method for tuning the PSS parameters of the power system of Kazakhstan.
- Determination of the investigated power unit and development of a digital model for the calculation of transients and modal analysis.
- Development of the algorithm of PSS tuning and control of oscillatory stability in real-time. Verification of correctness of the calculated PSS parameters for damping of LFOs.
- Develop WADS system architecture for identification and damping of LFOs in real-time using Smart Grid technologies;

- Recommendations and requirements for PSS devices in addition to existing standards in the Republic of Kazakhstan on excitation system of synchronous generators are proposed.

Research methods:

- - Analysis of existing and investigated in the scientific and practical field of classical, heuristic, and adaptive methods of tuning PSS, excitation system of generators;
- Experimental studies of transient stability in 500-220 kV power grids based on synchronized phasor measurements of the WAMS system;
- Modal analysis of the studied power area, creation of Bode diagram, search for PSS parameters based on the revisited residue method, stability calculations in specialized software packages DigSilent Power Factory and MATLAB Simulink.

The object of the study:

Intersystem 220-500 kV power grid and power plants in the Unified Energy System of Kazakhstan.

The subject of the study:

Operation modes of intersystem power grids in normal and transient operating conditions. Excitation system and PSS of power plant generators. Adaptive algorithms for tuning the PSS parameters.

Novelty of the thesis work:

1. The conducted analysis on monitoring and identification of LFO showed the existence of significant fluctuations in the power system of Kazakhstan, in particular on the transit 500 kV “North-South”;
2. Qualitative characteristics of LFOs on inter-area 220-500 kV grids of Kazakhstan power system have been obtained by WAMS system and by modal analysis in the developed model.
3. The algorithm of adaptive tuning of PSS parameters developed based on the revised residue method, is a practical solution for the complex closed power system of Kazakhstan, especially during changes in the network scheme and integration of RESs.
4. Calculations of PSS parameters for generators of Moynak HPP, based on the developed model on the real data of the regulation system, generator and adjacent equipment were performed;
5. The architecture of a new WADS system for Kazakhstan national power system was developed for adaptive tuning of PSS parameters for damping dangerous inter-area LFOs.

The main statements put forward for defense:

1. Identification of LFOs in Kazakhstan power network according to the data of synchronized phasor measurements.
2. Development of an algorithm for adaptive tuning of PSS parameters using mode and network parameters in the process ramp;
3. Development of the digital model of the Almaty power unit in the program environment Power Factory Dig Silent;
4. Results of modeling on LFO damping considering the updated tuned PSS parameters on the example of Moynak HPP.
5. WADS system design architecture for adaptive tuning of PSS parameters by identifying and damping dangerous modes of LFO.

The author's personal contribution is as follows:

- The influence of low-frequency oscillations on the stability of the power system of Kazakhstan was analyzed;
- An algorithm for adaptive tuning of PSS parameters and control of oscillatory stability in real-time was developed;
- WADS architecture was developed for the identification and damping of inter-area LFO.

Theoretical and practical significance of the work:

- The developed method and model of PSS adaptive tuning will allow electric power plants to adjust the operation of the generator excitation system to increase the capacity in normal modes and stability of inter-system power grids in case of emergency power imbalances.
- The results of the thesis were applied to develop recommendations and requirements of System Operator KEGOC for power plants in terms of PSS and AVR settings, which is confirmed by the letter received from KEGOC on approval of the research report.

Approbation of the work:

The main results and provisions of the thesis were reported and discussed at the following scientific conferences:

1. Professional Workshop on Ultra High Voltage Transmission and Smart Grid, 2018, Hong Kong, report “Condition and prospects of development of Kazakhstan's power electrical industry”;
2. 54th International Universities Power Engineering Conference (UPEC), Bucharest, 2019, report “Analysis of the Kazakhstan's Grid Oscillation Instability by using WAMS System and PSCAD Program”;
3. Kazan International Forum, online, 2022, report “Optimization of operation modes of digital Smart Grid systems”;

4. ENSO International Energy Summit, Almaty, 2023, report “The need to tuning the parameters of system stabilizers (PSS) of synchronous generators to improve the stability of UES of Kazakhstan”;

5. International Scientific and Practical Conference, AUES, Almaty, 2024, report “Identification of low-frequency oscillations on the transit ‘North-South’ of the unified energy system of Kazakhstan”.

The work also included a survey of Moynak HPP and Almaty CHP-2, and discussions with technical staff on the operation of the excitation system and PSS. The data obtained during the survey were applied in the development of the Almaty power unit model.

Publications:

There are 9 publications on the materials of the thesis, including 1 article in the journal included in the Scopus database and having a non-zero impact factor, 5 articles in journals from the Higher Attestation Commission list, 3 reports in the Proceedings of Scopus conferences, as well as 1 Patent for utility model.

Structure and scope of the work

The dissertation consists of an introduction, 4 sections, conclusion, list of used sources. The thesis is set out on 126 pages, and contains 14 tables, 67 figures, 34 formulas, and 7 appendices. The list of references contains 78 sources.