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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Sajjad Asefi

PhD Program: Engineering Systems

Title of Thesis: Advancements in power system state estimation: innovative algorithms and solutions for enhanced reliability and efficiency

Supervisor: Assistant Professor Elena Gryazina

Name of the Reviewer: Dmitrii Vladimirovich Shatov

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Date: 28-11-2023**

Reviewer's Report

Relevance of the research topic

The doctoral thesis by Sajjad Asefi is devoted to the problems of the power system state vector estimation. Modern power system is a complex and critical infrastructure connecting electricity producers and consumers. Effective estimation of the such a system state plays a very important role in their monitoring and control.

The thesis considers several practically oriented problems related to power system state estimation:

– detection of bad data provided online by SCADA and PMU measurement systems;

– detection and classification of several types of anomalies in power system: sudden load change, sudden generation change, false data injection attack of data transmitted by the SCADA system and other sensors;

– developing (and comparison with classical versions) of distributed state estimation algorithms;

– developing of a solution for the safe operation of the power system based on blockchain.

Solving these problems will improve the efficiency and reliability of power system, as well as reduce the costs of its operation. As a consequence, it will also increase security and reduce vulnerability of systems to cyber-attacks.

All the stated problems are actual, relevant and correspond to modern trends in the development of power systems: the developing of smart grids using artificial intelligence, decentralization, private generation, and etc.

The approaches used in the study are also relevant and represent a combination of the classical methods to solving state estimation problems with the modern machine learning ones, which can significantly improve the efficiency of the power system.

Research objective

consists of studying existing modern methods for power system state estimation, as well as their improvement using innovative and intelligent approaches based on supervised machine learning, increasing the efficiency, reliability and safety of the power system, which is very important from a practical point of view.

Thesis outline

The main part of the work consists of 6 chapters and a conclusion.

The Introduction describes the problems that arise during state estimation of power system, then the objectives and goals of the study are formulated, along with the author's contribution to the study, and an outline description of the work.

The second chapter contains a literature review in which the applicant describes the history of the state estimation development of power system, as well as the state of art in this area, special attention is paid to sources that consider problems similar in meaning: detecting anomalies in networks, machine learning and blockchain technology are also described.

The third chapter contains information about the models of transmission lines, shunt capasitors, loads and generators used in the work. Two models of power systems used as benchmark ones in all numerical experiments are also described. At the end of the chapter, a basic model of data processing based on weighted least squares for detecting bad data is described, as well as models for sudden load or generation changes, and finally the false data injection attack model used for data falsification.

The fourth chapter describes existing state estimation algorithms of power system that are common in practice, among which particularly centralized ones based on the maximum likelihood method for AC and DC systems and decentralized ones (algorithms based on matrix splitting, rumor models, decomposition

method and ADMM) are presented. The solution to the forecasting aided state estimation problem using an extended Kalman filter is described separately.

The fifth and sixth chapters contain the main results of the thesis: the fifth chapter describes algorithms for detecting, classifying and identifying anomalies in power networks, developed as part of the doctoral research, and shows the results of their application to the well-known standard benchmark models of power system. The algorithms are developed based on supervised machine learning. The implementation of a decentralized state estimation algorithm is described. The sixth chapter describes the details of the proposed algorithms software implementation in Matlab and in a more generic form on Python language. The use of blockchain technology to improve the security of the power system is described separately.

The conclusion contains outcome of the thesis and prospects for further research.

Main scientific results and their novelty

– development of anomaly detection and classification algorithm for power systems;

– development of topology-resilient classification solution which is robust in sense of network topology changes;

– comparative study of distributed state estimation methods;

– development of optimal power system partitioning method;

– development of enhanced data transfer security system.

The developed methods and algorithms are novel or significantly develop known approaches to state estimation of power systems.

Validity and reliability of the presented results

The main results obtained in the thesis are based on state estimation methods that are widely used in practice. Significant development of these methods is carried out using modern, innovative machine learning methods, the usage validity of which is confirmed by the literature review.

The reliability of scientific results is confirmed by numerous experiments performed on standard in this field benchmark models. The results of the study were verified by publications in the open press and presented at several international conferences on the relevant research topics.

Scientific and practical significance

The doctoral thesis is practically oriented: its main results are aimed at increasing the efficiency and reliability of energy systems. Algorithms for detecting and classifying anomalies in power systems can be

implemented in real monitoring and control systems. The scientific significance of the results lies in the development and comparative analysis of optimal decentralized algorithms for state estimation.

Comments on the thesis text

Along with all the noted advantages of the work, the following comments can be made about it:

1. The section devoted to the blockchain use falls a little out of the general outline of the research aimed at developing methods for state estimation of power system, although in general it corresponds to the main work topic.

2. According to Fig. 5-2, in case of bad data detected in the system, the proposed anomaly recognition algorithm is not applied. From this point of view, it is profitably for the malicious attacker to disguise his actions under analogous situation. This case is not considered in this work.

3. The classification algorithm contains a tunable parameter γ, which selection on practice is not described in sufficient details.

4. There are typos, negligent and illogical moments in the work:

– the work uses a huge number of acronyms and abbreviations, but the work lacks a separate list of them with explanations to make it easier to read.

– in the literature review, sections 2.3.1 and 2.3.2 are placed in section 2.3, dedicated to machine learning, although they do not relate to it in any way, so it is more logical to put them in a separate subsection.

– on page 55 in Figure 5-2 formulas (11) and (15) are used, but such numeration cannot be in the work.

– the work contains many references to formulas and figures, which are placed in the following sections, which makes reading difficult, for example, on page 31 there is a link to formula (4.45), which is located on page 49, and further notations from this formula are used starting from page 31 without additional explanation, on page 66 there is a reference to Figure 6-2, although the same plot is shown in Figure 5-5, located on the next page, and to which there is no reference at all in the text of the work, a similar situation is on page 75 with Figures 6- 6 and 5-13.

– the title of section 6.2.10 begins with a lowercase letter.

– on page 18 the abbreviation HDVC is not described and there is no explanatory link to the source where one could find out the explanation.

– on page 19 at the bottom instead of "prefect" there should be "perfect".

– on page 23 there is a typo at the bottom "domain,so".

– on page 30 the figures numbers are missing at the bottom.

– on page 43 in formula (4.17) the elements of the matrix H are not described and have not been introduced previously.

The noted comments are insignificant, mainly editorial in nature and do not reduce the overall positive assessment of the work, and do not cast doubt on the results obtained in the study.

Conclusion

The doctoral thesis under review is presented in the form of 120 pages text, which consists of six chapters, a conclusion, a list of references containing 125 sources and one appendix.

The work is written in a fairly strict language in accordance with the scientific style of narration; it leaves a positive impression of a consistent work devoted to the stated objectives of the research.

The main results of the thesis are presented in 4 articles and conference papers published in peer-reviewed journals and presented at international conferences. They correspond to the content of the work and reflect all the main results declared by the study author.

The doctoral thesis is written on a relevant, practically significant topic, has scientific novelty and represents a complete, consistent research work. The main results obtained by the applicant are reliable, the conclusions are justified.

Based on the above, the reviewer believes that the presented work satisfies the requirements for doctoral thesis, and its author, Sajjad Asefi, deserves to obtain the Ph. D. degree.

Provisional Recommendation

[✓] *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

[ ] *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

[ ] *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*