

OPINION

about the dissertation for awarding the educational and scientific degree "Doctor"

Field of higher education: 5. Technical sciences,
Professional field: 5.2 Electrical Engineering, Electronics and Automation, Scientific specialty:
02.21.01. Application of the principles and methods of cybernetics in various fields of science

Author of the dissertation: Eng. Ekaterina Popovska Slavova, Institute of Robotics at the Bulgarian Academy of Sciences (IR-BAS)

Member of the scientific jury: Prof. Dr. Eng. Galina Todorova Bogdanova – Todorova, Institute of Mathematics and Informatics at the Bulgarian Academy of Sciences (IMI-BAS)

Dissertation topic: Mathematical methods for research, modeling, analysis and forecasting in the energy and energy market

Scientific consultant: Assoc. Dr. Prof. Galya Georgieva-Tsaneva, IR-BAS

1. Topicality of the problem developed in the dissertation

The dissertation is oriented towards research in the field of mathematical methods for probabilistic forecasting of time series of electricity prices.

This topic is extremely topical and promising to study. Over the past two decades, changes have taken place in the electricity business. Competitive deregulated electricity markets have been created, where consumers choose their supplier and exchanges to buy and sell electricity. As a result of these processes, electricity price forecasting (EPF) has become a leading factor in important decisions by energy companies. The EPF is a complex task and one of the main areas of research in the electricity markets, where there are many more open issues and a number of difficulties in solving them.

2. Degree of knowledge of the state of the problem studied

The dissertation cites 139 sources, all sources in English. A thorough literature study of sources on the subject has been made. The extensive study of research on the topic, the precisely used scientific apparatus and the creative analysis show the good level of competence and in-depth knowledge of the PhD student's subjects.

3. General characteristics of the dissertation

The dissertation work consists of 183 pages (introduction, four chapters, conclusion, contributions, list of literature used /139 sources in Latin/, list of publications on the topic of the dissertation /6/ and annexes (22 pages). The structure and volume of work meet the requirements.

3.1 The author studies and **reviews the studies** of leading world and Bulgarian authors on the methods of forecasting, modeling and analysis in the energy and energy markets.

Electricity markets in the context of price research, methods for forecasting, processing and analysis of electricity prices, long-term and short-term methods for forecasting, processing and analysis of electricity prices, the main aspects of electricity markets and factors for analysis and EPF are discussed. The novelties and current trends in the development of methods for forecasting the time series of electricity prices are shown.

The main objective and the four tasks of the dissertation **are defined**.

3.2 Methods **for studying the long-term sustainability of time series of data** on electricity exchange prices are presented. The use of fractal time series analysis for calculating the Hurst exponent by the R/S method is described. The time series by the method of fluctuation analysis with elimination of the course (Detrended Fluctuation Analysis) are studied. Conclusions are drawn from the studies in the second part.

3.3 Applicable methods for the study of short-term sustainability of time series of data on electricity exchange prices are discussed.

The Autoregressive Integrated Moving Average (ARIMA) model for predicting time series of electricity prices in the "Day ahead" market and forecasting electricity prices in the "Day ahead" market through the Long Shortterm Memory Network (LSTM) model are presented. Results are derived and conclusions drawn.

3.4 The reporting of the data and the analysis of the results of the empirical study are discussed.

It summarizes what is set out in the framework of this study. The following were used: fractal time series analysis to calculate the Hurst exponent by the R/S method; Empirical analysis of time series of electricity prices through DFA; Empirical analysis and results of the time series forecasting models of daily and monthly electricity prices through ARIMA; Empirical analysis of electricity price time series by a recurrent neural network with long-termshort-term memory. The results obtained through the different models are presented.

3.5 The dissertation works ends with a conclusion containing summarized the key findings of the study and interpreting the results obtained.

The main contributions of the dissertation are outlined.

In the dissertation there is a correspondence of the selected methodologies of research with the set goals and tasks of the dissertation. The PhD student has shown knowledge of the studied problems and has proposed successful methods and approaches for their solution. New methodologies have been created, software algorithms have been implemented, analyses have been implemented, proofs have been formulated. Through the created methodology and the developed software, a complete solution to the problems is given. The main objective and the tasks set have been fulfilled.

The sequence and logic of the research prove the creative depth of the PhD student and the credibility of the conclusions and contributions made. The achieved results and publications are a guarantee for good preparation and knowledge of the topic under study.

4. Contributions to dissertation work

In the dissertation, the following contributions have been achieved:

4.1 Scientifically applied contributions

New methodologies and formulated evidence have been created through experimental studies and analyses.

- Two new methodologicals:
 - for research, analysis and EPF based on ARIMA, SARIMA and LSTM methods giving optimal price forecasts on the electricity market depending on the different input factors.
 - to study and analyze the long-term sustainability of time series of data on electricity exchange prices, based on the DFA method, which has not been done so far.
- Two experimental evidences:
 - the application of statistical methods to determine the Hurst exponent (R/S method) on electricity prices has been experimentally investigated. Studies show a maximum relative error of 6% in the calculated H, which shows the applicability of this method to study the fractality of the time series of electricity prices.
 - it has been shown by experimental research that the DFA method is more suitable in predicting continuous data on the cost of electricity compared to the R/S method. The comparative analysis showed a maximum relative error in determining the Hurst exponent 1.2% when applying DFA against 6% when implemented with R/S statistical method.
- Proof by analysis – in the analysis of short-term data, the advantage of forecasting using the SARIMA method (compared to the ARIMA method) has been demonstrated, as the variable nature of electricity prices indicates seasonality.

4.2 Contributions of an applied nature.

Two software algorithms and an analysis and forecasting procedure have been implemented.

- software and analyzed algorithms for analysis and forecasting of long-term data on electricity prices based on the application of the R/S method for determining the Hurst exponent and the DFA method have been implemented.
- software and analyzed algorithms for analysis and forecasting of short-term data on electricity prices based on the application of ARIMA, SARIMA and LSTM methods have been implemented.

- demonstration procedures for analysis and EPF have been set up depending on the type of input parameters set.

I accept the scientific and applied contributions (3) formulated by the doctoral student in the dissertation paper and note their importance for the considered scientific field.

5. Publications and citations on dissertation

The author has 6 publications in the list of publications. The publications refer to research on the subject of the dissertation and meet the minimum requirements. Two of the publications have SJR (0.2 and 0.182) and 4 of the publications are in collections of international scientific forums. All publications are joint and are in English.

The author has 7 known citations of three of the publications in the list of publications on the dissertation.

6. Assessment of the conformity of the dissertation abstract to the dissertation

The autoreferal consists of 47 pages. It has a good layout and structure.

There is a correspondence of the **dissertation abstract** to the dissertation as its structure (with few exceptions) follows that of the dissertation. It briefly describes all five parts of the dissertation and adequately reflects the basics of the dissertation (the research and analyses carried out, the results obtained, the conclusions and the contributions).

7. Critical remarks and recommendations on the dissertation

I have no significant critical remarks on the content of the dissertation and questions to the doctoral student.

Some spelling and syntactic errors have been noticed, as well as a lack of literary sources in the dissertation abstract.

I recommend that the PhD student describe in the future her research in another format (for example, as a monograph).

8. Reasons and clearly formulated conclusion

My conclusion about the scientific achievements of the doctoral student is based on the materials provided on the dissertation. The presented dissertation meets the requirements of the Law on the Development of Academic Staff in the Republic of Bulgaria, the Rules to the Law on the Development of Academic Staff in the Republic of Bulgaria, the Rules of the Bulgarian Academy of Sciences and the IR-BAS. The dissertation has topical and significant topics, good structure and way of presentation, sufficient volume and number of publications with proposed scientific solutions. The scientific indicators of the doctoral student and the results achieved give me grounds for a positive assessment. I propose to the scientific jury to be awarded the educational and scientific degree "Doctor" of eng. Ekaterina Popovska Slavova in Field of Higher Education 5.Technical Sciences, Professional field 5.2. Electrical Engineering, Electronics and Automation, Scientific specialty: 02.21.01. Application of the principles and methods of cybernetics in various fields of science.

Jan 19, 2024

Member of the scientific panel:
(Prof. Dr. Eng. Galina Bogdanova)