OPINION

on a thesis for the degree of Doctor of Science

Author of the thesis: Assoc. Prof. Dr. Eng. Iliyan Hristov Iliev

Thesis topic: "Optimization of electrical energy efficiency in reduced load mode and improvement of the quality and reliability of power supply systems"

Member of the scientific jury: Prof. Dr. Anatoly Trifonov Alexandrov – Technical University of Gabrovo

1. Relevance of the problem addressed in the dissertation in scientific and applied scientific terms.

Regulations are being developed worldwide to reduce electricity consumption, promote energy efficiency, and effectively manage other energy sources. Limiting carbon emissions is a key task in efforts to achieve energy efficiency. Renovating the existing buildings and improving energy management is vital to achieve emission reduction targets.

In recent years, there has been a decline in electricity consumption in Bulgaria. Changes in the capacity utilization of the industrial facilities and in the residential sector, the duration of their operation and reliability, relationships with energy suppliers, and the philosophy of formation and implementation of the electricity prices have a negative impact on the proper functioning of the electricity supply system (ESS).

The topic of the dissertation is definitely relevant and covers the study, systematization, and analysis of theoretical approaches related to the concept of achieving electricity efficiency (EEEf). The factors influencing this energy category have been identified and will be implemented in applied research to optimize electricity consumption in the country's industrial structure.

2. Degree of knowledge of the state of the problem and creative interpretation of the literature material.

The dissertation is 430 pages long, structured in 4 chapters, and contains numerous formulas, 229 figures, and 102 tables. The author has cited 294 literary sources used to assess the state of the problem. There are 190 literary sources in Cyrillic and 104 in Latin, 42 of which are from the last ten years.

The literature review provides an energy analysis of various factors affecting electricity efficiency. The main factors influencing the operational characteristics of electrical energy are defined. The characteristics and peculiarities of power and electrical energy losses, considered as a component of EEEf, are discussed. The state of the electricity sector and electricity consumption for the period 1990–2022 is analyzed, as well as the influence of reactive power and the related compensation of reactive loads, which are directly related to EEEf. It has been established that the quality of electrical energy has a strong impact on its efficient use in the operation of energy facilities. Quality indicators and their practical definition are formulated. The reliability of electricity supply, as a basic criterion for EEEf, and related concepts, properties, events, influencing factors, and requirements are discussed.

The problems related to energy efficiency in the ESS (legislation, directives, and standards) and energy auditing and management are analyzed. A critical expert approach to the category of "Energy Efficiency" and a concept for its transformation and appropriate application are proposed.

The literature review is specifically focused on the subject under study and clearly shows that Assoc. Prof. Dr. Iliyan Iliev has a very good understanding of the problem in both theoretical and practical terms.

3. Correspondence of the chosen research methodology and the set aim and objectives of the dissertation with the achieved contributions.

In the development of the dissertation, modern tools corresponding to its aim and objectives have been used.

In Chapter 2 the theoretical approaches that apply a differentiated approach to the assessment and analysis of different powers and power and electrical energy losses in the ESS are investigated. A comparative analysis of power theories applied in different procedures is made: the instantaneous power method in the α-β-0 coordinate system; the generalized instantaneous inactive power theory (GINAPT); Budeanu's power theory. A theoretical framework for the analysis of a "three-phase non-sinusoidal and unbalanced system" is presented. The active power losses are determined in accordance with IEEE Std 1459-2010 by applying a partial approach.

Theoretical frameworks applying an integral approach for the assessment and analysis of power and electrical energy losses in power systems, applicable to low, medium, and high voltage (average load method, maximum loss time method, generalized information method for the circuits and loads of the facility, practical probabilistic-statistical methods and approaches).

Theoretical studies have been conducted to determine the influence of static load characteristics on various operating parameters (electrical power balance with consideration of the voltage mode, compensation of reactive loads, timing of electrical consumers in order to form a uniform load schedule, economically feasible power transformer operating mode). Theoretical approaches have been developed to determine the optimal technical and economic mode of reactive load compensation using capacitor banks and synchronous motors, and an optimization algorithm has been developed. Contemporary solutions for reactive load compensation based on flexible AC systems have been examined, as well as the application of active and passive filters for regulating processes in the ESS.

The main sources that deteriorate the quality of electrical energy and electromagnetic compatibility and affect the EEEf are systematized. The "reliability of power supply," which is an essential factor for increasing the EEEf, is modeled and optimized. The distribution laws in the "theory of reliability" have been determined. Mathematical models for recoverable and non-recoverable elements in different types of connections have been formulated and their graphical interpretation has been presented as a basis for practical research.

In Chapter 3 of the dissertation, a large-scale study was conducted in 167 industrial enterprises from 9 sectors. The dependence of the specific electricity consumption on the voltage mode, the levels of reactive load compensation, and the load was established. Using probabilistic-statistical approaches, the stationarity and ergodicity of the studied stochastic processes are proven.

Modeling of active power losses in a multifactor space is performed. Based on expert analysis, four strategically significant factors of mode and circuit nature affecting active power losses have been identified: load schedule shape coefficient, equivalent resistance, power factor, and relative voltage deviation. A comprehensive multifactor approach has been applied using the theory of planned experiments, with the factors varying at three levels and the mathematical models defined for five main sectors (mechanical engineering, chemical and mining industries, electrical transport, food and beverage industry, and utilities). A graphical interpretation of the models in 2D and 3D space is presented, and conclusions are drawn. The influence of the static characteristics of the load on the power quality indicator and EEEf in the sectoral structure of the country and for individual industrial sites has been investigated. For a powerful industrial site in the chemical industry, the influence of the static characteristics of the load on the power quality indicator and EEEf has been determined. High levels of harmonics and asymmetry of current and voltage have been established. With the help of a planned experiment, the "power balance equation" (δP^*) in the country's industrial structure has been modeled. The research process is presented and the obtained results are analyzed. A graphical interpretation in two-dimensional and three-dimensional space is made, and a methodology for achieving high EEEf in the ESS of the respective sectors is developed. Optimal areas of the essential factors are determined according to the criterion $\delta P^*<0$ for the six main industrial sectors at three load levels. An original technical solution for optimizing the operating mode of a power transformer in

four transformer substations is presented. Experimental studies on EEEf in a ring-type ESS scheme have been conducted.

In Chapter 4 various optimization procedures based on different criteria are applied to achieve high EEEf in the country's industrial structure and for various industrial facilities. Optimal distribution and location of compensating capacities have been achieved based on the criterion of minimum annual costs.

Technical solutions for reactive power compensation using active filters are analyzed. The types of active filters are summarized according to the type of compensation. Based on the theory of instantaneous power, new theoretical approaches for representing the current vector are proposed. Active and passive filters for three-phase four-wire systems with asymmetrical load are synthesized.

The possibility of increasing EEEf by improving the quality of electrical energy is investigated. For different consumers in reduced load operation mode, the power losses due to deteriorated electrical energy quality indicators ΔPb are determined. An analysis of the obtained data is performed. In the multifactorial space, applying the theory of planned experiment, an optimization procedure was performed with the output parameter ΔPb and three significant factors. Using the formulated "complex multifactorial approach," mathematical models were developed and a graphical interpretation of the dependence $\Delta Pb = f(\delta U, \varepsilon U, KHC)$ was shown for nine industries and the public utility sector.

The methodology was tested on a powerful industrial facility with a nominal capacity of 30MVA using a multi-factor planned experiment for 6 groups of consumers at the facility, and the dependencies $\Delta Pb = f(\delta U, \varepsilon U, THDI)$ were constructed. The analysis of the results shows a high degree of adequacy, significance, and identity of the mathematical models, which enable the assessment of EEEf in the operation of the studied consumers. The weight of influence of each of the significant factors and the effects of their interaction have been determined.

For facilities in the electrical engineering, metallurgical, mining, and cement industries, various characteristics reflecting the correlation between EEEf and power quality have been studied. "New indicators of electrical energy quality" were analyzed, adequately and reliably reflecting the energy impact of the load on the quality of electrical energy.

For nine industrial sectors, the reliability of the power supply, the sustainability and stability of the operation of electrical equipment were studied, and possibilities for their improvement were proposed. The main causes of damage were analyzed, and the contribution of the deteriorated quality of electricity during emergency situations was assessed. It was found that the life of cable networks operating under conditions of deteriorated electricity quality indicators is reduced by about half.

4. Scientific, scientific-applied, and applied contributions of the dissertation

The contributions in the dissertation are scientific and scientific-applied in nature and are in the field of optimizing electrical energy efficiency in reduced load mode and improving the quality and reliability of power supply systems. They are related to proving, with new means, significant new aspects of existing scientific problems and obtaining confirmatory facts.

Scientific contributions

- A methodology has been developed for multifactorial modeling and optimization of various output parameters of electricity efficiency. The synthesized theoretical approach has been tested through scientific research experiments in the country's industrial structure. The adequacy, significance, and reliability of the constructed mathematical models have been proven, as well as the possibility of their application in optimization procedures according to various criteria.

- A scientifically based theoretical model for determining the power balance at a given point in the power supply system has been proposed. The so-called "power balance equation" (δP^*) has been defined, which represents a set of different energy indicators. The inequality $\delta P^*<0$ is

formulated, and as a result of the favorable combination of various influencing factors in the energy space under consideration, a positive energy effect is obtained and the power consumption is reduced. The optimization problem is solved using the theory of planned experiments.

Scientific and applied contributions

- Through the application of scientifically based approaches, the expediency of operating electrical equipment in the power supply system at voltage levels lower than the nominal ones specified in the standard has been proven. This leads to an improvement in EEEf and compensation of reactive loads, as well as to an increase in the reliability of the power supply.

- Mathematical models have been developed for nine industrial sectors, enabling a more accurate assessment of conventional power losses depending on all indicators of electricity quality.

- An approach for determining partial power losses based on the theory of instantaneous active power has been proposed. The approach has been tested in a study of industrial facilities operating at reduced load.

- A new concept has been developed for determining asymmetrical and non-sinusoidal modes, which are evaluated using power-weighted imbalance and non-linearity coefficients.

- To suppress resonance phenomena in power supply systems, approaches have been developed for their assessment, taking into account the influence of load. Their application makes it possible to increase the reliability and stability of the power supply.

- The correlation between the reliability of the power supply and its operating characteristics, in particular reactive load compensation and power quality, has been substantiated. Forecast results for reliability indicators in nine industry sectors have been obtained.

5. Assessment of publications related to the dissertation

There are 12 publications related to the dissertation, which can be classified as follows:

- By place of publication: articles in national magazines and journals – 1 [12]; reports in proceedings of international scientific conferences in Bulgaria – 8 [1–4, 6–9]; reports in proceedings of national scientific conferences, sessions, and seminars – 3 [5, 10, 11].

By language: in English – 5 [1–4, 9]; in Bulgarian – 7 [5–8, 10–12].

By number of co-authors: solo – 1 [12]; with two co-authors – 6 [1, 2, 5, 7, 8, 10]; with three or more co-authors – 5 [3, 4, 6, 9, 11]. In 4 publications, Assoc. Prof. Iliyan Iliev [6, 8, 9, 12] is listed first among the co-authors.

Assoc. Prof. Iliev meets and, according to certain indicators, exceeds the minimum national requirements. He has defended a thesis on the topic: "Research, analysis, and quantitative assessment of the real contribution to the deterioration of the quality of electrical energy by industrial consumers and the public utility sector" (indicator A - 50 points). He has submitted: a dissertation for the scientific degree "Doctor of Science" on the topic "Optimization of electricity efficiency in reduced load mode and improvement of the quality and reliability of power supply systems." (indicator B - 100 points); 12 publications (group of indicators D - 110.01 points), including 4 scientific publications in journals which are referenced and indexed in world-renowned scientific information databases (indicator D7 - 46.66 points) and 8 scientific publications in non-referenced peer-reviewed journals or in edited collective volumes (indicator D8 - 63.35 points); 37 citations (group of indicators E - 139 points), of which 4 in scientific publications, referenced and indexed in world-renowned scientific information databases (indicator E12 - 40 points) and 33 in non-referenced journals with scientific review (indicator E13 - 99 points). Assoc. Prof. Iliev has been the scientific supervisor of three successfully defended doctoral students and 24 successfully defended master's students. He has participated in 10 research projects.

I accept that the main results of the dissertation have been published and are known to the scientific community.

6. Opinions, recommendations, and comments.

I did not find any significant omissions in the candidate's work. Some technical errors have been made. I believe that the contributions can be summarized.

7. Conclusion

In conclusion, I can give a positive evaluation of the obtained results and the usefulness of the dissertation. The author of the thesis has demonstrated in-depth theoretical knowledge and practical skills for researching and successfully achieving the set aims and objectives.

The results achieved give me reason to propose that Assoc. Prof. Dr. Iliyan Hristov Iliev to be given the scientific degree of "Doctor of Science" in the field of higher education – 5. Technical Sciences, professional field – 5.2 Electrical Engineering, Electronics and Automation, for the needs of the laboratory "Robotic Systems in Energy" at the Institute of Robotics – Bulgarian Academy of Sciences.

Date: 30.05.2025

MEMBER OF THE JURY:

/Prof. Dr. A. Alexandrov/