FEDERAL STATE BUDGET EDUCATIONAL INSTITUTE OF HIGHER EDUCATION «MIREA – RUSSIAN TECHNOLOGICAL UNIVERSITY»

NATIONAL RESEARCH UNIVERSITY HIGHER SCHOOL OF ECONOMICS

OLEG A. IVANOV

DESIGNING DEVICES FOR AUTONOMOUS POWER SUPPLY OF THE SENSOR TELECOMMUNICATION SYSTEM FOR MONITORING THE STATUS OF GAS TRANSPORT NETWORKS

SUMMERY OF THE PHD THESIS

Scientific supervisor:
D.Sc., professor
Saygid U. Uvaysov

Moscow - 2018

GENERAL THESIS ASSESMENT

The relevance of research

At the present day, information and telecommunication technologies are increasingly used in various sectors of the national economy, including in the gas transport sector, which is an important part of Russia's fuel and energy industry.

Since the second half of the 20th century, the country has created the world's largest extensive network for the delivery of natural gas from the point of production to the end consumer. Currently, according to the evaluation of PJSC Gazprom, the total length of linear parts (LP) of the main gas pipelines (MGL) is about 170 thousand km and 40% of the LPs have already developed their nominal life, which is 30 years. Generally, gas mains are laid in extremely rough conditions which led to premature wear and aging. An unforeseen gas leaks may cause entail added costs for the maintenance of the gas pipeline network.

When designing new sections of the MGL, all necessary control devices of their state are already taken into account initially. But regarding the operated sections of gas transmission networks (GTN), the analysis carried out in work showed that the modern technical control tools do not allow creating a system of continuous and automatic monitoring. Consequently, it was revealed that at present day, using the distributed wireless sensor telecommunication system with the ability to transmit information about the location of the pipeline damage to the data collection point is the most promising option for the purposes of ensuring continuous monitoring of the state of the GTS. Since these sensor systems for detection of methane leakage are supposed to be located in distant, inaccessible places, that raises the problem of creating an uninterrupted and highly reliable system of autonomous power supply for its wireless sensory modules.

Currently known methods for the design of wireless sensor networks (WSN) are based on the principle of organizing the electrical supply of their modules from a single chemical source of current, which significantly limits the operating conditions and the running time, considering the strong dependence of its output

characteristics on environmental factors. Therefore, designing of the autonomous power supply (APS) devices of the WSN for monitoring the state of gas transmission networks using alternative energy sources, as well as creating algorithms and mathematical models for the operation of these devices, are the actual scientific task.

Level of scientific development of research topic

The problem of monitoring the state of gas transport networks has been given quite a lot of attention in recent decades. And new solution methods emerged simultaneously with the development of computer technology and the means for the development of computer modeling and information processing. There are a lot of well-known studies in this field written by I.A. Bublichenko, P.M. Bondarenko, A.G. Gumerova, M.L. Gurariya, S.A. Egurtsova, D.A. Ionina, V.V. Klyueva, V.I. Kozintsev, V. Y. Kositsyn, E.M. Medvedeva, V.M. Orlova, I.I. Plyusnina, A.N. Soldatova, I.V. Samokhvalova, P.E. Bushmeleva, V.A. Goncharova and many other domestic and foreign scientists whose contribution to the creation of monitoring systems for gas transmission networks is indispensable.

The design methodology of power supplies is explicitly described in the works of A.A. Bass, G.V. Kozharsky, V.I. Orekhov, E.M. Romasha, Y.N. Kofanov, S.R.Tumkovsky, S.U. Uvaysov, P. Chetty, A. Salama, R. Berkowitz. Additionally, there is plenty of powerful software tools for computer modeling of electrical, thermal and mechanical processes such as SolidWorks, ANSYS, MicroCap, ASONIKA.

However, not much attention is paid to designing power supplies using alternative energy sources, especially when it comes to ultra-low power levels (hundreds of milliwatts). At the same time, the existing researchers don’t take into account the development of methods for increasing energy efficiency and the impact of operating conditions on the receive/transmit modules of telecommunication systems.

In this context, the scientific task of creating a design method based on the models and algorithms of APS WSN which monitoring the state of the GTN is timely, relevant and has all the prerequisites for its solution.

Thus, **the object of research** is the process of designing the WSN for monitoring the technical condition of the GTN. **The subject of the investigation**: method, models, algorithms and methodology of design of autonomous power supply of modules of sensor telecommunication system for monitoring the state of gas transmission networks.

The task of the study is to improve the energy efficiency of the WSN monitoring the technical state of gas transmission networks by developing a design method and algorithms for the operation of autonomous power supplies of its wireless modules.

To achieve this goal, **the next theoretical and applied problems** should be solved:

1. Analysis of the APS WSN characteristics and the state of the problem of their design.

2. Development of a method for designing the APS WSN for monitoring the technical condition of the GTN.

3. Study on the influence of environmental conditions on the modes of operation of autonomous energy sources.

4. Research and development of models and algorithms for the operation of GTN modules monitoring the technical condition of the GTN to reduce the overall energy consumption of the APS.

5. Development of a methodology for designing APS devices for WSN modules.

6. Approbation and implementation of the results of work in the design practice of APS WSN.

Research methods

The research is based on methods of system analysis, methods of mathematical and simulation modeling, methods of numerical experiments,

reliability theory, methods of construction of telecommunication systems, methods of designing radio engineering and telecommunication devices and systems.

The main provisions of the dissertation defense

1. Method and methodology of designing devices for autonomous power supply of wireless modules of sensor telecommunication system for monitoring the technical condition of gas transmission networks, which allow increasing their energy efficiency by 30%.

2. Model of the distribution of electric power flows from sources to load in an autonomous power supply system, which allows determining the requirements for the solar panel of the wind generator and battery, based on the sensitivity of the detector, location and weather conditions.

3. Algorithm for ensuring the reliability requirements of the wireless sensor telecommunications system to achieve a probability of failure-free operation of not less than 0.95.

4. A set of algorithms for the functioning of the sensor telecommunication system monitoring the technical condition of gas transmission networks, providing an increase in the battery life of wireless modules by 10% and reducing energy consumption by 20-30%.

Scientific novelty of the research

1. Proposition of the method of designing the APS WSN devices monitoring the technical condition of the GTN, which differs from the known ones, taking into account the values of the gas leakage detector parameters, geographic location, meteorological factors and the possibility of alternative energy sources usage, which allows increasing the energy efficiency of wireless modules up to 30%.

2. The proposition of the different mathematical model of APS WSN, which allows studying the distribution of electric power flows from sources to load and to calculate air-time intervals for the wireless module of the WSN, depending on the environmental conditions and the operating mode of the device.

3. The algorithm developed for ensuring reliability requirements allows taking into account the features of the WSN topology and algorithm of operation, as well

as circuit-based solutions of its components and data transmission channel failure-free parameters during the design process.

4. A set of algorithms developed for the operation of the WSN module:

- an algorithm for transmitting the GTN state monitoring data with a variable transmitter power depending on changes in the point-to-point WSN topology caused by failures of the intermediate modules;

- The algorithm of power management which takes into account the current parameters of electric power sources to maintain the uninterrupted functioning of the WSN module that differs from those known for the implementation of additional controlled settings.

5. Proposed technique based on the developed models and algorithms allows the design of energy-efficient WNS by developing the APS of their wireless modules.

The practical significance of the study

The practical significance of the study is that the proposed method, models, and design methodology, as well as reduction of the average power consumption of wireless modules, allow increasing the energy efficiency and reliability of the wireless sensor telecommunication system for continuous monitoring of the state of the GTN up to 20-30%.

Research implementation

The primary results of this research are implemented in the design of radio engineering products and power supply devices of the enterprises of JSC «NIICHIMMASH", JSC "MRTI RAS", where the provisions of the proposed engineering and methodical complex are applied to improve the energy efficiency and reliability of this equipment along with the educational process for the preparation of bachelors and masters of the Moscow Institute of Electronics and Mathematics of the Higher School of Economics at lectures and practical studies.

Testing of the results of research

Articles resulting from the research in whole or in part were reported and discussed at the following international and Russian scientific conferences:

International scientific and practical conference "Innovations based on information and communication technologies" (Sochi) 2010, 2014, 2015; International scientific-practical conference "Innovative technologies, scientific and technical achievements, their legal protection" (Tolyatti) 2011; International Scientific and Practical Conference of Students and Students (Moscow), 2012; All-Russian scientific and technical conference "Energy: Efficiency, Reliability, Security" (Tomsk), 2012; international scientific and practical conference "Innovative Information Technologies" (Prague), 2012, 2013; International scientific-practical conference "Innovative, information and communication technologies" (Moscow), 2016.

The reliability of the obtained results is confirmed by the appropriate use of the mathematical apparatus, carried out numerical experiments, by comparison of the obtained data with previously published results of other researchers, as well as by the implementation of the results of research into the engineering practice of designing power supplies.

Publications

The main results of the thesis are published in the leading peer-reviewed scientific and technical journals, which are included in the List of the Higher Attestation Commission of the Ministry of Education and Science of Russia (3 papers), in the materials of international and sectoral conferences (11 papers), furthermore publications indexed in the international Scopus scientific citations (3 papers).

Scope and structure of the thesis

The thesis consists of an introduction, four chapters with conclusions, conclusions, a list of references and applications.

MAIN RESULTS OF THE RESEARCH.

As a result of the research tasks, the following results were obtained:

1. The review of the problem domain was carried out and, based on the features of the functioning of the autonomous power supply devices of the sensory

telecommunication system for monitoring the state of gas transport networks and the requirements imposed on them, the scientific research task is set.

2. Based on a comparative analysis of existing solutions in the field of the use of autonomous energy sources, recommendations for their use for autonomous power sources of power supply devices for a sensory telecommunication system for monitoring the state of gas transmission networks are proposed.

3. The method for designing power supplies for wireless sensor network devices using alternative energy sources is suggested, which allows taking into account the influence of geographic location and meteorological factors.

4. Proposed mathematical model of an autonomous power supply system allows one to investigate the distribution of energy flow from sources to loads, moreover, developed algorithm for ensuring reliability requirements allows for the design process to take into account the features of the topology and algorithm for the functioning of the wireless sensor telecommunications network, as well as the circuit solutions of its components and data transmission channel reliability parameters.

5. The set of algorithms for the functioning of the sensor telecommunication network module was developed, in particular:

- algorithm for transmitting GTN status monitoring data, which allows controlling the transmitter power depending on changes in the topology of the wireless sensor telecommunications network point-to-point caused by failures of the intermediate modules;

- Power management algorithm that takes into account current parameters of electric power sources for the organization of uninterrupted operation of the module;

- algorithm for controlling the charge of the battery with the advent of control of several additional parameters, which makes it possible to increase its operational characteristics;

6. The suggested method based on the evolved approach, models and algorithms, allows designing energy-efficient wireless sensor telecommunication

systems by developing adaptive devices for autonomous power supply of their modules.

7. Approbation and experimental verification of the results of the work were carried out using the example of an autonomous power supply and wireless telecommunications system developed using the WPM-Design PC.

8. The results of the thesis are implemented in the industry and the educational processes of the universities.

ARTICLES ON THE THESIS THEME

Articles in Russian peer-reviewed scientific journals included in the list recommended by the Higher Attestation Commission of the Ministry of Education and Science of Russia:

1. Шумов Ю.Н., Ермилов Ф.М., Иванов О.А. Электромеханические накопители энергии – состояние в мировой практике и перспективы развития. // Новые технологии, 2012г. С. 29-38.

2. Гольберг О.Д., Увайсов С.У., Иванов И.А., Иванов О.А. Обеспечение качества характеристик источников бесперебойного питания в условиях помех, вызванных нелинейной нагрузкой. // Технологии электромагнитной совместимости, 2013г., С. 55-64.

3. Иванов О.А., Гольдберг О.Д., Хелемская С.П. Автономная система электроснабжения на основе возобновляемых источников энергии // Энергосбережение и водоподготовка, 2014г. С. 60-64.

Articles in publications indexed in international scientific bases (Scopus):

4. Ivanov O., Avdeuk O., Bushmeleva K., Ivanov I., Uvaysov S. Model for Calculating the Reliability of a Wireless Sensor Telecommunication System for Monitoring the Gas Transmission Network State. 2018 Moscow Workshop on Electronic and Networking Technologies (MWENT). Proceedings. – Moscow: National Research University "Higher School of Economics". Russia, Moscow, March 14-16, 2018. IEEE Catalog Number: CFP18N39-CDR. ISBN: 978-1-5386-3497-4.

5. Oleg A.Ivanov, Ilya A.Ivanov, SaygidU.Uvaysov, Svetlana S.Uvaysova. The Algorithm for Battery Charge Control of Renewable Energy Sources - Wind Turbine and Solar Panel. 2016 International Siberian Conference on Control and Communications (SIBCON). Proceedings. National Research University Higher School of Economics. Russia, Moscow, May 12-14, 2016. IEEE Catalog Number: CFP13794-CDR. ISBN: 978-1-4799-1060-1.

6. Uvaysov S.U., Ivanov I.A., Ivanov O.A. Power supply system for wireless sensor network. // Сборниктрудов International Siberian Conference on Control and Communications (SIBCON), 2015г.

Other papers:

7. Иванов О.А., Коробков С.А. Инновационные подходы в построении источников бесперебойного питания. // Инновации на основе информационных и коммуникационных технологий: Материалы международной научно-практической конференции. – М.: МИЭМ, 2010г., С. 390-391.

8. Иванов О.А., Коробков С.А. Инновационный подход к оценке качества в системах бесперебойного питания. // Инновационные технологии, научные и технические достижения, их правовая защита: Сборник статей IV Международной Научно-практической конференции – Тольятти – М.: Издательство «Типография Ника», 2011г., С. 99-103.

9. Иванов О.А., Коробков С.А. Влияние искажений формы напряжения на надежность системы бесперебойного питания. // V Международная Научно-практическая конференция учащихся и студентов: Сборник статей. – М.: МИЭМ, 2012г., С. 517-518.

10. Иванов О.А., Коробков С.А. Основные типы ИБП с двойным преобразованием энергии // Энергетика: Эффективность, надежность, безопасность: Материалы XVII Всероссийской научно-технической конференции. – Томск: Издательство ООО «СПБ Графикс», 2012г., С. 192-194.

11. Иванов О.А., Голдберг О.Д., Коробков С.А. ИБП с бустером в цепи питания инвертора. // Инновационные информационные технологии: Материалы международной научно-практической конференции. – М.: МИЭМ, 2012г., С. 418-420.

12. Иванов О.А., Коробков С.А. Особенности современных типов источников бесперебойного питания. // Инновационные информационные технологии: Материалы международной научно-практической конференции. – М.: МИЭМ НИУ ВШЭ, 2013г., С. 151-153.

13. Увайсов С.У., Иванов И.А., Иванов О.А., Азизов Р.Ф. Принцип размещения датчиков утечки метана из магистральных газопроводов. // Инновации на основе информационных и коммуникационных технологий. Материалы XI Международной научно-практической конференции. - М.: НИУ ВШЭ, 2014, С. 289-292.

14. Лышов С.М., Королев П.С., Иванов О.А., Панасик Д.С. Структура автоматизированного комплекса диагностирования дефектов конструкции электронных средств. // Инновации на основе информационных и коммуникационных технологий. Материалы Международной научно-практической конференции. - М.: НИУ ВШЭ, 2015, С. 266-269.

15. Иванов И.А., Иванов О.А. Алгоритм ограничения потребляемой мощности приемо-передающего модуля элемента сенсорной сети. // Инновации на основе информационных и коммуникационных технологий. Материалы Международной научно-практической конференции. - М.: НИУ ВШЭ, 2015, С. 391-394.

16. Иванов О.А. Ограничение потребляемой мощности приемо-передающего устройства мотов сенсорной сети. // Межвузовская научно-техническая конференция студентов, аспирантов и молодых специалистов им. Е.В. Арменского. Материалы конференции. - М.: НИУ ВШЭ, 2016. С. 6.

17. Иванов О.А., Бушмелев П.Е., Увайсов С.У., Бушмелева К.И. Методика проектирования устройств автономного электропитания телекоммуникационной системы мониторинга состояния газотранспортных

сетей. // Инновационные, информационные и коммуникационные технологии: Материалы международной научно-практической конференции. – М.: МИЭМ, 2016г., С. 54-57.