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QUALITY OF THE INFORMATION FLOW MANAGEMENT AT STOCHASTIC ENERGY CONSUMPTION CONDITIONS

Abstract. *Modern energy systems are rapidly changing and becoming increasingly complex. This process is facilitated by the growing demand for distributed energy resources, renewable energy sources, and distributed generation. This makes the energy system highly stochastic. An integral part of the concept of smart grids is the production of energy from distributed energy sources. Modernization of the energy network with the help of intelligent technologies allows us to fully take into account the peculiarities of energy consumption. The smart grid paradigm envisions flexible energy demand and storage to cope with the variability of renewable energy sources. A necessary condition for the implementation of demand response is an improved infrastructure, especially information and communication technologies. The paper presents the results of research on the quality of information flow management under conditions of stochastic energy consumption by maintaining a stationary queue of information transmission through the network and preventing overloading of the controlled network segment. The stages of monitoring and assessment of the network state, as well as the methodology of identification of network parameters are presented. According to the results of the analysis of the system of key network parameters and the specifics of their application for managing the quality of network service, it has been established that using the statistical approach one can distinguish between the key parameters of the network. The wireless network has been researched, which allows us to build a quality of service management system by regulating and shaping traffic. It is shown that when using a polling system with feedback on the speed of buffer filling to organize requests in the network, it is possible to maintain a stationary queue with a non-stationary flow of requests.*

Keywords: wireless network, information delay, stochastic energy consumption.

1. Introduction

Modern energy systems are rapidly changing and becoming increasingly complex. The forms of production, transportation and use of energy are transforming all over the world. For example, renewable energy sources are on the rise and are beginning to replace traditional generating units in energy systems [1]–[2]. The growing demand for distributed energy resources, renewable energy sources and distributed generation leads to the fact that more and more distribution networks change the one-way flow of electricity to a two-way one [3]. This makes the energy system highly stochastic [4].

It should be noted that energy production from distributed energy sources is an integral part of the concept of smart grids. In particular, in the UK, the concept of "smart local energy systems" has become popular as a concept around which the idea of coordinated decentralization can be organized. Smart local energy systems include information and communication technologies to provide automation and self-regulation of distributed energy resources to support balancing and flexibility between energy vectors at the local level [5]. Modernization of the power grid with the help of intelligent technologies makes it possible to fully take into account the peculiarities of energy consumption. Thus, electricity consumers who use smart meters with two-way communication functions together with modern communication infrastructure can now participate in the network.

Smart grids should integrate cost-effective energy resources [6] to enable traditional grid-dependent consumers to become active consumers [7] and to some extent solve distribution grid problems such as voltage fluctuations [8] and grid capacity [9].

The smart grid paradigm implies flexible demand and energy storage in order to cope with the variability of renewable energy sources. In this aspect buildings are often put forward as a potential supplier of flexibility services through demand side management and distributed energy storage, partly as thermal energy. In [10], the influence of advanced control algorithms on the use of building energy flexibility in an all-electric residential building ready for the smart grid is investigated. The researchers found that energy cost reductions of up to 21% and 43% can be achieved using a rule-based and intelligent algorithm, respectively, without compromising thermal comfort in the building.

Smart dispatching and modeling techniques that should be used in demand response programs have a positive impact on energy systems. For example, in work [11] it was proved that the appropriate demand response is beneficial for reducing both the costs of operating the power system and the costs of users. Demand response has been widely regarded as an effective way to provide regulation services for smart grids by controlling demand-side resources via new and improved information and communication technologies. A prerequisite for the implementation of demand response is an improved infrastructure, especially information and communication technologies.

Information and communication technologies have been constantly improved during the last decades, and the most advanced of them, for example, wireless communication networks, can facilitate the effective management of intelligent energy systems [12]. With the increasing complexity of energy systems due to the high penetration of renewable energy sources and the growing variety of requirements, communication technologies that coordinate the work of energy system participants are becoming increasingly important to ensure the reliability of energy systems [13]–[14].

One of the main problems in information and communication technologies, as well as research on large-scale power systems, is the difficulty of stabilizing voltage and frequency for power systems [15]. A popular method used to model systems that contain a high level of uncertainty is stochastic programming. The study [16] presents a new energy and reserve planning model for a power system using stochastic programming to optimize energy and reserve planning in order to minimize the operating costs of a renewable energy network structure.

Another challenge in implementing smart grids is ensuring a continuous flow of real-time data to enable feedback. For example, in [17] the question of studying stochastic characteristics and the quantitative method of time delay is considered, the cyber level and physical components in global energy systems are modeled. Considerable attention is paid to the process of transmitting a data packet at the cyber level and the distribution of probabilities of multiple delays in a spatial sequence using mass service theory and signal convolution methods.

The aim of this article is to ensure the quality of information flow management in conditions of stochastic energy consumption by maintaining a stationary queue of information transmission over the network and preventing overloading of the controlled network segment.

2. Research methodology

When optimising the parameters and structure of communication networks in the target function includes a large number of basic and additional parameters, which determines the quality-of-service (QoS).

The technology of monitoring and analysis is laid in the process of designing communication networks. It is an integral part of the overall problem of ensuring the continued functioning of the network, in particular, the QoS. The task of network design involves three stages: the choice of network topology, the choice of technologies, on the basis of which will be implemented and the choice of equipment. In real situations, for example, when creating wireless networks, the choice of topology is dictated by the specifics of the use of the radio channel. The topology "star" and a combination of topology "ring" and "common bus" are most appropriate. They are essentially determined by the variants of the wireless network architecture: an independent configuration (Ad Hoc) and infrastructure configuration (structured network). Despite the fact that the differences between these architectures are insignificant, they significantly affect indicators such as the number of users who can connect to the network, the scale of the network, network interference resistance, etc. In turn, among selected technologies, the advantage is usually given to one of many. This is quite logical, since the mixing of heterogeneous technologies within a single autonomous segment of the network will certainly lead to inconsistencies in the technical and operational characteristics, it will cause the need to support a large number of network exchange protocols, resolving conflicts between heterogeneous protocols and interfaces, etc. As a result, there will be inefficient use of network resources and reduced network performance.

Thus, the problem of the choice of equipment becomes decisive. The technology of analysis, monitoring and diagnostics is a set of diagnostic tools and methods of their use that allow an objective assessment of the quality of the work of hardware and applications in the network and justify recommendations for improving their work [18].

2.1. Methodology of monitoring and estimation of network state

The method of continuous network diagnostics is to split the process into the next interconnected stages.

1. At the first stage, diagnostics is performed on the physical level to exclude errors and correctly interpret the results of further testing.

2. At the second stage it is expedient to conduct diagnostics of the terminal nodes of the network by stress testing of the network in two modes:

- calibration mode with load only on the network to detect hardware and software implementation errors;
- mode loaded only on the network to detect problems with the interaction of stations, bottlenecks on the server and in communication channels.

3. The final stage of the diagnostic of the network is the diagnostics of the applied network software.

The effectiveness of the use of the network is largely determined by the quality of management in conditions of overload. As long as the network is loaded insignificantly, the number of packets received and processed is equal to the number of those arriving at the input of the switching node. However, when a very large amount of data enters the network, overload may occur, and performance may worsen. With excessive downloads, the bandwidth of a channel or network throughput may become nil. This situation leads to a network collapse. Overload generates avalanche processes: overflow buffer leads to loss of packets that have to be transmitted repeatedly or even several times. The processor of the sending party receives an additional parasitic boot. All this suggests that overload control is an extremely important process. It is necessary to distinguish between flow control and overload control. Flow control means the balancing of the sender's flow and the ability to receive and process the receiver. In this type of control, it is assumed that there is feedback between the recipient and the sender. In the process, as a rule, only two partners are involved. Overloading – a general phenomenon related to the network as a whole or to its segment.

2.2. Methodology of identification of network parameters

Measurement and control of the information signal are traditional for automatic control systems, but do not find application in the transmission area because of the spatial diversity of the input and output of transmission channels, resulting in the need to transmit to the point of measurement and control the missing signal there in uncorrected form. In addition, there is a delay in signalling and control information, which leads to appropriate delays in management and, more dangerously, can at all lead to loss of stability of the diagnostic, monitoring and control system as a whole. We propose definition of channel characteristics by solving the discrete convolution equation of the form:

$$y(n) = \frac{1}{N-m+1}\sum_{m=0}^{N-m+1} x(n)h(n-m) = \frac{1}{N-m+1}\sum_{m=0}^{N-m+1} x(n-m)h(n).$$

In this case, measurement of input and output signals is required. Since the data transmitted at the physical level is the signal information, the implementation of the measurement process is simplified: there is no need to transmit any information about it to the receiving station of the network. Very interesting is the method of determining the characteristics of the channel on the measurable function of mutual correlation. The method is based on the definition $g(n)$ by solving the equation of convolution, which binds $R_x(m)$ with $h(m)$ and the autocorrelation function $R_x(m)$ of the input signal:

$$R_{xy}(m) = \frac{1}{N-m+1}\sum_{m=0}^{N-m+1} h(n)R_x(n-m).$$

The results of correlation analysis also serve as a key indicator of monitoring and regulation of data flows and Web services. This is necessary to ensure the secure transmission of information over the network, forecasting and preventing the overload of a controlled network segment. Thus, the current monitoring and management of the security level in the network, which is an integral part of the overall management of the quality of service, can be successfully carried out by statistical methods, in particular, by the method of correlation-regression and entropy analysis.

3. Results

Let's use the polling method for dissolving this problem. For this purpose, let's write the mathematical model of the query process for elements of wireless network. The polling system consists of M queues for network elements. For each of the elements by random law, an order for the issuance of a certain amount of data is received. The process of receiving inquiries is stationary and ergodic. The probability of receiving at m-th element at the same time more than one request is considered to be of the second order of smallness. During service time $[t_i \dots t_i + \tau]$, your $\psi_m(l_m)$ data sets can be sent. l_m– the length of the queue at a time t_i; ψ_m– discipline of service (cyclic, periodic based on the poling table, by random rule, with priorities). The probability of serving exactly k requests in the interval τ denote $p_{\tau k}$.

We formulate the conditions that must satisfy the discipline of service.

If at the moment of requesting the m-th item in the queue already there are $l_m - 1$ queries, they are served according to the discipline of FIFO (first in - first out) or FIFO with priorities. Service queues leave the system. Then the request goes to the next item. It is believed that conditions $\psi_m(1) = 1$ with probability $p_{\tau 1} = 1$; $\psi_m(l_m) \leq l_m$ with probability $p_{\tau m} < 1$ always executed.

Let λ is the average intensity of the flow of requests at the interval of observation, μ – the average intensity of the request service; p_m– the probability of a query on the m-th element. Then, when the condition $\lambda\left(\frac{1}{\mu} + \max_M \frac{p_m}{\Psi_m v_m}\right) < 1$ is fulfilled, there is a decrease in the length of the queue, when $\lambda\left(\frac{1}{\mu} + \max_M \frac{p_m}{\Psi_m v_m}\right) = 1$, it is convergence to the stationary value of the queue length, and when $\lambda\left(\frac{1}{\mu} + \max_M \frac{p_m}{\Psi_m v_m}\right) > 1$ – the queue length in the system increases indefinitely until the queue is filled. In the latter case, there may be a loss of queries and there is a need to organize a repeat request. Here v_m is the average number of queries entering the m-th element on the interval of observation.

Let's consider the problem of the estimation of the queue length in the non-stationary flow of queries. As is well known, the conditions of regularity and absence of after-effects are feasible for a wide range of conditions. At the same time, the assumptions about stationarity give rise to serious doubts, and sometimes they are really erroneous.

In order to provide a stationary (or close to it) queuing length mode in a non-stationary flow of requests, we have developed a modified polygon method with feedback, whose parameters are determined not only by the effects of the analysis of the size of the filled part of the total buffer volume, but also on the speed of its filling. Considered exhaustive, gateway and l-limited discipline of service.

The service system is asymmetric, and the signalling and control information is delayed, in general, different for each serviced item. Such a model is described by a system of differential-difference equations (equations with a deviating argument).

To simplify the problem and obtain asymptotic estimates, suppose that the control system can be described with accuracy acceptable for this application by linear differential equations with coefficients constant on the observation interval:

$$y'_{asi}(t) = b_i y_{asi}(t-\tau) + u_i(t-v_i) + \xi_i(t) \tag{1}$$

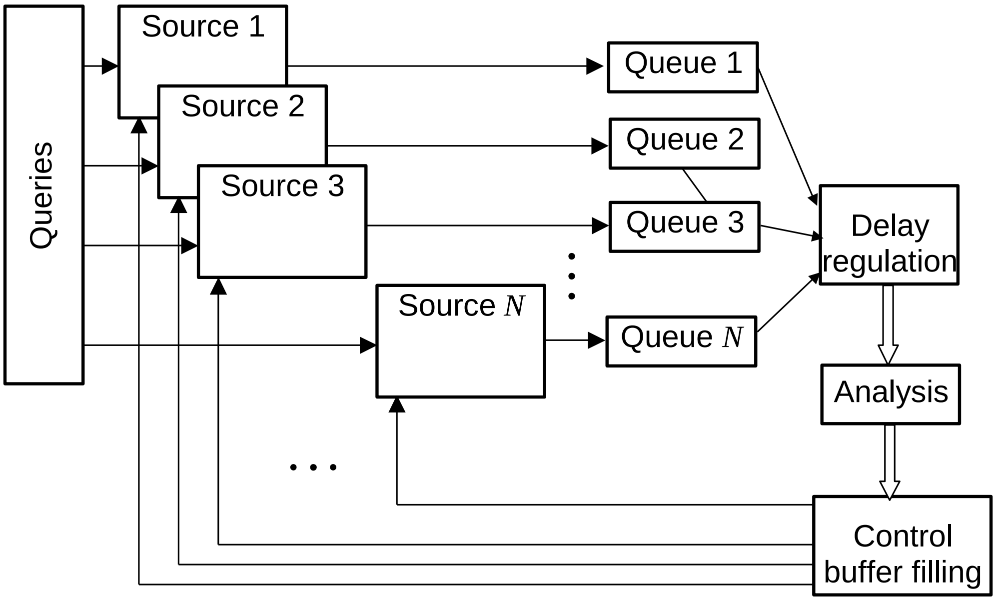

Fig. 1. Model of a polling system with a periodic query and limited comprehensive service with feedback on the rate of filling the buffer

It is well known that for equations with a deviating argument, the method of approximating differential equations by difference equations is particularly effective.

We write the difference equation with the first-order differences for the initial equation (1) without additive noise in the observations:

$$\frac{y_{asi}(t) - y_{asi}(t-\Delta t)}{\Delta t} \approx b_i y_{asi}(t-k\Delta t) + u_i(t-m\Delta t), \tag{2}$$

where Δt is elementary interval; $k\Delta t = \tau_i$ is the delay of information about state of object; $m\Delta t = v_i$ is the delay of control signal.

The equation (2) for the normalized elementary interval $\frac{\Delta t}{T_p} = 1$ will take the following form:

$$y_{asi}(n) \approx y_{asi}(n-1) + b_i y_{asi}(n-k) + u_i(n-m), \quad n = 0,1,2,3,\ldots \tag{3}$$

After performing the z-transform (3), we obtain the expression for the system function of the control system parameters of the discipline of service of the terminal nodes:

$$H(z) = \frac{z^{-m}}{1 - z^{-1} - b_i z^{-k}}. \tag{4}$$

Thus, when using a polling system with feedback on speed of buffer filling to organize queries in a network, stationary queuing can be maintained with non-stationary flow of queries.

4. Conclusions

Next-generation communication technologies would improve connectivity and responsiveness, which could lead to more efficient and smarter operations of the energy systems with high penetration of renewable energy and increased distributed energy sources.

The paper presents the results of research the quality of information flow management in conditions of stochastic energy consumption by maintaining a stationary queue of information transmission over the network and preventing overloading of the controlled network segment. When using the key parameters of the telecommunication network's efficiency as a complex system with delayed signalling and control information it is possible to predict its state and solve the problems of quality management of the service in real time.

In order to develop a method for determining the average value of packet service time based on the Markov model of the behaviour of a network of homogeneous nodes, a wireless network consisting of N nodes was investigated. The main purpose of developing a simulation technique is to find the mean time value of the service packet T, measured from the moment either the packet arrives in the empty queue of the given node, or the end of the service of the previous packet from this queue, either obtaining an ACK acknowledgment, or ending the time interval after the last unsuccessful transmission attempt.

References

1. Song, Y., Lin, J., Tang, M., & Dong, S. (2017). An internet of energy things based on wireless LPWAN. *Engineering*, 3(4), 460–466. https://doi.org/10.1016/J.ENG.2017.04.011
2. Kostenko, G., & Zgurovets, O. (2023). Current state and prospects for development of renewable distributed generation in Ukraine. *System Research in Energy*, 2(73), 4–17 [in Ukrainian]. https://doi.org/10.15407/srenergy2023.02.004
3. Wang, M., Mu, Y., Jia, H., Wu, J., Yu, X., & Qi, Y. (2017). Active power regulation for large-scale wind farms through an efficient power plant model of electric vehicles. *Applied Energy*, 185, Part 2, 1673–1683. https://doi.org/10.1016/j.apenergy.2016.02.008
4. Hussain, S., Lai, Ch., & Eicker, U. (2023). Flexibility: Literature review on concepts, modeling, and provision method in smart grid. *Sustainable Energy, Grids and Networks*, 101113. https://doi.org/10.1016/j.segan.2023.101113
5. Fell, M. J., Vigurs, C., Maidment, C., & Shipworth, D. (2023). Smart local energy systems as a societal project: Developing a Theory of Change. *Smart Energy*, 11, 100109. https://doi.org/10.1016/j.segy.2023.100109
6. Plaum, F., Ahmadiahangar, R., Rosin, A., & Kilter, J. (2022). Aggregated demand-side energy flexibility: A comprehensive review on characterization, forecasting and market prospects. *Energy Reports*, 8, 9344–9362. https://doi.org/10.1016/j.egyr.2022.07.038
7. Zhao, N., Zhang, H., Yang, X., Yan, J., & You, F. (2023). Emerging information and communication technologies for smart energy systems and renewable transition. *Advances in Applied Energy*, 9, 100125. https://doi.org/10.1016/j.adapen.2023.100125
8. De Coninck, R., & Helsen, L. (2016). Quantification of flexibility in buildings by cost curves – Methodology and application. *Applied Energy*, 162, 653–665. https://doi.org/10.1016/j.apenergy.2015.10.114
9. Reynders, G., Diriken, J., & Saelens, D. (2017). Generic characterization method for energy flexibility: Applied to structural thermal storage in residential buildings. *Applied Energy*, 198, 192–202. https://doi.org/10.1016/j.apenergy.2017.04.061
10. Pallonetto, F., De Rosa, M.,& Finn, D. P. (2021). Impact of intelligent control algorithms on demand response flexibility and thermal comfort in a smart grid ready residential building. *Smart Energy*, 2, 100017. https://doi.org/10.1016/j.segy.2021.100017
11. Ding, Y., Song, Y., Hui, H., & Shao, Ch. (2019). Integration of air conditioning and heating into modern power systems. *Springer*, 279 p.
12. Yap, K. Y., Chin, H. H., & Klemeš, J. J. (2022). Future outlook on 6 G technology for renewable energy sources (RES). *Renew Sustain Energy Reviews*, 167, 112722. https://doi.org/10.1016/j.rser.2022.112722

13. Hui, H., Ding, Y., Shi, Q., Li, F., Song, Y., & Yan, J. (2020). 5G network-based Internet of Things for demand response in smart grid: a survey on application potential. *Appl Energy*, 257, 113972. https://doi.org/10.1016/j.apenergy.2019.113972
14. Nechaieva, T.P. (2022). Modeling ensuring demand-supply balance of the power system in conditions of significant renewable generation. *System Research in Energy*, 1-2(68-69), 42–49 [in Ukrainian]. https://doi.org/10.15407/pge2022.01-02.042
15. Zgurovets, O., & Kulyk, M. (2021). Comparative analysis and recommendations for the use of frequency regulation technologies in integrated power systems with a large share of wind power plants. *Studies in Systems, Decision and Control*, 346, 81–99. https://doi.org/10.1007/978-3-030-69189-9_5
16. Ozay, C., & Celiktas, M. S. (2021). Stochastic optimization energy and reserve scheduling model application for alaçatı Turkey. *Smart Energy*, 3, 100045. https://doi.org/10.1016/j.segy.2021.100045
17. Zhang, G., Li, J., Bamisile, O., Cai, D., & Huang, Q. (2022). A novel data-driven time-delay attack evaluation method for wide-area cyber-physical smart grid systems. *Sustainable Energy, Grids and Networks*, 32, 100960. https://doi.org/10.1016/j.segan.2022.100960
18. Tolstikova, O.V., Ponomarenko, O.V., & Vodopyanov, S.V. (2021, April 15–17). Issues of providing end-to-end QoS with economies of hardware and software resources. *Collection of abstracts of reports of the XIII International Scientific and Practical Conference "Computer Systems and Network Technologies" (CSNT-2021)*, Kyiv.

ЯКІСТЬ УПРАВЛІННЯ ІНФОРМАЦІЙНИМИ ПОТОКАМИ В УМОВАХ СТОХАСТИЧНОГО ЕНЕРГОСПОЖИВАННЯ

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Анотація. *Сучасні енергетичні системи швидко змінюються та стають все більш складними. Цьому процесу сприяє зростання попиту на розподілені енергетичні ресурси, відновлювані джерела енергії та розподілену генерацію. Це робить енергосистему високостохастичною. Невід'ємною частиною концепції розумних мереж є виробництво енергії з розподілених джерел енергії. Модернізація енергомережі за допомогою інтелектуальних технологій дозволяє повністю врахувати особливості енергоспоживання. Парадигма розумної електромережі передбачає гнучкий попит і зберігання енергії, щоб впоратися з мінливістю відновлюваних джерел енергії. Необхідною умовою впровадження реагування на попит є вдосконалена інфраструктура, особливо інформаційно-комунікаційні технології. У роботі наведено результати дослідження якості управління інформаційними потоками в умовах стохастичного енергоспоживання шляхом підтримки стаціонарної черги передачі інформації мережею та запобігання перевантаженню контрольованого сегмента мережі. Наведено етапи моніторингу та оцінки стану мережі, а також методологію ідентифікації параметрів мережі. За результатами аналізу системи ключових параметрів мережі та специфіки їх застосування для управління якістю обслуговування мережі встановлено, що за допомогою статистичного підходу можна розрізняти ключові параметри мережі. Досліджено бездротову мережу, яка дозволяє побудувати систему управління якістю обслуговування шляхом регулювання та формування трафіку. Показано, що при використанні системи опитування зі зворотним зв'язком за швидкістю заповнення буфера для організації запитів у мережі можна підтримувати стаціонарну чергу з нестаціонарним потоком запитів.*

Ключові слова: бездротова мережа, затримка інформації, стохастичне енергоспоживання.

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