Mathematical model of parametric virtualization of technocenosis data

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Abstract. The article discusses a mathematical model of parametric virtualization of technocenosis data. The basis of the model is the methodology of rank analysis, which is aimed at studying complex technical systems. The implementation of the parametric data virtualization model allows you to create a subject-oriented information database that can be used for the functioning of digital platforms and services, as well as to complement the architecture of the Internet of Energy. The database serves as a data storage, includes a primary digital data layer and secondary digital layers of the first, second and third stages. The primary data layer is the results of processing and verification of the initial resource values. The secondary layer of the first stage contains the results of static modeling procedures, and the secondary layer of the second stage contains the dynamic and bifurcation models of the rank analysis methodology. The secondary layer of the third stage stores data on the performance indicators of the rank analysis methodology procedures. The information of each layer is combined into an OLAP cube, which allows you to fully describe the parametric virtualization of the digital platform or service data. The practical implementation of the proposed model was carried out in the hardware and software complex for monitoring the power consumption of the power grid company. Based on the OLAP-cube, automated workstations for verification and data processing, short-term and long-term forecasting, trend detection and construction of typical electrical load graphs have been developed and implemented. The economic effect from the implementation of the model can amount to more than 3000 thousand rubles per year.

Keywords: model, virtualization, parameter, data, technocenosis, digital platform, digital service, OLAP-cube.

1 Introduction

The modern pace of development of infocommunication technologies around the world has enabled to create technological basis for the social and economic spheres of human life. As a consequence, a new type of economic activity has appeared which is called the digital economy. Nowadays many platforms and services of the digital economy are being actively developed and implemented. As for the energetic field, digital power engineering is presented as an element of the digital economy. Its main task is to manage technical and socio-economic subsystems of power systems during generation, distribution and consumption of energy resources using digital platforms, services and automation tools.

Analysis of the research into the scientific field of digital power engineering showed that now there is a fairly high number of concepts for its development [1-5]. The content of these concepts presents solutions for the problems of increasing the reliability of power supply, modernizing electrical installations as well as reducing energy losses and number of accident situations. However, little attention is paid to development and creation of digital platforms and services for the interaction of a consumer (individuals or legal entity) with the power system.

Recently a group of the scientific and technical initiative “Energinet” has developed the concept of the Internet of Energy within the framework of digital power engineering. The premises for the elaboration of this concept are based on the fact that at the present moment the energy systems that have been developed on the basis of a traditional centralized structure are becoming less efficient. This is mainly due to the development of new infocommunication technologies, changes in the socio-economic and political situation in the world as well as the shift of consumer demand.

“At its core, the Internet of Energy is a decentralized electric power system, which implements intelligent distributed management, carried out through energy transactions among its users” [3].

It can be used by individuals and legal entities which have electrical installations that allow generating, accumulating, distributing and consuming electric power. Subjects that provide various services to the owners of electrical installations are also considered as users [6-8].

Thus, taking into account the key points of the concept of the Internet of Energy, it can be concluded that digital power engineering should include new digital platforms and services to ensure the sustainable operation of the energy system. On the other hand, it should maintain the highest energy efficiency and minimize energy losses due to a high-quality energy management process. In this regard, one of the main tasks is to develop the mathematical model for the virtualization of data on the power consumption of the technocenosis.

2 The concept of constructing a model of parametric virtualization of technocenosis data

Currently, scientists and engineers This is one of the global markets of the National Technology Initiative “EnergyNet” developed the concept of Internet energy [3]. The article proposes to supplement this architecture with a mathematical model of virtualization of data on power consumption at the user level (individuals or legal entities), which further is served as a basis for developing power consumption monitoring service.

The methodology of rank analysis of technocenoses became the basis for the development of the mathematical model. From the practical point of view, technocenosis is viewed as an energy system operating on the basis of the structure of the Internet of Energy. From the theoretical point of view, it is considered as an interconnected set of individual objects with non-Gaussian properties, having unified management and logistics system. More detailed information about the concept of «technocenosis» and the methodology of rank analysis can be found in the following scientific works [1; 4-6]. The rank analysis methodology suggests the implementation of static, dynamic and bifurcation models of optimal power consumption management, which include a number of rank analysis procedures [9-11].

Virtualizing data on power consumption at the first stages, a certain subject-oriented information database on power consumption is formed (Figure 1). Basically, it is data storage. One of its main functions is decision support for using digital services or platforms.

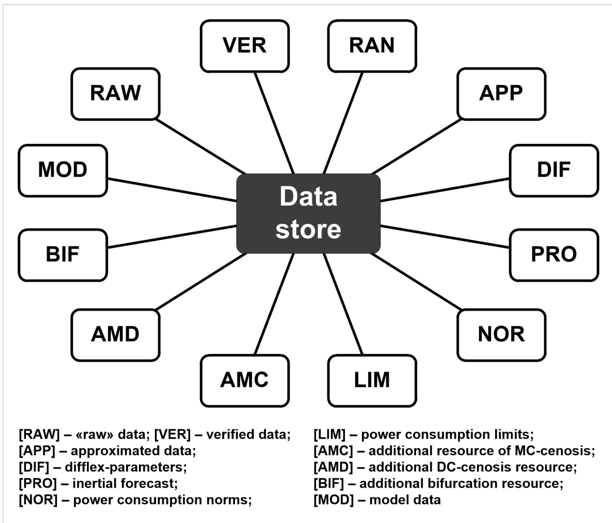

Fig. 1. Structure of the data storage for the model.

Thus, parametric data virtualization should be understood as a method of creating a digital twin of the object under study (technocenosis) based on software that uses the values of the data storage. Computational modules that implement rank analysis procedures are used as software [1].

At the initial stages of virtualization, a rank parametric distribution is constructed based on the initial «raw» data, which presents the following function:

$$[\{W_k\}_{k=1}^{n} \xrightarrow[f:W\to R]{} \{R_k\}_{k=1}^{n}] \xrightarrow[Approx]{} W = f(x), \tag{1}$$

$\{W_k\}_{k=1}^{n}$ – range of resource value;
$\{R_k\}_{k=1}^{n}$ – range of ranks;
$W(x)$ – rank function;
x – rank measure.

Before ranking, the set $\{W_k\}_{k=1}^{n}$ is subjected to verification, on the results of which a set of verified values $\{W_k^{VER}\}_{k=1}^{n}$ is formed. This operation is based on algorithms for eliminating erroneous, equal and zero values $\{W_k^{VER}\}_{k=1}^{n}$ for power consumption.

Next, the values $\{W_k^{VER}\}_{k=1}^{n}$ of the set are compared with the values of the set of topological ranks $\{R_k\}_{k=1}^{n}$ in descending order. After the ranking, the ranged values are approximated. The approximation method is set by a researcher. Figure 2 shows a graphical view of the rank parametric distribution.

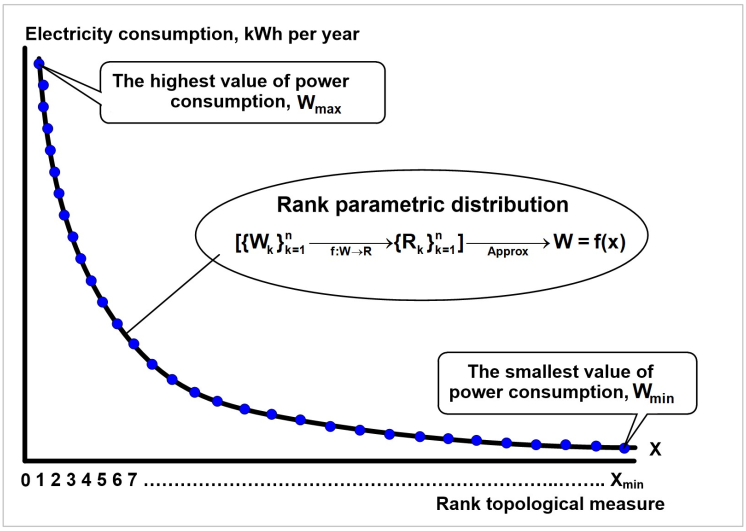

Fig. 2. Rank parametric distribution.

So, rank parametric distribution is a numerical function, which belongs to the range of $\{W_k^{RAN}\}_{k=1}^n$. Developing the rank parametric distribution on power consumption can be presented in the following way:

$$\begin{cases} \{W_k^{RAW}\}_{k=1}^n \xrightarrow[\text{Verific}]{} \{W_k^{VER}\}_{k=1}^n; \\ \{W_k^{VER}\}_{k=1}^n \xrightarrow[\text{Rangin}]{} \{W_k^{RAN}\}_{k=1}^n; \\ \{W_k^{RAN}\}_{k=1}^n \xrightarrow[Approx]{} \{W_k^{APP}\}_{k=1}^n, \end{cases} \quad (2)$$

$\{W_k^{RAW}\}_{k=1}^n$ – range of «raw» values of energy consumption;
$\{W_k^{VER}\}_{k=1}^n$ – range of verified values;
$\{W_k^{RAN}\}_{k=1}^n$ – range of ranged values;
$\{W_k^{APP}\}_{k=1}^n$ – range of approximated values.

From Figure 2 it can be seen that the primary layer of the data storage consists of four sets (Figure 3) [1].

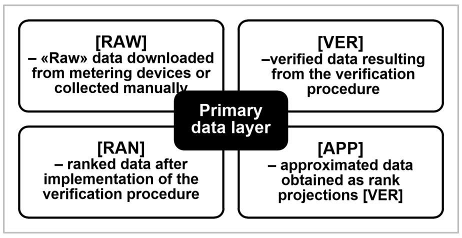

Fig. 3. Primary data layer of the data storage for the model of parametric virtualization.

The implementation of a static model of power consumption enables to form the secondary layer of the first stage of the data storage. It includes the values of the diflex parameters that are recorded during the examination of anomalous objects, the results of short-term, medium-term and long-term forecasts, norms and limits for power consumption established as a result of the rationing and potentiation procedures. Figure 4 shows the structure of the first stage of the secondary layer [1].

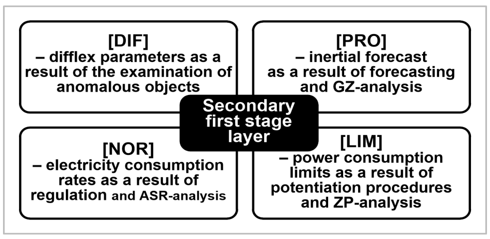

Fig. 4. Secondary layer of the first stage of the data storage for the model of parametric virtualization.

During the implementation of the dynamic and bifurcation models of the methodology of rank analysis of the technocenosis, the values of the additional resources of MS and DC analyzes modeling in various ways are imported into the data storage. Such values in the data storage form a secondary layer of the second stage (Figure 5) [1].

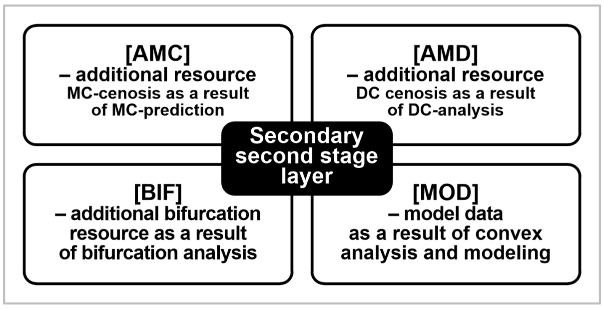

Fig. 5. Secondary layer of the second stage of the data storage for the model of parametric virtualization.

Thus, the digital data layer is the structural unit of the storage. It can be represented as a two-dimensional or three-dimensional array. The values of the digital layer are identified by the index, the number of the time intervals and the parameters of the results of the rank analysis models.

3 Cubing data

The final operation of the mathematical model of parametric virtualization is the creation of an OLAP data cube which is a multidimensional array of values of energy consumption, located for a long time in the data storage (Fig. 6).

Rank	Technocenosis OLAP-cube layer data on power consumption										
	...	1	2	3	4	5	6	......	t	......	τ
1	...	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	W_{16}	......	W_{1t}	......	$W_{1\tau}$
2	...	W_{21}	W_{22}	W_{23}	W_{24}	W_{25}	W_{26}	......	W_{2t}	......	$W_{2\tau}$
3	...	W_{31}	W_{32}	W_{33}	W_{34}	W_{35}	W_{36}	......	W_{3t}	......	$W_{3\tau}$
4	...	W_{41}	W_{42}	W_{43}	W_{44}	W_{45}	W_{46}	......	W_{4t}	......	$W_{4\tau}$
5	...	W_{51}	W_{52}	W_{53}	W_{54}	W_{55}	W_{56}	......	W_{5t}	......	$W_{5\tau}$
......	...	......	......	......	......	......	......	......	......	......	......
k	...	W_{k1}	W_{k2}	W_{k3}	W_{k4}	W_{k5}	W_{k6}	......	W_{kt}	......	$W_{k\tau}$
......	...	......	......	......	......	......	......	......	......	......	......
n-1	...	$W_{(n-1)1}$	$W_{(n-1)2}$	$W_{(n-1)3}$	$W_{(n-1)4}$	$W_{(n-1)5}$	$W_{(n-1)6}$	......	$W_{(n-1)t}$	......	$W_{(n-1)\tau}$
n	...	W_{n1}	W_{n2}	W_{n3}	W_{n4}	W_{n5}	W_{n6}	......	W_{nt}	......	$W_{n\tau}$

Fig. 6. OLAP-cube of data for parametric virtualization [1].

Mathematically, the digital data layer on the power consumption parameter in an OLAP-cube can be described as following [1]:

$$\left\langle W_{kt}^{OLAP} \right\rangle \xrightarrow[\substack{k=1..n \\ t=1..\tau}]{p=fix} \left\langle \begin{matrix} [RAW]_{kt} & [DIF]_{kt} & [IPK]_{kt} & [AMC]_{kt} \\ [VER]_{kt} & [PRO]_{kt} & [IPZ]_{kt} & [AMD]_{kt} \\ [RAN]_{kt} & [NOR]_{kt} & [IPE]_{kt} & [BIF]_{kt} \\ [APP]_{kt} & [LIM]_{kt} & [DFU]_{kt} & [MOD]_{kt} \end{matrix} \right\rangle; \quad (3)$$

$\left\langle W_{kt}^{OLAP} \right\rangle$ – sequence of OLAP-cube of data;
k – rank;
t – time interval;
τ – number of time intervals.

In order to clarify the elements (3), it should be reminded that data aggregators are created and implemented when data is cubed. Aggregators can be primary and secondary. Their purpose is to provide interoperability among the digital layers of the data storage [1]. For a complete description of parametric virtualization of technocenosis data, the OLAP-cube should be supplemented with additional secondary layers (Figure 7).

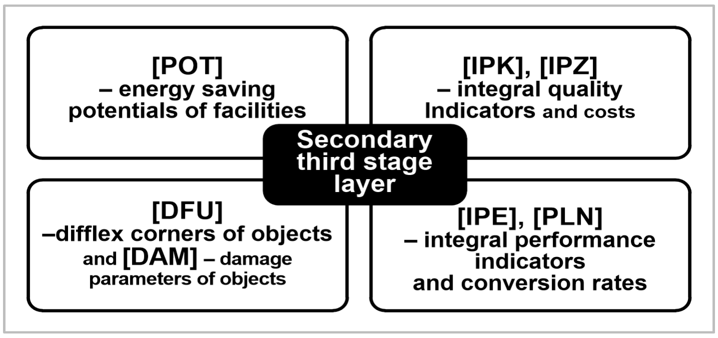

Fig. 7. Secondary layers of the third stage of data storage for the model of parametric virtualization.

Then the mathematical formulae of the OLAP-cube will take the following form. Parametric OLAP cube of technocenosis data on power consumption:

$$\left\langle W_{kt}^{OLAP} \right\rangle \xrightarrow[t=1..\tau]{k=1..n} \left\langle \begin{matrix} [RAW]_{kt} & [DIF]_{kt} & [IPK]_{kt} & [AMC]_{kt} \\ [VER]_{kt} & [PRO]_{kt} & [IPZ]_{kt} & [AMD]_{kt} \\ [RAN]_{kt} & [NOR]_{kt} & [IPE]_{kt} & [BIF]_{kt} \\ [APP]_{kt} & [LIM]_{kt} & [DFU]_{kt} & [MOD]_{kt} \end{matrix} \right\rangle; \quad (4)$$

primary aggregators:

$$\begin{cases} w:\{[RAW],[VER],[RAN]\} \to [APP]; \\ w:\{[VER],[RAN],[APP]\} \to [DIF]; \\ w:\{[VER],[RAN],[APP]\} \to [PRO]; \\ w:\{[VER],[RAN],[APP]\} \to [NOR]; \\ w:\{[VER],[DIF],[PRO]\} \to [LIM]; \\ w:\{[APP],[DIF],[PRO]\} \to [AMC]; \\ w:\{[APP],[DIF],[PRO]\} \to [AMD]; \\ w:\{[APP],[DIF],[PRO]\} \to [BIF]; \end{cases}$$

secondary aggregators:

$$\begin{cases} w:\{[APP],[DIF],[PRO]\} \to [POT]; \\ w:\{[APP],[DIF],[POT]\} \to [IPK]; \\ w:\{[APP],[DIF],[POT]\} \to [IPZ]; \\ w:\{[APP],[IPK],[IPZ]\} \to [IPE]; \\ w:\{[APP],[DIF],[IPE]\} \to [DFU]; \\ w:\{[APP],[DIF],[IPE]\} \to [DAM]; \\ w:\{[APP],[IPE],[DAM]\} \to [PLN]; \\ w:\{[DFU],[DAM],[PLN]\} \to [MOD], \end{cases}$$

$\left\langle W_{kt}^{OLAP} \right\rangle$ – sequence of OLAP-cube of data.

The practical implementation of the mathematical model of virtualization of data on the power consumption of the technocenosis was carried out in the software and hardware complex (HSC) for monitoring the power consumption of the regional transport network complex AO “Yantarenergo”.

4 Implementation of the model in the software and hardware complex for monitoring power consumption of the regional transport and network complex of AO “Yantarenergo”

The HSC database and storage were developed in the MS SQL Server 2019. Operating panels of automated workplaces are written in C # using the WPF platform. The use of this software made it possible to implement OLAP analysis based on the mathematical model of data virtualization on energy consumption of technocenosis.

HSC includes the main window, which contains an interactive map with objects of OA “Yantarenergo”, AWP for data processing and verification, AWP for short-term and long-term forecasting of power consumption, AWP for building a trend and typical graphs of electrical load. Figure 8 shows fragments of HSC elements [6].

The computational operations of AWP for data processing and verification are based on the use of the system (2), and the values of the primary digital layer of the OLAP data cube were used as the initial data (Figure 6). The work of the rest of the AWP was carried out on the basis of (3) and (4), using secondary digital data layers on the power consumption parameter of the OLAP-cube.

Implementation of the HSC at the facilities of OA “Yantarenergo” made it possible to significantly increase the efficiency of power consumption management at facilities by reducing routine operations for accounting and storing billing data on electricity consumption, cleaning them from errors and replenishing lost data [6].

In addition, based on the analysis of secondary digital layers of OLAP-cube data, the quality of fixing objects with abnormal power consumption, the accuracy of forecasting, fixing the range of normal power consumption based on the analysis of the trend in the power consumption of objects and typical graphs of electrical load have significantly improved.

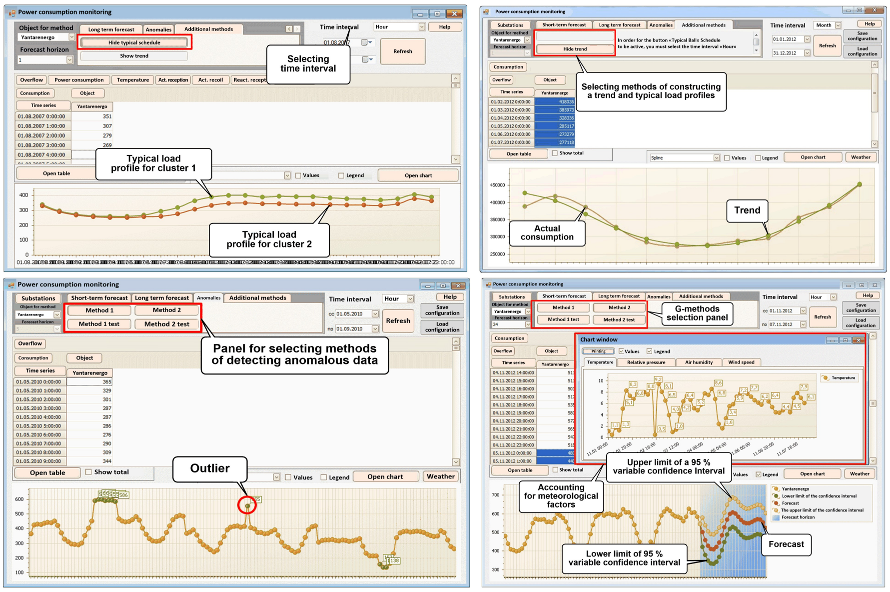

Fig. 8. Fragments of elements of the software and hardware complex monitoring power consumption of regional transport network complex of AO "Yantarenergo" [6].

The use of the HSC during the year, due to the implementation and updating of the data of the digital layers of the OLAP cube, will account for:

1. Decrease in costs when paying fines for excessive deviations of electricity values in the wholesale market (approximately 1,800 thousand rubles per year).
2. Effective economic benefit due to the implementation of OLAP analysis technologies (approximately 1,200 thousand rubles per year).

5 Conclusion

The mathematical model for parametric virtualization of technocenosis data makes it possible to form a subject-oriented information database on energy consumption: data storage. One of its main functions is decision support when using digital services or platforms. The digital data layer is the structural unit of the storage.

The theoretical basis of the model is the methodology of rank analysis of technocenoses which involves the implementation of static, dynamic and bifurcation models of optimal control of power consumption. Based on the results of these models, digital data layers are formed, which are then combined into an OLAP cube of technocenosis data.

The developed model can be implemented as digital services and platforms, situational centers, artificial intelligence systems, etc. As shown by its practical implementation in AO "Yantarenergo", the economic effect can reach approximately more than 3000 thousand rubles per year.

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