Visualization of the Operational Parameters Archive of a Nuclear Reactor

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Abstract

For the most part, the solution of the problem of visualizing any data depends on the structure, size and type of data provided. In this work, the data are archives of RBMK or VVER reactors provided from different control and protection systems of the reactors. Despite the fact that several visualization complexes have already been developed, the visualization task is still relevant due to the necessity to improve the quality of monitoring systems and operational personnel. This paper describes the mathematical apparatus for express analysis of the archive of operational parameters of a VVER nuclear reactor. The developed software makes it possible to carry out express analysis of the VVER reactor archive in terms of plotting altitude or time graphs, as well as using dynamic visualization using the Chernoff faces method, which in turn can provide scientific and practical benefits due to improvement the work quality of operating personnel and conduction analysis of situations that requires additional attention and more detailed analysis. Also, the fundamental concept of this work is the method of scientific visualization, which is widely used in various theoretical and experimental studies. It can be said that the main aim of scientific visualization is to make invisible visible.

Keywords

Operational Parameters Archive, Scientific Visualization, Data Analysis, Express Analysis, Nuclear Reactor

1. Introduction

Often, when conducting scientific research related to the peculiarities of the operation of a nuclear reactor, one encounters the tasks of analyzing archived data. For example, power plant workers can analyze existing archives in order to adjust the further operation of the reactor. At the same time, during the data analysis, it is possible to identify anomalies in the operation of the reactor and, by conducting a study on the causes of the occurrence of such behavior, prevent their further manifestations, thereby increasing the safety of operation of the reactor itself. Also, when using additional support, operators of nuclear power plants can increase the safety of facilities by quickly responding to changes in parameters or exceeding any of the parameters of the maximum permissible values.

The safe operation of powerful nuclear power reactors is ensured by the availability of information and computational systems that allow measuring, calculating, and monitoring the most important parameters of a nuclear power unit.

At the stations, there is a station-wide data exchange network between the process control systems. Information from various systems at regular intervals enters the data warehouse. Further, the workers of the power unit analyze the data obtained and correct the operation of the reactor.

The files located in the data warehouse are not convenient for analysis, therefore, the task arises of forming such a data warehouse into which an archive containing the values of the main parameters of the power unit functioning according to the selected sections would be loaded. The archival information accumulated in this repository can be further used for various studies.

Depending on the task, the requirements for the nature, type and volume of stored information, as well as the degree of its granularity, may differ significantly. For example, to solve the problem of

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assessing the quality of the work of operating personnel, it is necessary to store information on the type and number of monitored parameters, the values of which have gone beyond the limits established by the regulations, the number and type of operator impacts on the control object (movements of the control and protection system organs (CPS), adjustment of the coolant flow rate, etc.), the degree of spatial stability of the three-dimensional energy release field, etc. for several hours. When solving the problem of identifying the causes of failure, for example, fuel elements, fuel assemblies and cassettes, information for a period from several days to several years may be required. In this case, the prehistory of the behavior of the limiting parameters of the reactor and the power unit may be of interest. For example, for a RBMK-type reactor (high-power channel-type reactor), such parameters as the power of each channel, its power generation, coolant flow through the channel, indications of the systems for monitoring the tightness of the cladding of fuel elements (CFE) and monitoring the integrity of technological channels (TC) [5], linear load on the fuel element, stock up to the crisis of heat exchange, the number of permutations of the fuel cartridge, etc. For a VVER-type reactor (water-water power reactor), the limiting parameters partially coincide with the above, but also contain significant additions and differences associated with the difference in the design of the reactors. For example, the limiting parameter is the concentration of boric acid, the absence of boiling of the coolant, the pressure in the reactor, etc.

However, despite the fact that the tasks listed above are of different nature, the archive of operational parameters of RBMK and VVER reactors should allow solving each of them and, moreover, serve as an information base for solving newly arising problems. With the current level of development of computing systems at NPPs (nuclear power plants), it is possible to organize the storage of all experimental and calculated information with high detail in time over a long period of operation, however, problems arise with the express analysis of a large amount of data.

The fundamental concept in the development of software for the express analysis of the archive is the method of scientific visualization. Scientific visualization is a modern effective approach to data analysis that allows visualizing arrays of data of different nature - abstract or real. Visual information is better perceived and allows to convey the result to the user quickly and efficiently. Physiologically, the perception of visual information is fundamental for humans. The success of visualization directly depends on the correctness of its application, namely on the precise structuring of the approach and the data itself. The essence of the scientific visualization method lies in the fact that the initial analyzed data is associated with some of their static or dynamic graphic interpretation, which is visually analyzed, and the results of the analysis of this graphic interpretation are then interpreted in relation to the original data.

2. Research of existing software packages

From the point of view of express analysis of the archive, software [9] has been previously developed and presented that allows to export, preprocess, and visualize multidimensional data of the RBMK archive. This software was developed using effective modern data visualization tools. Since the archive is mostly multidimensional data, the problem of reducing the dimension of the space of variables was solved to present 2D or 3D visualization for further processing and making judgments about the safety of a nuclear reactor.

The first method used to solve the problem is the method of principal components. The multidimensional vector of parameters and maximum allowable values were projected onto the first three principal components, which, as a rule, reflected most of the variance. Further, the trajectory of the motion of the parameters in the main components was deduced. At the same time, the boundary of the maximum permissible values was visualized in the space of variables. Going beyond the settings of at least one of the parameters leads to an unplanned decrease in power, which can lead to an emergency.

In Fig. 1, you can see when parameters are approaching or crossing limits and analyze time slices to identify the cause. The color of the point for the time slice indicates the deviation of the values from the mathematical expectation in accordance with the scale. In the role of the missing lower (upper) limits, the minimum values over the entire (specified) time interval were chosen.

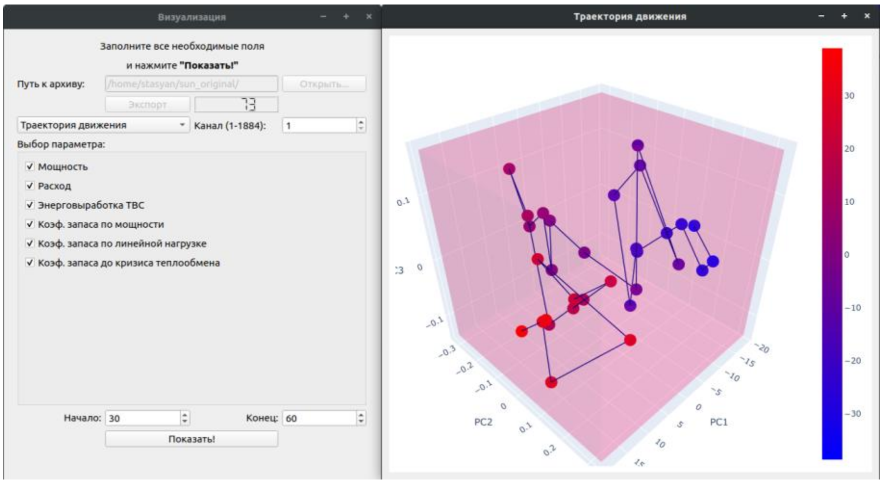

Figure 1: An example of using an application for visualizing the trajectory of movement

The second, no less popular method for visualizing multidimensional data, was the Chernoff Faces method. This approach allows to visualize multidimensional data using a human face for these purposes [11]. Individual parts of the face, such as eyes, eyebrows, nose, lips, depict the meanings of various signs, changing their size, shape or position. Usually, the Chernoff faces method is used when it is necessary to group (cluster) objects according to several characteristics, or when it is necessary to analyze presumably complex relationships between variables.

The result of visualization by the Chernoff faces method is observed in Fig. 2. Analyzing the results obtained, it is possible to draw conclusions when some of the parameters deviate greatly from their average values, when maximums or minimums are reached, or to find implicit relationships between the parameters (when visualizing more parameters). Such an approach, with the simultaneous use of a larger number of parameters, would make it possible to visually highlight clusters of similar facial expressions or find hidden dependencies of parameters among themselves.

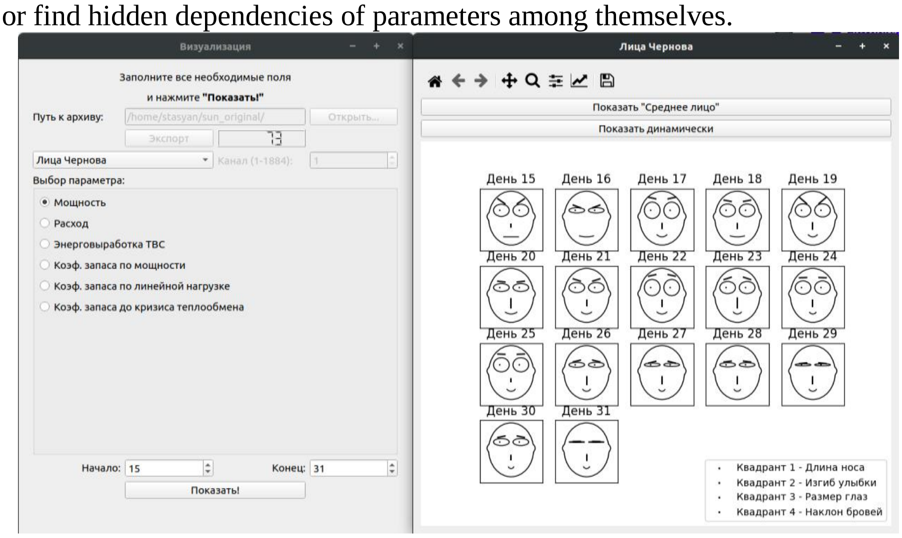

Figure 2: An example of using the application for visualization by the Chernoff faces method

Performing a visual analysis of the visualization result, you can manually select clusters of similar values, or outliers. For example, in Fig. 2, you can note that on days 17-25 the eyes on the face are greatly expanded, however, starting from day 26, the eyes are narrow, which suggests that it is necessary to pay attention to this transition and analyze the archive in more detail on days 25-26. You can also pay attention to day 16 - you can notice that the nose on the face is practically absent, which indicates that there was some deviation on this day and a deeper analysis is needed to identify the causes. Similar outliers can be observed on days 15 and 19 - the eyebrows on the face are heavily frowned, which also indicates any deviations from the normal operation of the reactor.

Thus, this method allows you to visually identify deviations on the face. This is due to the peculiarity of human perception of the face and the ability to instantly detect even the slightest changes in it.

3. Software package for express analysis of VVER reactor archive

Based on the existing developments for carrying out express analysis in the field of visualization of the RBMK archive, software for the VVER archive was developed. The developed software makes it possible to analyze the archive by constructing high-altitude or time graphs and Chernoff faces, allowing to select the parameters and settings of the desired visualization. Fig. 3 shows the main window of the application. This complex allows connecting to a database storing pre-downloaded data and customizing the configuration of the desired visualization.

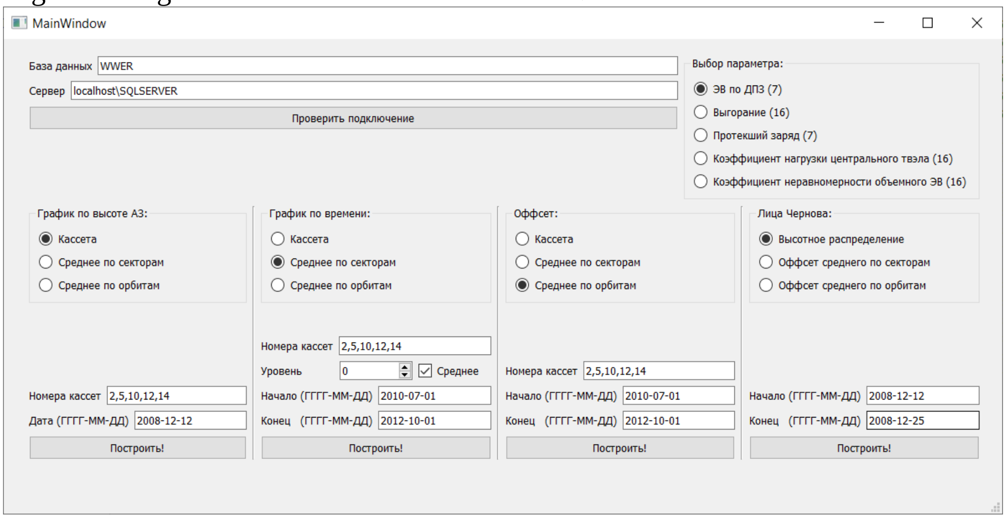

Figure 3: Main window of the implemented software

To build any type of graphs offered by the complex, it is first needed to select the parameter to be visualized. At the moment, the complex supports the following parameters:

- Power generation by the DPZ;
- Burnout;
- Leaked charge;
- Load factor of the central TVEL.

At the same time, the program was developed considering the possibility of adding parameters for visualization.

Also, to reduce the number of displayed parameters and further visualization, the core was divided into 60-degree sectors of symmetry (Fig. 4).

For the same reasons, the active zone was divided into orbits separately in a similar way (Fig. 5). Further, for each sector (orbit), the parameter value is averaged for all TCs contained in the sector (orbit), and the average value is visualized in the form of graphs to study the behavior of generalized parameters over time.

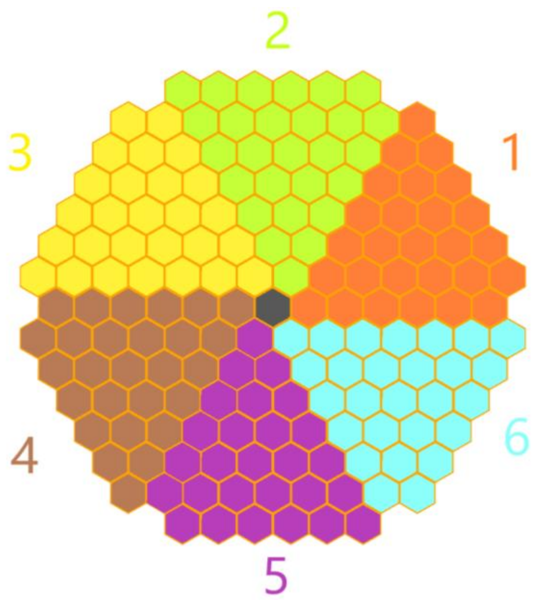

Figure 4: Division of the core into 60-degree sectors of symmetry

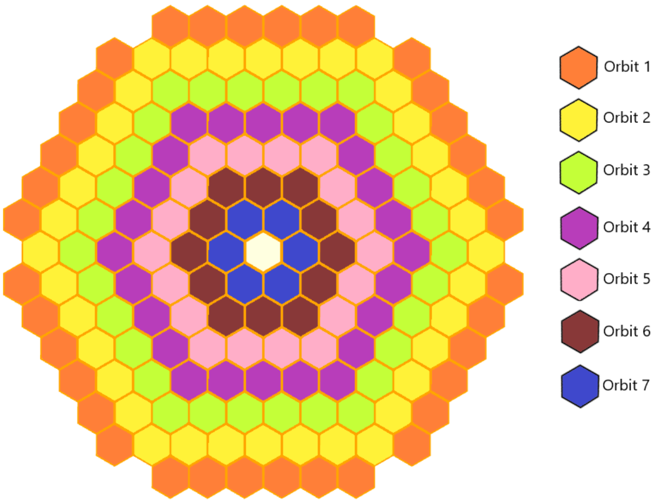

Figure 5: Division of the core into orbits

The developed software package can be conceptually divided into 4 parts. Each part is a separate type of visualization that can be built by preconfiguring the required configurations. Also, the developed software allows to work with graphics: change the scale, adjust colors and line types, save the graph as a graphic image. All types of visualizations offered by the complex are shown in Figures 6-9.

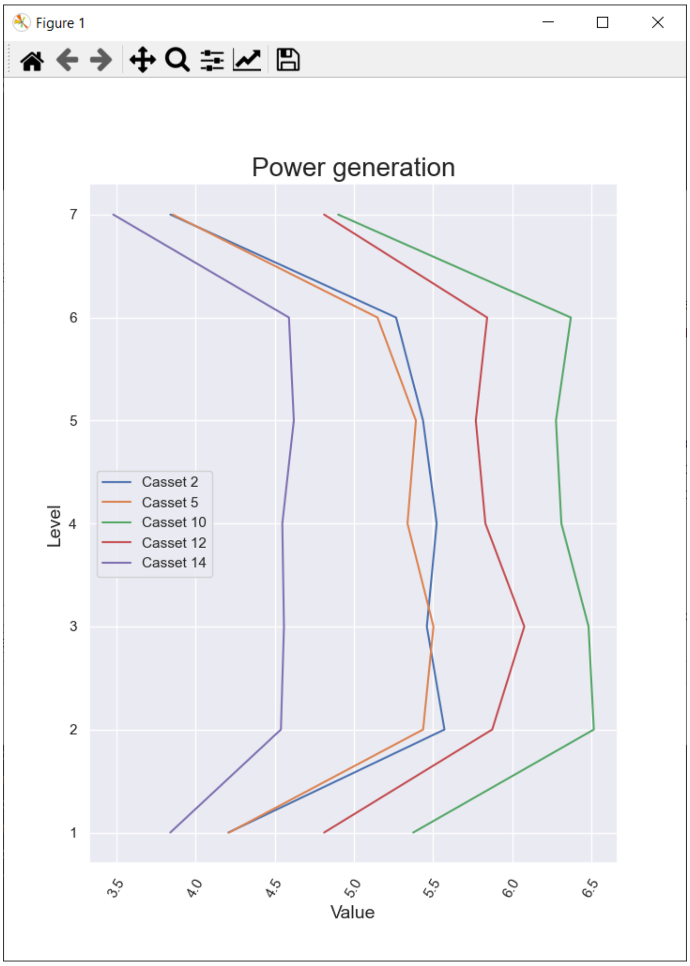

Figure 6: Diagram of the parameter distribution over the height of the reactor core

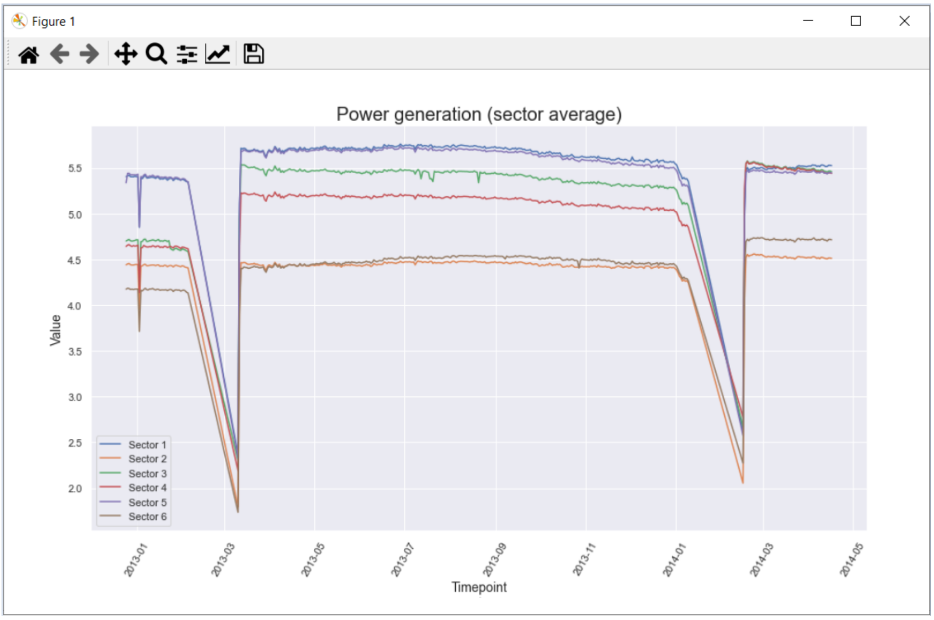

Figure 7: Parameter timeline

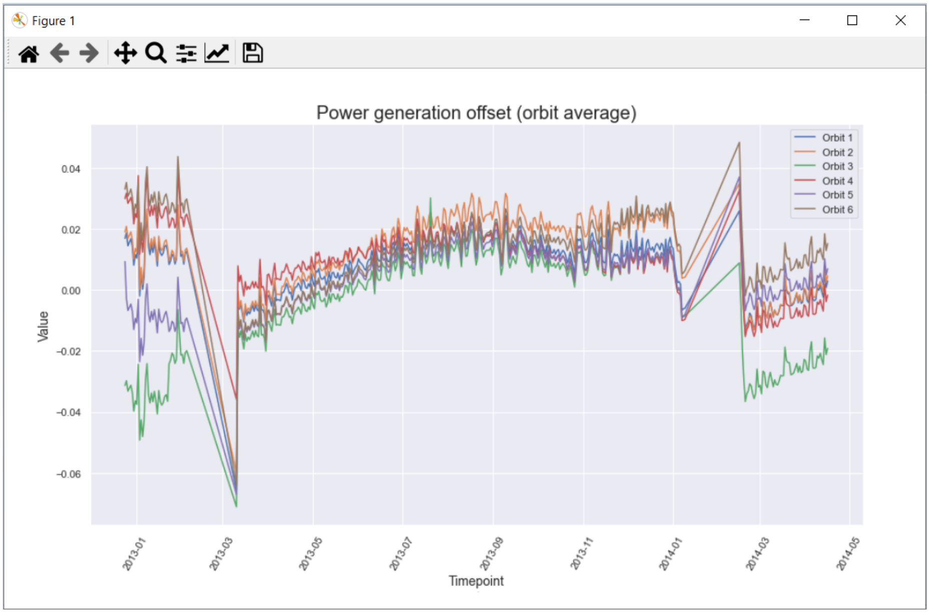

Figure 8: Parameter offset timeline

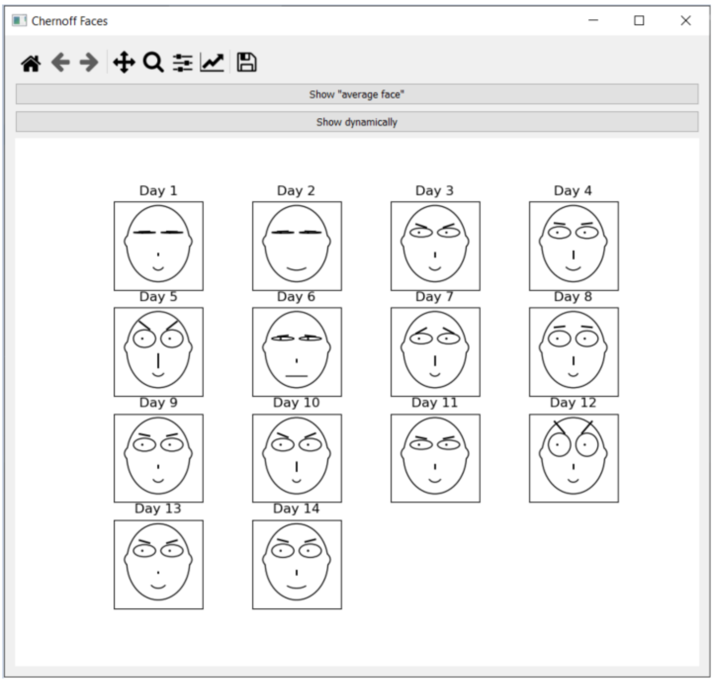

Figure 9: Static rendering with Chernoff faces

It should be noted that the type of visualization with the use of Chernoff faces also supports dynamic changes in the characteristics of the face, which allows visually, "in real time" to trace the dynamics of changes in the face in comparison with the "average face" – face, that characteristics take average values for the selected time slice. An example of such visualization is shown in Fig. 10.

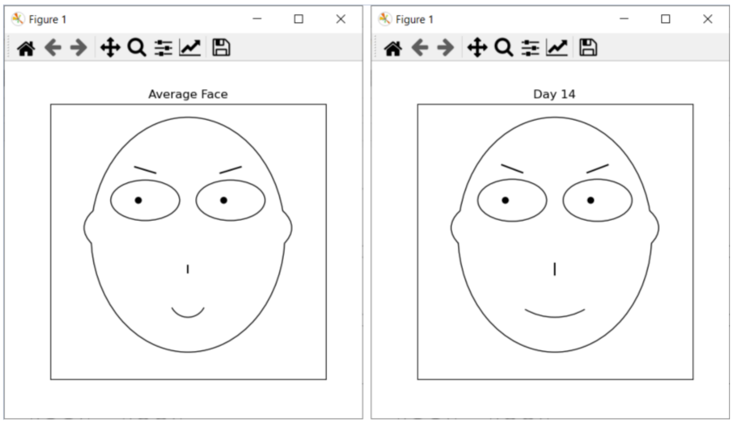

Figure 10: Dynamic rendering with Chernoff faces

At the same time, each of the visualizations allows to preprocess data for a more general visualization. The following options are available for preparing data for further visualization using one of the proposed methods:

- Cassette (output of the parameter value for the cassette);
- Sector average (sector-averaged parameter value);
- Orbital average (orbital-averaged parameter value);
- Height distribution (only for Chernoff faces);
- Offset of the average by sector (only for Chernoff faces);
- Orbital average offset (only for Chernoff faces).

Applying these methods, it is possible to draw conclusions when some of the parameters deviate greatly from their average values, when maximums or minimums are reached, or to find implicit relationships between the parameters (when visualizing more parameters).

4. Conclusion

This article presents a software package for visualizing the archive of a VVER-type nuclear reactor. This complex has an advantage over the previously developed ones in terms of performing express analysis and building dynamic visualization. With the help of this complex and the developed methods, it is possible to construct visualizations with the desired settings and, thus, to reveal anomalies or patterns in the behavior of parameters in time. Also, adapted visualization based on the Chernoff faces method allows to cluster generalized parameters, or to identify strong deviations, thereby speeding up the process of the analysis itself. After conducting a generalized study, it is possible to move on to a more detailed, in-depth study of the movement of individual parameters to identify the reasons for this behavior.

The novelty of this software is using of new methods applied to the archives of operational parameters of nuclear reactors. In this area, the use of new methods can reveal new patterns, as well as improve speed and quality of the analysis of the reactor behavior in different time slices (for example, during the day or throughout the year). Also, a structured approach based on the scientific visualization method allows the implementation of software that can be used both for post-analysis of the archive and for use by operational personnel. In this case, the software is developed in such a way that, when using various archives and configuration settings, to obtain a result that can be interpreted to the initial object of consideration - the reactor.

Also, the implementation of new software systems for visualizing the archives of a nuclear reactor makes it possible to approach the solution of the analysis problem from the point of an express analysis of the archive and thus conduct a study of multidimensional archive data using appropriate methods.

The proposed software can be used both by the operating personnel of the NPP as an auxiliary one in order to increase the efficiency of monitoring the operation of the power unit, and in order to analyze the existing archive database.

It is planned to continue working on improving the quality and stability of the developed software package, as well as expanding the functionality and adding new features.

5. References

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