Information Technology of Decision-Making Support on the Energy Management of Hybrid Power Grid

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Abstract. This paper is devoted to the development of information technology for decision making support when controlling the parameters of the hybrid power grid (HPG), considering the meteorological forecast and changes in the required level electricity generation and consumption in the HPG. The problem of decision making in the HPG management is formed under conditions of uncertainty and incompleteness of input information, therefore, it cannot be considered as an optimization problem, but should be considered as a multidimensional and multiscale problem. In this study, models for the collection and preliminary processing of information, models for determining the level of generation from renewable energy sources (RES), models for forecasting electricity consumption, a model for assessing the quality of electricity and a decision-making model are formed, which constitute the algorithmic and information support of information technology for decision support. Management decisions are made using additional current information on the effectiveness of the established regime, as well as forecast information obtained based on the proposed models.

Keywords: Decision-making · Hybrid power grid · Information technology

1 Introduction

The innovative development of global energetics is characterized by increased requirements for the efficient use of available energy resources. This requires restructuring the infrastructure of electricity production, storage, distribution, and consumption. Thus, the importance of technological innovations aimed at energy saving, such as Smart Grid, is growing.

The Smart Grid is designed to provide real-time data on the almost instantaneous balance between electricity demand and its current level. The data management used to

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operate and maintain the Smart Grid requires data analysis and decision support tools to achieve grid reliability by reducing peak demands and increasing energy efficiency.

One way to increase the energy efficiency of the Smart Grid implementation is to integrate it with RES. It is economically and ecologically expedient to introduce distributed energy production from different types of RES. This approach to electricity generation has several advantages. Firstly, the usage of the HPG with RES reduces electricity losses during electricity transportation. Also, it is possible to generate electricity for consumers for their own use and give surplus energy to the centralized network [1]. Local RES can be used for electricity generation [2]. Distributed electricity generation is also characterized by low environmental pollution. The combination of different energy sources ensures the stability HPG operation, as the advantages of each RES complement each other.

Operation of the Smart Grid based on renewable energy requires the development of the HPG operation management tools such as decision support systems (DSS) for operation management, analysis of the possibility of energy production depending on constantly changing weather conditions and electricity needs of consumers.

2 The Analysis of Management Peculiarities of Hybrid Power Grids with Renewable Energy Sources

Many countries have begun to respond to the challenge of changing the concept of electricity generation, distribution, and grids reconfiguration. Thus, new markets for centralized and distributed renewable energy are emerging in all regions of the world. Over the last few years, the capacity and production of devices for converting energy from renewable sources into electricity has been growing. The estimated share of renewable energy in the total amount of produced electricity is also growing [3].

New generation electrical grids must become cyber physical system under integrated intelligent control. This transformation can provide opportunities for energy saving - for example, by changing the paradigm of "centralized" to the paradigm of "decentralized" electricity generation. This can be achieved by changing the logic of the process of electricity production and distribution and the usage of modern software that offers functional energy optimization. Therefore, the urgent problem is the digitization of the processes that accompany the energy life cycle. This can increase profits, and such a transformation aims to make better use of available energy resources, especially RES. Intelligent management of complex cyber physical systems focuses on the ability of systems to perceive information, obtain useful results and change their behavior, as well as to store knowledge gained from previous experience.

The Smart Grid can be divided into parts called MicroGrid. The key idea of Smart MicroGrid is the integration and coordination of operations of all network users, regardless of their generation. The flexibility of Smart MicroGrid control is achieved by introducing a large number of interconnections into the grid and the inclusion in the automated process of more intelligent decision-making methods that use current grid status measurement data. Typically, MicroGrid includes distributed power units with distributed generation units, distributed energy storage devices, and different types of end consumers [4]. Distributed energy sources are electrical energy sources that are not directly connected to a centralized power system [5].

To control the power grid, mainly local automatic regulation means are used, as well as periodic measures to maintain the grid efficiency. The presence of electricity additional sources at the level of consumers such as solar batteries, wind turbines greatly complicates the process of power supply management, especially in terms of coordination of operation modes of the distribution grid and subscriber power grid.

Optimal energy management of the HPG, in general, requires improvement and development of management and technical methods and tools. Today there are no effective management systems of the power grid on the consumer side. This necessitates the improvement of a methodological basis for energy management information support.

3 Problem Statement

The aim of the study is to increase the efficiency of decision-making in the management of the HPG with RES by developing models, information technology, and creating DSS to support energy management decision-making under uncertainty.

To achieve this goal, it is necessary to solve the following tasks:

- create a model of data collection and pre-processing to formalize the real-time data collection process, ensure data verification and completeness, pre-process data that is necessary to support decision-making on the HPG management;
- develop models for determining the level of electricity generation from different types of RES depending on the existing constantly changing forecast meteorological indicators in conditions of unclear input data;
- improve the model of short-term forecasting the electricity consumption level, create a model for assessing the quality of electricity produced in the HPG, develop a decision-making model that allows to choose the HPG operation mode for effective decision-making on the HPG management;
- develop algorithmic, information support of the decision-making process and information technology of decision support in the HPG management, design the architecture and develop the DSS software.

4 Decision-Making in the Management of Hybrid Power Grids with Renewable Energy Sources

Safe and efficient HPG operation is a multidimensional and large-scale problem. Typically, interactions at all operation stages affect the behavior of the entire power grid. Thus, the task of the HPG management on different stages of its life cycle can be represented by a number of interrelated activities. Information decision support in the HPG management should be described as a process that focuses on consumers who operate the HPG – end users.

The decision-making task on the HPG operation at each stage can be formalized by a tuple:

$$TDM = \langle A, E, O, D \rangle,$$

where A – a set of available alternatives of the HPG operation modes,
E – a decision-making task environment,
O – a decision-maker preferences,
D – actions on the set of alternatives.

Figure 1 shows the scheme of decision-making on the HPG management. The process of decision-making on the HPG management in BPMN notation is described in Fig. 1 [6].

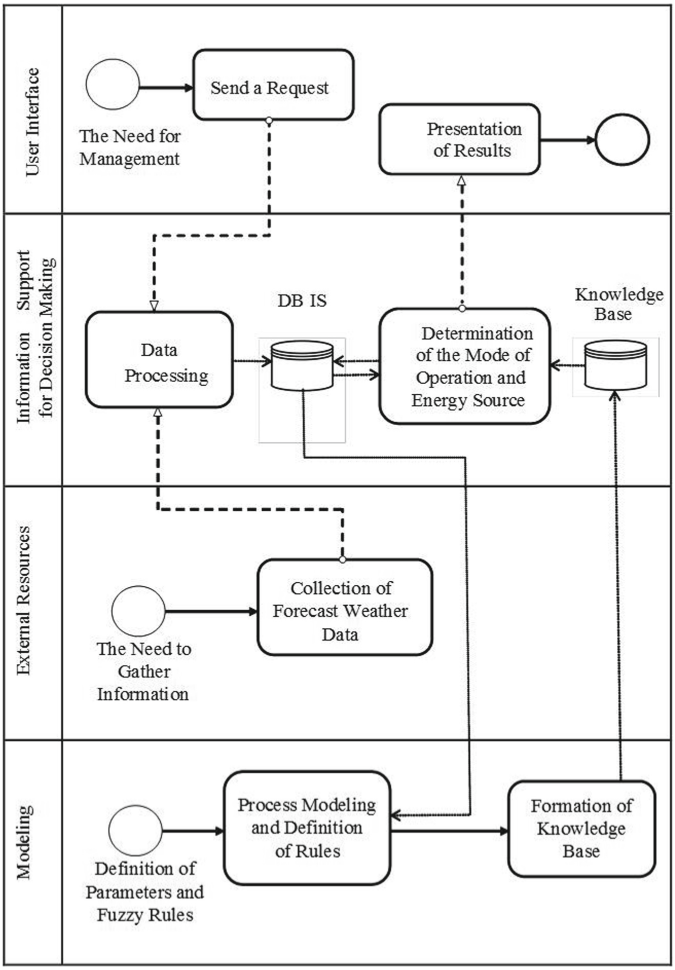

Fig. 1. Model of the decision-making process on the HPG management.

Analytical decision support on the HPG management is based on modeling. In the studied decision support process such developed models are used:

- the model of data collection and preprocessing;

- models for determining the level of electricity generation from different energy sources;
- the model for forecasting the level of electricity consumption, the model for assessing the electricity quality produced by the HPG;
- the model of fuzzy inference to determine optimal HPG operation, which provides a balance between power generation and consumption with a sufficient level of electricity quality, and gives recommendations for determining the energy source or a combination thereof.

To determine the decision on the HPG regime operation the knowledge base is used. It contains fuzzy rules, formulated on the basis of a survey of experts, and takes into account their experience with the HPG operational logic. As a result of data analysis in the process of choosing a solution in the user interface of decision-maker results and recommendations for the choice of energy source or a combination thereof are displayed.

Thus, decision-making is choosing from all available alternatives one variant that ensures effective HPG operation. In the general case, the management decision is based on defining the management goal, analysis of reliable data that characterize a particular management situation, and purposefully affects the object of management [7].

In this study it is proposed to use the DSS for modeling processes and determine sets of parameter values and fuzzy rules, to implement decision support processes on the HPG operation. To store data and organize access to them in the DSS have been created the database, which is essentially a set of interconnected data stored on a server, and is used to describe a subject area of the HPG operation management [8].

The process of the DSS functioning is described as follows:

$$Process \rightarrow O \times S_p \times Z \times D_S$$

The set of the DSS tasks Z is given as follows:

$$Z = Z_m \cup Z_{pg} \cup Z_{pu} \cup Z_f ,$$

where Z_m is a set of tasks for information collecting and processing; Z_{pg} - a set of tasks for forecasting the level of electricity generation; Z_{pu} - a set of tasks for forecasting electricity consumption; Z_f is a set of decision-making tasks.

5 Information Technology of Decision Support on the HPG Management

Information technology used to manage complex technical systems, which is essentially HPG, is a set of methods and tools for collecting, processing, storing, transferring information and knowledge to solve management problems in the form of special software.

Information technology of the HPG management is a combination of models and algorithmic support of processes: collecting meteorological data and data on the current state of the HPG and each of its components, pre-processing of these data, determining the level of generation from RES or various RES combinations, forecasting the level of consumption, determining criteria for assessing electricity quality, as well as decision support for determining the effective mode of HPG operation, and data visualization.

The interaction of processes provided by the proposed information technology which consists of five stages is presented in Fig. 2 in the form of a functional model.

Stage 1. Data collection. At this stage, data are collected and validated. The collection of meteorological and sensor data is performed at three-hour intervals during the day. From the collected data set in the process of data pre-processing fuzzy data sets are formed.

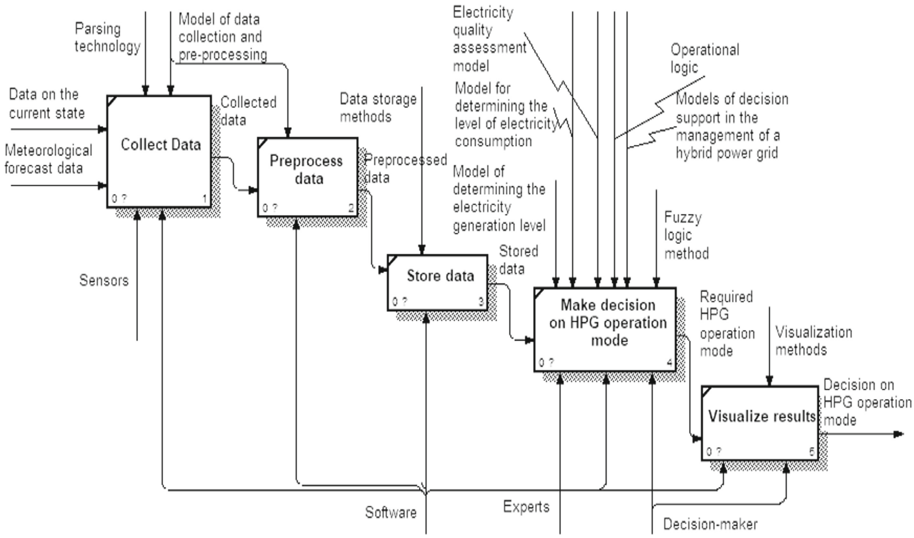

Fig. 2. Functional model of information technology of decision support on the HPG management

As a result of data extraction and sensor polling, the parameters of the HPG operation under current meteorological conditions are collected, as well as meteorological forecast data for the next three hours. This time interval is defined because usually the weather data does not change faster.

Stage 2. Preliminary data processing. At this stage, the sets of collected data are interpreted in the form of fuzzy sets for further use in models of power generation, consumption, and electricity quality assessment. Also, at this stage forms of interrelations between data are established.

Stage 3. Data storage. All collected and pre-processed data are stored in the database. The models used in the decision-making process refer to the collected and processed data. The results of the using models of determining the level of generation, consumption, forecasting and quality assessment are also stored in the database until they are used in the decision-making process.

Stage 4. The decision-making process. It carries out in accordance with the developed models and software. This process consists of subprocesses: determining the level of generation from RES or their various combinations in accordance with the forecast weather conditions, forecasting the level of electricity consumption for the next three hours, assessing the electricity quality, and the process of choosing an effective mode from possible available alternatives. The decision-making model takes into account the HPG operational logic. It uses a knowledge base consisting of fuzzy rules formed during a survey of experts. The result of this process is to determine the effective mode of the HPG operation, which is characterized by a balance between electricity consumption, and generation.

Stage 5. Results visualization. At this stage, the results are displayed for decision-makers in the user interface. Decision-maker receives recommendations for the management of the HPG operation in the form of concrete instructions for switching on or off specific switches that provide connection/disconnection of energy sources, balance load, and external network.

5.1 Model of Data Collection and Pre-processing

The first stage of the decision support process on the HPG management the real-time data collection of the HPG operation and environmental conditions, verification of compliance between the collected data and the HPG characteristics, erroneous data detection, and processing of the collected data for further use. In the general case, the data comes in three ways: from sensors and meters, transmitted via a communication channel; from external information sources such as weather forecast website, and entered by the user. In this case, the functions of data collection, data transfer, verification, preparation for further use and storage, are implemented. Displaying the collected data must be accessible through a web interface regardless of the software platform used by the end user.

All data used in the first stage of the HPG management can be described by a set $M_p = M_{po} \cup M_{pi}$. It consists of two subsets: subsets M_{po}, containing the parameters that are collected from external information sources (this data is variable over time) and are entered by the end user; subset M_{pi}, containing the calculated parameters.

Many of the parameters collected and entered by the end user M_{po}, can be represented as follows:

$$M_{po} = \{Mwo, Mres, Mg, MPl, M_{tech}\},$$

where $\mathrm{M_{WO}}$ is a data set of weather conditions forecast; $\mathrm{M_{res}}$ - a data set on the available HPG with RES configuration; $\mathrm{M_{Pl}}$ - a data set on the geographical location of the HPG with RES; $\mathrm{M_g}$ - a data set on the existing distribution networks in the area, to which it is planned to connect HPG with RES; $\mathrm{M_{tech}}$ - a data set that characterizes the current technical HPG condition (for example, the charge level of the battery).

Data $\mathrm{M_{res}}, \mathrm{M_g}, \mathrm{M_{Pl}}$ are entered once at user registration, data $\mathrm{M_{wo}}, \mathrm{M_{tech}}$ are collected from external sources in the operational mode, affect the HPG current state, and are decisive for the management decisions support.

The successful management of the HPG with RES depends also on the possibility of timely receipt and processing of the necessary reliable meteorological data. The sources of data collection on the forecast and current weather conditions are web systems for forecasting weather, which provide ever-changing dynamic data. Therefore, it is necessary to ensure the collection, pre-processing, and accumulation of data that change over time.

The input dataset M_{wo} can be represented as a set of weather forecast data that is collected online. It is described by an ordered set of elements:

$$M_{wo} = \{(t, E, T, V)\},$$

where t – time interval for which meteorological indicators are provided on the weather website (hours);

E – level of insolation and precipitation in qualitative characteristics, (clear; partly cloudy; cloudy; cloudy and precipitation;

T – temperature, °C;

V – wind speed can also be represented by a range of values, м/c.

The set of time intervals t consists of three-hour intervals during the day, through which the monitoring indicators are collected:

$$t = \{time : time \in Z, 0 \leq time \leq 23\}.$$

The set of time intervals for collecting weather conditions T_w, through which they are collected, can be represented as follows:

$$T_w = \{time_n : time_n = 2 + 3(n - 1), 1 \leq n \leq 8\}|T_w| = 8.$$

Control for the correctness of the data extraction and storage processes lies in verification of received data, control of recording the meteorological parameters into the database, and providing a stable connection to the weather forecast website.

Information on the level of insolation and precipitation comes in qualitative characteristics described by linguistic variables, such as “clear”, “weak cloudiness”, “cloudiness”, “heavy cloudiness”. These data are characterized by additional non-uniformity in accordance with different periods (days, months, seasons). For further use, their quantitative values are determined [9].

5.2 Model of Determining the Electricity Generation Level

An efficient HPG operation mode is a balance between electricity generation and consumption. Therefore, the decision support process is to determine such a balance by choosing from the many available alternatives of HPG modes. The first stage of forming a set of alternatives of HPG modes is finding the possible level of power generation from RES under the predicted weather conditions, taking into account the HPG operational logic [10]. The object of this study is the HPG, which uses two complementary wind and solar RES for power generation.

The HPG operational logic is performed in the following sequence: the total generated electricity from solar panels and wind turbines in a certain time interval, the power demand of the consumer in this time interval are determined. It is also determined which of the RES has the highest performance under given climatic conditions. If the generated electricity amount is greater than necessary for consumption, the surplus electricity is sent to battery storage. If the battery is fully charged, the surplus electricity is sold to the external network. In case of an insufficient level of power generation, if the charge level of the total battery capacity is more than 50%, the battery uses as a power resource

[11]. The minimum battery charge is maintained to support the electricity supply in case of an emergency. The main principle of HPG operational logic is to maintain a balance between electricity generation and consumption in the autonomous mode without the electricity involvement from the external grid.

Developed mathematical models that determine the forecasted level of electricity generation depending on weather conditions are given in [12].

5.3 Model for Determining the Level of Electricity Consumption

To support decision-making in the HPG management, it is important to develop a model for electricity consumption forecasting, which will determine the effective mode of the HPG operation. It is known that electricity consumption depends on many variables (e.g., consumer load, environmental conditions, etc.). To solve this problem deterministic and probabilistic methods are used. The most common method today is regression analysis.

In most cases, information on electricity consumption may be incomplete, or it may be interval or fuzzy, so the usage of traditional methods of electricity consumption estimating and forecasting becomes a difficult task given the uncertainty and incompleteness of the information. Thus, the task of building a forecasting model of electricity consumption is related to solving the problem of input information uncertainty. One way to solve the uncertainty is to build forecasting models based on fuzzy regression analysis, which, unlike conventional regression analysis, is not based on probability theory but on possibility and fuzzy set theory.

In our case, it is obtained and investigated a regression dependence for long-term and short-term forecast of the HPG user electricity consumption. The input data are the results of electricity consumption measurements for the previous year. The developed forecast model is possible to obtain a daily schedule of electricity consumption for any day of the month of the following year, as well as an operational forecast for the next day with a breakdown into three-hour intervals.

In [13] the long-term forecast based on the results of power consumption data processing for the previous year was developed. The correction of this model for short-term forecast and its quality assessment were made on a sample of source data that were not used in long-term model development.

5.4 Electricity Quality Assessment Model

The main criterion for the ability to integrate the HPG with the centralized electricity network is the electricity quality. The term “electricity quality” is vague. Thus, a system of indicators and norms was introduced to assess the electricity quality [14]. The proposed technique does not contain complex mathematical calculations and can be easily implemented in the DSS software.

Generalized indicators of electricity quality can take values from the range [0, 1]. In this case, if you exactly follow the requirements of existing standards for assessing the electricity quality, then different from value 1 are clearly assessed as the lack of the required electricity quality. With a deeper implementation of the fuzzy approach in assessing the electricity quality, it is possible to avoid such a rigid differentiation due to the deterministic approach.

The developed methodology allows monitoring changes in the electricity quality even when the main HPG operation indicators are within acceptable values, to analyze the dynamics of changes in quality indicators, and to determine preventive measures to normalize the electricity quality. That is, it can be considered as the main criterion for managing the HPG operation [15].

The presented method of fuzzy assessment of conformity of quality indicators to the accepted fuzzy norms allows forming various integrated quality indicators taking into account features of loads in a power supply network.

The proposed method allows not only to assess the degree to which quality indicators meet the accepted standards but also to monitor changes in electricity quality even if the basic indicators do not exceed the allowable values, to form rules for managing modes of the HPG operation used in the DSS [15].

5.5 Models of Decision Support in the Management of a Hybrid Power Grid

The problem of decision-making in the HPG management is solved under conditions of uncertainty and incompleteness of the input information, which makes it impossible to formalize it in the form of an accurate mathematical model [11]. Different measurement scales with different levels of detail are used to assess the parameters that affect the HPG operation, so the decision to determine the effective mode of the HPG operation cannot be considered as an optimization problem but should be solved as a multidimensional and large-scale problem.

The task of decision-making is to find a rational solution that belongs to the set of alternatives. At the same time, there is a vagueness in the formulation of the problem, as it is present both in the description of the set of alternatives and in the criteria by which the effective solution is determined. In this case, it is advisable to use the fuzzy preference relation method [16]. If the fuzzy decision-making problem can be formalized in the form of a fuzzy mathematical programming problem (discrete programming) and the problem of achieving a fuzzy goal can be formulated, then the approach proposed by R. Bellman and L. Zadeh can be used to solve it [17]. According to this approach, the solution is considered to be the intersection of fuzzy sets of goals and possible alternatives.

The task of decision-making in the HPG management cannot be reduced to the problem of discrete programming, because it is much more complex and non-linear. Therefore, we propose to include in the solution only those alternatives that are not strictly dominated by others, fuzzy criteria and fuzzy constraints should be subsets of different universal sets. Due to the impossibility to formalize the decision-making task in the HPG management in the mathematical formulation, it is necessary to rely on the experts' knowledge about the real decision support process and take into account the operational logic of the grid. It is possible to describe the information on decision making in the form of the ratio of advantages to a set of alternatives, which can be obtained by interviewing experts, as experts have knowledge about the HPG operation, which cannot be formalized due to the complexity of these processes.

From the possible existing states of HPG operation, the one that allows achieving a balance between electricity generation and consumption with sufficient quality of generated electricity should be selected. The choice of decision from a set of alternatives should also be based on the operational logic of the grid. Therefore, in this case, an effective method of decision-making is fuzzy logic. This approach was chosen for decision support on the HPG management. It involves further development methods of the HPG control by using controllers with fuzzy logic.

The effective mode is determined taking into account the current HPG state and meteorological forecast data. It is designed to ensure effective HPG functioning in the next three hours [18].

6 Conclusions

The developed information technology provides data collection, processing, and storage that are necessary for effective HPG management. The main task of information technology is to support the decision-making on the reasonable selection of the effective mode of the HPG operation, which allows providing effective HPG management. Information technology does not affect the operation of automatic control and regulation devices but determines changes in the HPG operation mode in order to normalize the quality of electricity. It also allows efficient electricity consumption by prompt changes in the hybrid network structure by providing recommendations regarding switching off or on of RES, storage battery in the mode of charge or discharge, balance load to increase energy saving.

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