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INTELLIGENT ENERGY SUPPLY MANAGEMENT SYSTEM IN THE MUNICIPAL SECTOR

Igor NEVLUDOV[1], Andriy SLUSAR[1], Kyrylo KRUSTALOV[1], Sofia KRUSTALOVA[1], Shakhin OMAROV[1]

[1]Department of Computer-Integrated Technologies, Automation and Mechatronics, Faculty of Automation and Computerized Technologies, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

ABSTRACT

The subject of this study is the methods, tools and intelligent systems for managing energy supply in the public utilities sector. The object of the study is the process of energy management in the municipal sector. The purpose of the study is to develop an intelligent energy management system in the public utilities sector. To achieve this goal, the following tasks were solved: the main problems of energy efficiency in the housing and communal services sector were analyzed and ways to solve them using modern technologies were proposed; the methodology for developing an intelligent system (SmartGrid) was chosen; the architecture of an intelligent energy management system was proposed; the algorithm of the intelligent energy saving management component was presented; to determine the electricity consumption in the system, a methodology was used that involves the collection and analysis of data from the Machine learning algorithms, such as the support vector method, neural networks, and decision trees, are used to determine the optimal mode of energy consumption. Conclusions: the use of the proposed system will reduce the cost of energy supply in the municipal sector and increase its energy efficiency, the possibility of integration with other municipal management systems.

Keywords: intelligent system, energy supply management, utilities, machine learning, energy efficiency, optimization, data analysis.

1. INTRODUCTION

In recent years, the demand for energy in various spheres of human activity, including in the municipal sector, has grown significantly. Ensuring energy supply and energy saving have become urgent issues in the face of rising energy costs and depletion of natural resources.

The development of an intelligent energy management system in the housing and utilities sector could be an important step in solving these problems. Such a system will automate the energy management process and ensure more efficient use of energy resources [1].

Today, Smart Grid technology is widely used. In essence, Smart Grid is a complex power system that unites resource suppliers, energy facilities and consumers into a single "intelligent" power grid. It involves the use of new digital technologies, multi-tariff meters and energy distribution devices that ensure the reliability and transparency of energy production, transmission, distribution and consumption.

The smart grid will enable the creation of a discrete energy system that will help eliminate leaks and combat non-payers more effectively. The transition of housing and utilities facilities to Smart Grid technology, based on advanced network analytics and the use of modern automated control systems for data acquisition and processing (SCADA), as well as the ability to remotely monitor and control equipment, will allow energy companies to extend the life of equipment, reduce the cost of grid modernization and prevent grid failures.

2. METHODOLOGY

The methodology used in this study is based on a systematic approach to the analysis and development of intelligent energy management systems. The first step was to analyze energy efficiency problems in the municipal sector and existing energy management systems. For this purpose, we used data from reports and statistics on energy consumption in cities and towns. The analysis helped to identify the main problems that arise in the field of energy supply to the municipal sector [2].

The second stage was to develop the concept of an intelligent energy management system based on modern technologies and machine learning algorithms. For this purpose, a detailed analysis of the requirements and functions to be performed by the system was conducted, and its architecture was determined.

The third stage of the work was the creation of a prototype of the system, which allowed us to test and debug the system's functions. For testing, data from real municipal facilities were used, which were collected using sensor networks [3].

The National Energy Technology Laboratory of the U.S. Department of Energy defines Smart Grid as a set of organizational changes, a new process model, information technology solutions, as well as innovations in the field of automated process control systems (APCS) and dispatch control in the electric power industry, etc.

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According to the European Commission, which deals with the development of a technological platform in the energy sector, Smart Grid is a network that meets the requirements of energy efficient and economical operation of the power system through coordinated management and modern two-way communications between power grid elements, power plants, storage sources and consumers [4].
The European Commission believes that Smart Grid can be described by the following principles of operation:
- flexibility - the network should be adaptable to the needs of electricity consumers;
- accessibility - the grid should be available to new users, and new connections to the global grid can be made by user generating sources, including renewable energy sources with zero or reduced carbon dioxide emissions;
- reliability - the grid must guarantee the security and quality of energy supply in accordance with the requirements of the digital age;
- cost-effectiveness - innovative technologies in the construction of the Smart Grid together with efficient management and regulation of the grid should be of the greatest value.

The structure of the Smart Grid includes the following components as shown in Figure 1:
- smart metering (the first step towards a smart grid);
- smart grid;
- energy efficiency;
- consumer technologies.

The main difference in the operation of the Smart Grid is as follows: in traditional networks, current flows from generation to the consumer through wires in accordance with a predetermined level of voltage and resistance, while in the case of the Smart Grid implementation, the network will be able to independently regulate the energy supply depending on the decrease or increase in consumption. Businesses and residential buildings (i.e., consumers) are installing smart meters that transmit consumption information. This fact makes it possible to adjust the use of electrical appliances over time and distribute electricity depending on the need, which significantly reduces costs [5].

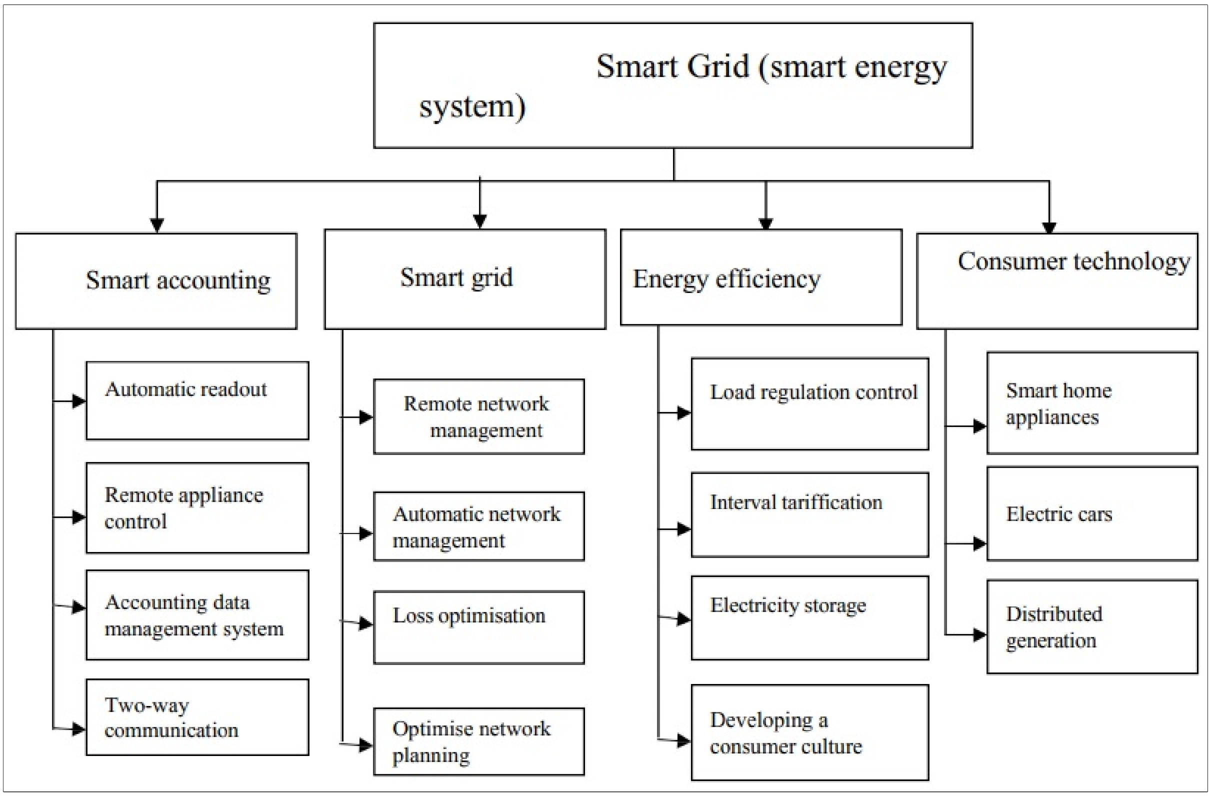

Figure 1. The structure of the Smart Grid

The main elements of smart grids (SG) include:
SCADA - (Supervisory Control and Data Acquisition System) - an automated control system;
EMS - (Energy Management System) - energy consumption management system;
DMS - Distribution Management System - distribution organization system;
OMS - Outage Management System - an emergency outage management system;
GIS - Geographic Information System - geographic information system;
PDC - Phasor Data Concentrator - a phase channel concentrator;

WAMS - Wide-Area Measurement Systems - a system for monitoring transient conditions;
MDMS - (Meter Data Management System) - measurement data management system;
SER - (Sequence Event Record System) - a system of sequential error recording;
DFR - (Digital Fault Recorder System) - a system of digital fault recording;
SER - (Sequence Event Record System) - system of sequential error recording;
DFR - (Digital Fault Recorder System) - a system of digital emergency recording;
SMD - (Smart Metering Data) - a system of intelligent data metering;
PMU - (Phasor Measurement Units) - a vector measurement device is not currently included in IM, but experts believe that this device will become an integral part of IM [6].
When studying and implementing IM, the IM architecture is very important. The IEEE 2030-2011 standard is used as a guide for implementing IM and defines the architecture and the main interacting objects. This standard defines a reference model that uses a systems approach to provide guidance on the interoperability of various communication components, energy systems, platforms, and information systems. The Advanced Communications Technology Model provides a set of network components to ensure the communication of generation, transmission and distribution of energy resources [7]. The IEEE 2030 model is shown in Figure 2.

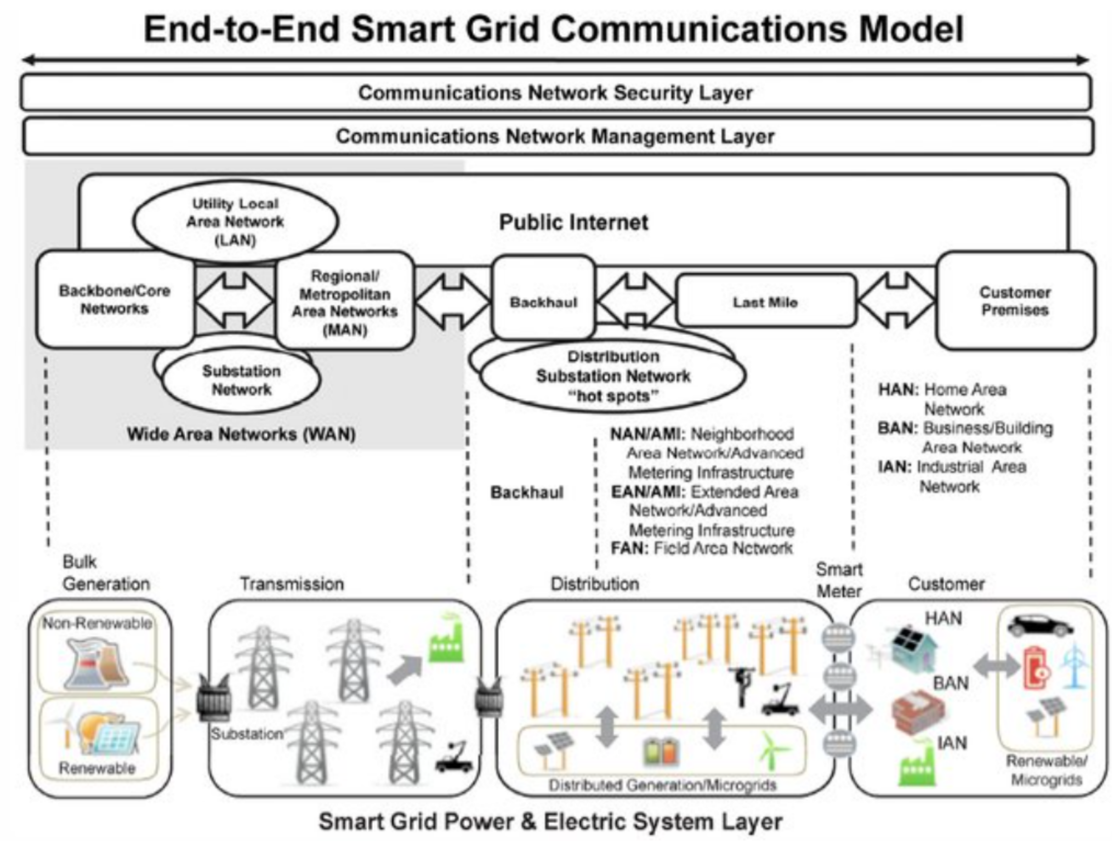

Figure 2. IEEE 2030 model

3. SYSTEM ARCHITECTURE

When designing such systems, it is necessary to take into account the following areas of knowledge: development of intelligent systems based on the principle of functioning of biological objects, intelligent control systems, hybrid intelligent systems, intelligent data processing (data mining) and knowledge extraction from data (and similar), evolutionary intelligent systems. Despite the abundance of approaches and theoretical research, critical issues in design remain:
- selection and formation of the structure of the model of the management object (identification);
- checking the quality of data;
- adaptation of models to changes in the object's behavior;
- interpretation of results and replication;
- formation of a knowledge base based on both expert knowledge extraction (e.g., CBR) and data mining (CRISP-DM) methods.
Let us consider the proposed architecture of the intelligent system. The system consists of the following main components as shown in Figure 3:

- a semantic layer for selecting (describing) the problem (not considered in this paper);
- data loading and data quality manager;
- query manager;
- a data warehouse with an OLAP structure with a manager for loading information from external data sources and a layer that provides access to the warehouse (for example, an object data schema, linq);
- components of model and method libraries;
- components of process libraries (a process is a sequence of method calls to solve a problem;
- metadata or knowledge base;
- component of intelligent formation and management of processes and metadata flows.

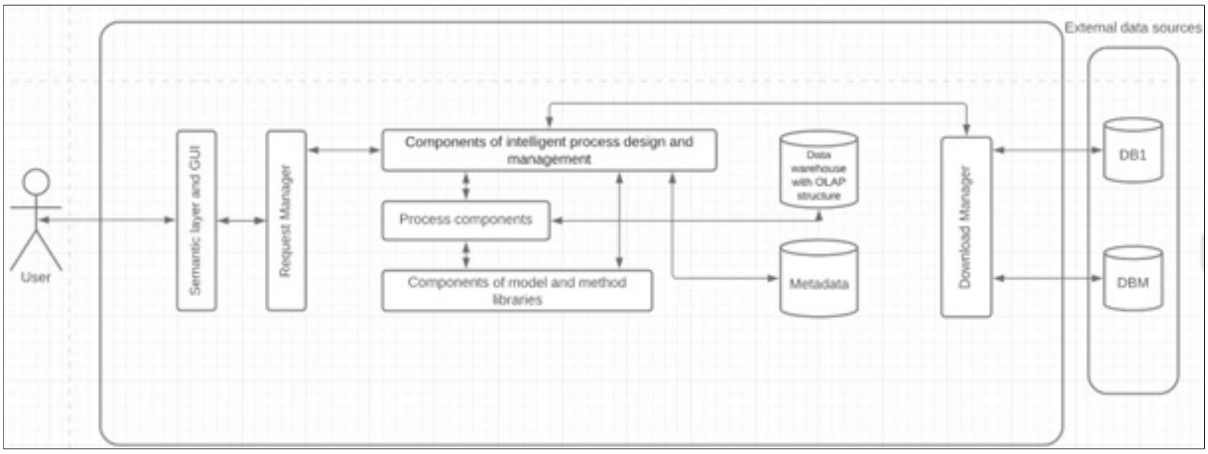

Figure 3. Architecture of an intelligent energy management system

The intelligent control component is of the greatest interest. The algorithm of the component is similar to the decision-making algorithm:
1) analysis of the problem and initial data to solve the problem;
2) formation of alternatives at the level of processes (set of models) and at the level of model settings;
3) formation of the objective function, formation of a system of constraints, criteria for selecting decision alternatives based on the available knowledge in the knowledge base, quality criteria (accuracy, stability);
4) selection of a process that optimizes the objective function under the constraints.
Thus, as a result of the functioning of the intelligent unit, models of the control object (identification task) and the control device (control task) are formed.

4. IMPLEMENTATION OF AN INTELLIGENT ENERGY SAVING CONTROL UNIT

Processes, from the point of view of an intelligent control unit, are the result of its operation. The input information is data characterizing the object of management (here, a consumer or a network of electricity consumers), constraints (on variables, for example, the interval of change in values within a certain period of time), and target characteristics (model accuracy, stability). In addition, a knowledge base and the implementation of models and methods of intelligent information processing are used to synthesize processes. Since a process is a sequence of model application, we will highlight some tasks:
- Task 1: forming a sequence that is optimal in terms of the objective function;
- Task 2: determining the optimal set of input variables for the first and subsequent models;
- Task 3: determining the number of models depending on the number of identified types of dynamics of the control object;
- Task 4: determining the structure and parametric optimization of the model.
Based on the above, the block of processes should include:
- data quality analysis process;
- forecasting process;
- process of calculating energy saving potential.
Let's consider the procedures for synthesizing the forecasting process. The input information is the readings of electricity consumption, enterprise status sensors (working - closed), temperature sensors, wind speed, time stamp (date - time). The information was collected during the time T with an interval of 15 minutes. The target function is the root mean square deviation (RMSE error). It is necessary to make a forecast on the forecasting horizon a. There is a set of connectivist forecasting models and information pre-processing models.
The block algorithm is characterized by the following steps.
1) Determine the amount of available information (sensors).

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2) Perform data quality analysis using the outlier and anomaly detection approach based on the forecasting model.
3) Perform a one-parameter analysis and build a one-parameter model for predicting electricity consumption:
a. Select *K* samples of data based on seasonal analysis with the same statistical characteristics (based on, for example, chi-square analysis);
b. Conduct autocorrelation analysis to determine the lag value (*n*) and the number of variables *N*. Generate *K* models (based on the basic moving average model);
c. Calculate the average error E_1;
d. If the error exceeds 10%, then select neural networks as the basis, form and configure *K* models;
e. Calculate the average error E_2;
f. If the error exceeds 10%, then proceed to the multivariate analysis.
4) Perform multivariate analysis and build a multivariate model for predicting electricity consumption.
a. For each sensor, select input variables: determine the value of *N* - the number of points in the time series to be included in the model and *n* - the number of discrete samples between points ($n \neq const$). The selection is based on productive rules with a high degree of confidence. The rules have a left-hand side:
- type of control object;
- statistical characteristics of the consumption value distribution;
- type of sensor.
The right side includes:
- values $<N, n>$,
- aggregation level (15 minutes, 30 minutes, 1 hour, 4 hours, 12 hours, day).
a. Change the input data vector and perform the formation and parametric optimization of the model(s);
b. Calculate the average error E_3 (or the integral accuracy index IA) for the considered objects;
c. If the condition $E_3 < E_2$ is met, then go to step 3.a. Otherwise, exclude the added parameters in the input vector and reduce the confidence level of the rule.
5) Analyze the energy saving potential by comparing the predicted values with the measured values.

5. STUDY RESULTS

The paper presents the concept of synthesis of an intelligent automation system for energy supply management. The formation of forecasting processes based on the algorithm below will make it possible to achieve the formation of forecasting models in an automatic mode without the participation of an expert at the time of model formation and verification. The formation of a knowledge base about the process can take place in the background, and knowledge about the process of forming forecasting models can be extracted from the data.
The developed intelligent energy management system has demonstrated its effectiveness and prospects for application. The system allows to reduce the cost of energy supply, reduce the number of power outages as a result of accidents, and ensure better and more efficient operation of the energy supply system.
The system uses a methodology that involves collecting and analyzing data from the control interfaces of electrical appliances connected to the system to determine electricity consumption. Various machine learning algorithms, such as support vector machines, neural networks, decision trees, etc., are used to determine the optimal mode of energy consumption.

As a result of the study, a prototype of an intelligent energy management system for utilities was developed, which includes a database, a data processing unit, a machine learning unit, a decision-making and control unit, and a user interface. The prototype system was tested in real operating conditions, which allowed us to obtain additional data to analyze the effectiveness of the developed energy management system. The test results showed that the developed system can reduce energy consumption in municipal networks by 15-20%. In addition, an important aspect of using the developed system is its ability to integrate with other municipal management systems, such as water supply and sewage, which allows creating an integrated municipal management system to achieve maximum efficiency and resource savings.

6. CONCLUSIONS

The study resulted in the development of an intelligent energy management system for the municipal sector. Machine learning methods were used to implement the system, which made it possible to obtain accurate energy consumption forecasts and optimize the energy supply management process.
The developed system was tested in real operating conditions and showed a 15-20% reduction in energy consumption. An important aspect of using the developed system is the possibility of its integration with other municipal management systems.
Thus, the developed system can become an effective tool for reducing energy supply costs in the municipal sector and improving its energy efficiency.

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