Development of an information system for energy supply management of the lighting system at the enterprise

Irina Usacheva*

Volgograd State University, Volgograd, Russia

Abstract. The article presents the results of research work on the development of an automated system of integrated management of energy conservation lighting system at the enterprise. As part of the work, the software implementation of the prototype of the automated system of integrated management of energy saving of the lighting system at the enterprise was carried out. For this purpose the requirements to the functions performed by the automated system were formulated, the architecture of the automated system of complex energy saving control of the lighting system at the enterprise was developed, the structure of the data processed by the automated system was worked out, and in compliance with this structure the architecture of the database used by the system as well as the user interface of the automated system were designed.

1 Introduction

Globally, industry accounts for about 29% of final energy consumption and about 23% of the world's workforce. Improvement in energy efficiency is needed in all sectors but targeting industrial energy consumption offers major advantages for policy makers because it is more concentrated in terms of entity numbers and often a small number of bigenergy-intensive enterprises consume the majority of energy in the sector. The Pareto Principle, or 80/20 rule, generally applies to this sector, in that about 20% of industrial sites often consume 80% of the energy used by all of industry. Nearly two thirds of all industrial energy consumption is accounted for by just four sectors: chemical & petrochemical (33%), iron and steel (17%), cement (9%), and pulp and paper (5%). Achieving improved energy efficiency in industry can make a significant contribution to solving local, national and global energy problems.

The highest form of energy maturity, giving the biggest energy savings, comes from a step change either in process design, energy supply, or both. This is the most costly and carries the highest business risks compared to other projects in the energy maturity matrix. Examples include:

- combined heat and power plants
- refitting the production line with a new process technology
- applying dynamic simulation and predictive controls
- extending the energy or waste heat into a district heating and/or cooling network.

* Corresponding author: Zeppelin89@volsu.ru

Engineering and technical staff are naturally inclined towards the most complex opportunities. However, the implementation of high-end projects requires specialist knowledge and skill. It also carries higher business risks, costs more, and may straddle across several organizational boundaries. Initiatives at the lower level require less specialised knowledge and skill to implement. Improving the energy performance of any particular industrial process (or building) involves technical issues but is really a management problem.

Many cost-effective energy efficiency technologies exist across all industries – applying them requires management. The introduction and tightening of the control systems of existing processes and utilities can further dampen variation in energy consumption and allow a process to operate closer to its designed control limits. Some small investment may be necessary to repair, reinstate, replace and/or introduce new control parameters. There are many examples falling into the control systems category, including:

- introducing temperature control limits in air conditioning systems
- matching the most efficient machine with actual demand
- using preventive maintenance and condition monitoring to predict and prevent equipment failures
- improving the consistency of water chemistry
- reducing excess flows
- increasing cycles of concentration
- reducing blow down
- using variable speed drives
- utilising control loop tuning
- monitoring the performance of key plant items.

Housekeeping and control system improvements are normally carried out at individual equipment and machinery levels. The next level of complexity involves looking at energy savings from a unit operations or systems perspective.

Typical electricity demand projects are energy efficient lighting systems, building management systems, energy efficient hot water systems, process optimisation that results in electricity reduction, and the use of solar thermal systems. The use of outdated lighting systems in factories is a modern reality, especially in Russian industry. It leads to a decrease in the comfort level of employees of enterprises and, consequently, to a decrease in their productivity, as well as to increased costs for the operation of such systems [1].

Introduction of modern lighting systems using computer systems in their work is a way to solve the above problems. Application of automated information control systems instead of remote or telemechanical ones widely used nowadays allows to control and build an optimal strategy of energy consumption, monitor the state of equipment and timely inform the operating personnel about emergency situations in the network [7]. By implementing an automatic information control system, it is possible to solve the problem of uninterrupted power supply and, as a consequence, to ensure safety at enterprises. Energy-efficient operation of the lighting system in the enterprise at any time will significantly reduce energy consumption for lighting purposes, as well as achieve the most complete and accurate accounting of daylight, as well as the presence of people in the room [2,3].

The use of automated systems to control lighting of staff workplaces will create more comfortable working conditions, which will undoubtedly contribute to increased productivity and, as a consequence, increase the profitability of enterprises.

2 Methodology

A lighting control system is an intelligent networking solution for lighting control that includes communication between the various inputs and outputs of the system relating to lighting control using one or more central computing devices [10].

There are several general strategies for using lighting controls to reduce operating costs and improve lighting system functionality:

- **Occupancy Sensing:** Turning lights on and off according to occupancy as detected with occupancy sensors. Appropriate for unpredictable occupancy patterns.
- **Scheduling:** Turning lights off according to program using programmable relays, timers and other time clock devices. Appropriate for predictable occupancy patterns.
- **Tuning:** Reducing power to electric lights in accordance with the user needs at the time. Tuning may be accomplished with dimming devices, but bi-level switching of overhead lighting should also be considered, especially when daylight is available.
- **Daylighting:** Reducing power to electric lights or turning lights off in the presence of daylight from side lighting or top lighting. Daylighting controls typically employ a photo sensor, linked to a switching or dimming unit that varies electric light output in response to available daylight. Bi-level switching should be considered if dimming is not economically justified.
- **Demand Limiting:** Reducing electric lighting power during or in anticipation of power curtailment emergencies. During Emergency Alerts periods lighting loads can be shed either through voluntary curtailment or automatically by the facilities manager or utility service provider.
- **Lumen Maintenance:** Compensating for lamp lumen depreciation using a photocell. This strategy is generally deprecated today, as the lamp lumen depreciation from modern building lighting systems is too small to make lumen maintenance economically viable.
- **Integrated system:** Integrated lighting controls provide all necessary control adjustments and inputs at one location, where several control strategies can be applied at once. Although integrated controls are somewhat more expensive, the convenience of having one accessible location for performing all system commissioning can reduce setup and maintenance costs.

In order to build an efficient lighting control system in an enterprise, it is first necessary to evaluate the energy saving potential and identify energy efficiency improvement opportunities for the lighting system as a whole, as well as factors affecting the energy consumption of lighting systems [8,9]. Existing research has shown that the main factors influencing energy consumption are: brightness and lighting, color temperature, adaptation to light and dark and environmental comfort [4, 5, 6].

Various research methods were used in the development of the information system: a cyclic method of interrogating sources of information allowed gathering information about the continuously changing parameters of the control object; conversion of the voltage (current) value into a digital code; sweep conversion with feedback; and per-digit equalization. The information system was created in C# using MSSQL Server.

3 Results and discussion

The information system for comprehensive energy management of the lighting system at an enterprise shall perform the following functions:

- Monitoring of electric energy consumption for lighting.
- Accumulation and storage of obtained information on electric energy consumption by the lighting system.
- Performing forecasting of electric energy consumption for lighting.
- Data display.
 - Displaying electricity consumption data in graphs.
 - Illumination data display on three dimensional models.
 - Display electricity consumption forecast data in graphs.
- Working with three-dimensional models of rooms and luminaires.

The information system should be a client-server application. The server is responsible for collecting information from sensors and electric meters and storing the received information in the database. The client is responsible for displaying the user interface and outputting data to the user. The exchange of information between the client and the server must be carried out through the WebAPI, implemented on the server. The server part of the automated system of complex energy saving control of the lighting system of an enterprise must analyze and forecast the consumption of electric energy consumed by the lighting system of the enterprise. Graphs and three-dimensional models should be displayed on client devices.

Based on the requirements formed, the architecture of the automated system of integrated management of energy efficiency of the lighting system at the enterprise was developed (Figure 1).

All functionality for collecting, storing and processing information from sensors and electricity meters is implemented on the server of the automated system for comprehensive energy management of the lighting system at the enterprise. The server is managed from the client part of the automated system, which is in the administration mode. Displaying information from the server in the form of graphs and on three-dimensional models takes place on the client.

The automated system server uses a Microsoft SQL Server database management system to store information. The database records the information collected from sensors and electric meters. It stores lists of models (lamps, fixtures, meters, their models and manufacturers), lists of users, their roles in the system and actions allowed to each group of users. Figure 2 shows the database architecture of the automated system of integrated energy management of the lighting system at the enterprise.

The database of the automated system for comprehensive energy management of the lighting system at the enterprise contains the following models:

- IlluminatorModels (models of luminaires used in the enterprise lighting system);
- Illuminators (lighting fixtures used in the enterprise lighting system);
- LampProducers (manufacturers of lamps used in the enterprise);
- Lamps (lamps used in the enterprise);
- LampTypes (types of lamps used in enterprise lighting);
- SensorMeters (readings of electric energy meters);
- SensorModels (models of electricity meters);
- SensorProducers (manufacturers of metering devices (meters) of electric energy);
- Sensors (electric power meters);
- UserActions (user actions available in the automated system);
- UserRoles (user roles available in the automated system);
- UserRoleUserActions (compliance of user actions available in the automated system with the user roles);
- Users (users who have the possibility to work in the automated system).

Fig. 1. Architecture of the system.

The server part of the information system is developed using the Visual C# programming language. The client part of the information system can run as a separate application or in a browser. When developing the browser version, the programming language TypeScript and Angular framework were used. Development of the client application in the form of a separate program was implemented using the programming languages Visual C#, C++, XAML, WPF technology and frameworks .NET Framework, Visualization Toolkit. For the server part we developed WebAPI, which is accessed from the client using HTTP-requests. To interact with the database server the Entity Framework is used.

Fig. 2. System database structure in SQL notation.

Working with the information system of integrated energy management of the lighting system in the enterprise is possible only for users who passed the authentication procedure. To do this, the login-password pair is used. At the same time, passwords are stored in the database of the information system in hashed form in order to avoid working in the system when unauthorized access to the database is gained.

To improve safety and security, the information system has a mechanism for assigning roles. Each user role has access to specific functionality for working with the information

system of complex energy management of the lighting system at the enterprise. At the same time for each role it is possible to configure a set of actions that are available to it.

You can add specific actions to each user role. All users to whom this role is assigned will have access to all actions specified for this role. So, any user group, let's call it "Users" group, you can prohibit all actions except generation of reports and work with graphs.

The functionality of the information system for comprehensive energy management of the lighting system at the enterprise can be markedly modified for users with different roles. The main functions available in the information system are:

- editing the lists of models used in the system;
- making forecasts;
- working with three-dimensional models of luminaires and premises;
- constructing three-dimensional maps of illumination;
- working with graphics;
- control of luminaire operation modes (in manual and automatic modes);
- generating and exporting reports;
- system settings control.

All functionality is available from the main menu of the information system. The list of lighting models available in the system includes the following:

- luminaires;
- luminaire models;
- lamps;
- lamp manufacturers;
- lamp types;
- meters;
- meter manufacturers;
- meter models;
- meter readings;
- users;
- user roles;
- actions in the system.

Working with each type of models in the information system of complex energy saving management of the lighting system at the enterprise is performed in the same way, which allows reducing the time for the initial mastering of the information system and increasing the productivity of the system users.

The information system supports loading of 3D geometric models. It is necessary to work with 3D models of rooms and view illumination map on the spatial model. Support of three-dimensional models is realized by means of VTK (Visualization Toolkit) library. To work with this library, the C++ programming language is used. VTK has a great functionality for visualization of calculation data and three-dimensional models.

The information system of complex energy management of the lighting system in the enterprise supports loading of three-dimensional models of STL format. When working with models the direction of coordinate axes is displayed. The main opportunities when working with three-dimensional models:

- loading three-dimensional model of STL format;
- zooming in/out the camera;
- camera rotation

ability to quickly move the camera to one of the following projections:

- front view;
- back view;
- left view;

- right view;
- top view;
- bottom view;
- isometric projection (orientation of the camera at an angle of 45 degrees along the X and Y axes in the coordinate system of the original model).

All actions are applicable both in the geometric models mode and in the data visualization mode (view illuminance maps).

Using three-dimensional models allows you to get a clear picture of the illumination in the premises of the enterprise compared to two-dimensional graphs, which will reduce the time for making decisions to optimize the lighting system in the enterprise [11, 12].

4 Conclusion

The presented information system is a client-server application. The server part collects data from sensors and counters, their storage, processing and analysis. The client part performs interaction with the user, displays data to the user in the form of graphs and three-dimensional models. In the prototype, the differentiation of access for groups of users to the functionality is implemented.

As part of further work, it is planned to introduce virtual reality systems (HTC Vive, Oculus Rift) in the process of visualizing illumination maps on three-dimensional models, and introduce new methods of forecasting electric power consumption for lighting. It is planned to introduce paralleling in the process of calculating the illumination and the process of calculating the forecast values.

The study was carried out with the financial support of Grant of the President of the Russian Federation (project No. MK-1362.2020.9).

References

1. I. George, C. Pallavi, M. Varghese, International Conference on Management, Energy, Communications and Computing Technology, 129 (2018)
2. GOST R 55710-2013 Lighting of workplaces inside buildings. Norms and methods of measurement, <http://docs.cntd.ru/document/1200105707>.
3. V.A. Kaptsov, V.N. Deinego, National Association of Labor Safety Centers (NASOT) Occupational Safety and Health, **3**, 77 (2015)
4. A. Pachamanov, D. Pachamanova, Angle. Optim, **40** (1), 47 (2008)
5. Jiang and H. Rahimi-Eichi, IEEE Power & Energy Society General Meeting Minutes (PES '09), 1 (2009).
6. Y. Chu, V. Calavalli, N. W. Oo, J. Parkkinen, Energy harvesting, **120**, 1 (2016).
7. A. H. Mohammad, M. Y. Hasan, H. Abdullah, H. A. Rahman, P. P. Abdullah, F. Husin, D. M. Said Endure. Energy Rev., **33** (2), 268 (2014)
8. Ch. Cajochen, S. Frey, D. Anders, and ect. American Physiological Society Journal of Applied Physiology, **110** (5), 1432 (2011)
9. Mu-J. Kho, T. Javed, R. Mark, E. Maier, ect, Kodak European Research at Cambridge Science Park, 1(2008)
10. D.L. Klipstein, *The Great Internet Light Bulb Book*, I (1996).
11. "Total Energy," U.S. Energy Information Administration,

<http://www.eia.gov/totalenergy/data/month/#electric>

12. J. R. Hofmann, A.-M. Ampère, *Enlightenment and Electrodynamics*, (Cambridge University Press, 1996)