EXPERT SYSTEM FOR DESIGN OFF-GRID RENEWABLE ENERGY SOURCES

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Abstract

The paper is treated with issues of design kits renewable electricity using computer-aided-based expert computer system. The expert system was designed and implemented as a special problem-oriented computer program that enables designers to optimize the functional and performance parameters island (Off-Grid) power sources with maximum use of existing local potential of renewable energy resources. Philosophy expert system is based on a comprehensive approach to solving the problems of specification power demand, through the choice of particular energy facilities with optimum performance dimension, the optimal design of battery power and the optimal design of the entire system. Expert system contains a database of available solar and wind sources of electric power, standby generators, batteries and inverters for automatic optimization proposal system. Timetable commissioning of electrical loads is optimized by genetic algorithm.

Keywords: expert system, computer support, renewable energy, island systems, genetic algorithm

1 Introduction

Expert systems are computer artificial intelligence tools designed to facilitate the decision-making process to solve complex tasks for which it is necessary to make the optimal choice of specific means and methods used. History of expert systems dates back to the 40 years of the last century. The increased interest in similar applications is dating back to the end of 60 years, and thus linked with the beginning of intensive development of computer technology. Currently, there are universal expert system based on the "if - then" rules [1, 2, 3, 4], which are suitable for solving the tasks requiring a fast decision of the large amount of data. In solving problems of a technical nature have universal expert systems limited use, because in addition to the process of selecting the optimal system components are required to be functional interaction and often even considering stochastic input conditions. The solution is problem-oriented expert system with problem-specific databases and modified algorithms decision arising from the nature of the problems. Examples could be expert systems for various different applications, for the analysis of time sequence [5], statistical analysis [6], the analysis of sediment rocks [7], mapping of countries [8], failure analysis [9, 10] etc.

Expert system application is a computer program that contains the following modules:

- user interface - sphere of application
- The data structure containing the knowledge of the subject area
- database describing the behavior of the components of the subject area
- inference machine comprising a knowledge of the reciprocity of data structures and
- system enabling the analysis of the results and interpretation of their impact on solving the problem.

The proposed computer expert system for renewable energy sources is a means of optimizing the proposal Off-Grid (off the electrical grid) energy-based analysis of the specific local conditions for obtaining energy with maximum economic effect. Philosophy of expert system is based on a comprehensive approach to solving the problems of specification power demand, through the choice of particular energy facilities with optimum performance dimension, the optimal design of battery power and the optimal design of the entire system [11].

For specific applications of renewable energy sources (RES) is always required economic optimization. On the one hand, the requirements envisaged applications and other economic demands and return on invested funds, especially when there are conventional alternatives. The assessments of all technical and economic aspects are useful when designing have available computer tools for functional simulation of the proposed system.

The simulation program must take into account the high variability of input requirements relating to future applications must be able to absorb information about local conditions and have implemented the optimal models of functional blocks. The result of the simulation process the data for optimal sizing of the energy sources used at an acceptable economic performance of the entire application.

Expert system is programmed in the integrated development environment (IDE) C ++ Builder with enjoyment BDE (Borland Database Engine) with dBase database files. The advantage of this IDE is that the developed application can be run under different operating systems on different computing devices (PCs, tablets, mobile phones). The application includes different forms with many tabs for various calculations, several interactive database tables, and the main context menu, quick and standard buttons, a lot of statements, help and languages.

2 Typical configuration OFF-GRID systems of renewable energy

Configure systems of renewable electricity depends on the type of renewable energy and local conditions for their use. In our conditions, as a source of energy use:

- solar energy using photovoltaic panels
- wind energy using wind turbines
- local hydropower in the flow, or the accumulation mode and
- geothermal energy.

Hydroelectric and geothermal energy sources are local and capacity limited and therefore for unrestricted use is only suitable solar or wind energy. The problem is the stochastic nature of their performance, which requires that every system of renewable energy sources must be supplemented by means of energy storage, as well as alternative sources for time alignment and capacity of production and consumption.

A typical system of RES in the starting line-up includes four basic blocks:

- sources of electrical energy
- battery power
- energy converter with a control of electronic system and
- power loads.

All units are connected via a bus system, which is structured to the power and signal part. Power section is designed for the transmission of energy with minimal losses [12]. The system RES can be solved with one power bus and operating voltage by the electrical appliance, or as two buses, wherein the portion of the source voltage is matched to the battery power (DC voltage 12, 24, 48 V) appliances and second bus voltage is adapted to the normal grid voltage (AC 230V and 50Hz). The signal bus is intended for data collection and management activities of all elements of the system. The criterion for the optimal function is the balance of power sources and power consumption. The system has also external communication with superior computer, which can do functionally configure the system, monitor its operation and diagnose its functionality. The block scheme of the system with one power bus B is illustrated in Fig. 1a. SB is a signal bus divorced in all functional units. The condition for the operation of such a system is equipped with all sources and possibly appliances energy converters enabling conversion of electrical energy to and from a common power bus. Advantage of one bus RES is a simple modification kit system, the disadvantage is the higher cost and complicated management of energy flow and energy storage. Two buses RES configuration is shown in Fig. 1b.

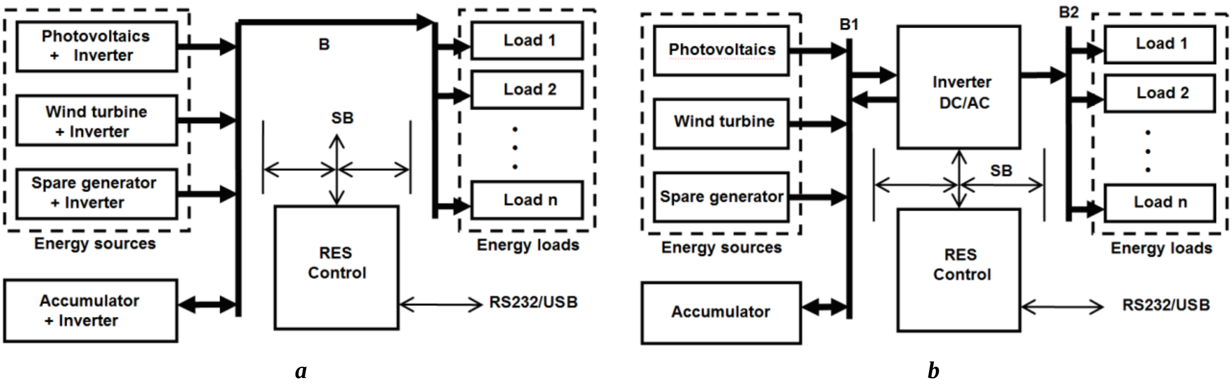


Fig. 1. Example of block structure with one bus (a) and two buses (b) of the RES.

3 Description of the RES expert system

The proposed expert system includes software tools comprising:

- the library databases available equipments for obtaining energy from renewable sources,
- forms for entering input and output parameters of application,

• the means for specifying local conditions, features RES
• the simulation tool for analyzes of RES system properties
• evaluation instruments for optimizing future applications.

Application software expert system is divided into several modules:
• an interactive module for specifying input parameters
• the selection of functional blocks source of supply in the library databases
• simulation module
• optimization module
• the module of strategy evaluation for the optimal system design.

An example of the assembly of the main window expert system RES is shown in Fig. 2. Currently, the system is equipped with a trilingual description (Slovak, Czech and English) and is open to any number of other languages. Multilingualism also applies to database structures, because all original database files are created in Microsoft Excel and can be immediately updated directly by the user of an expert system.

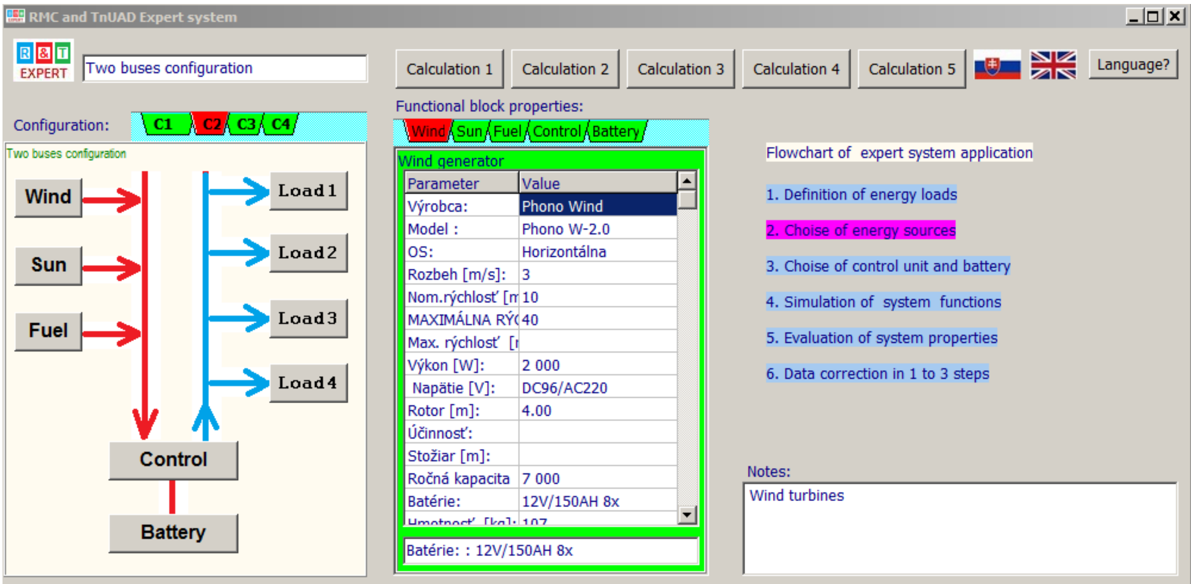


Fig. 2. The main window of expert system RES.

3.1. Interactive module for insertion of input parameters

The module allows adding a set of projected energy appliances, the electric power consumption and timing of their actions. Individual parameters can be entered interactively direct by completing the form input data (Fig. 3) or loading from initialization text file. The initialization file can be written in a text editor (Notepad, Wordpad). Edited form data can be saved to a new file for future use. The initialization file can contain data for up to 100 appliances. Data format initialization file is derived from the standard Windows initialization file type "*.ini". The day-long process of the necessary input and also energy consumption is shown graphically. Graphics are for changing the input data directly translated. The variability of energy consumption is achieved by loading different schemes appliances enrolled in various initialization files.

3.2 The module for selection of function blocks contained in the library databases

Program based on the given input conditions offers remaining energy sources and organize resources offered in order according to their suitability for the intended application. At the same time takes into account the estimated cost of the whole system.

The system includes the following databases:
• wind generators
• solar photovoltaic panels
• spare sources
• battery power
• drives and control system
• database characterizing properties of resources, according to their location

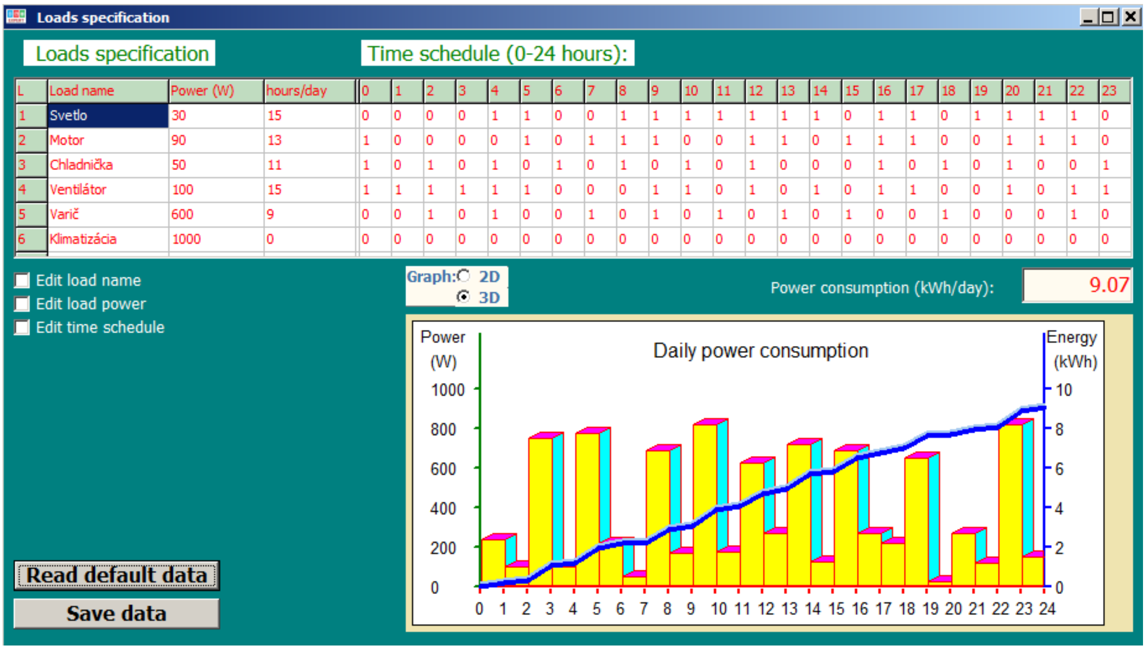
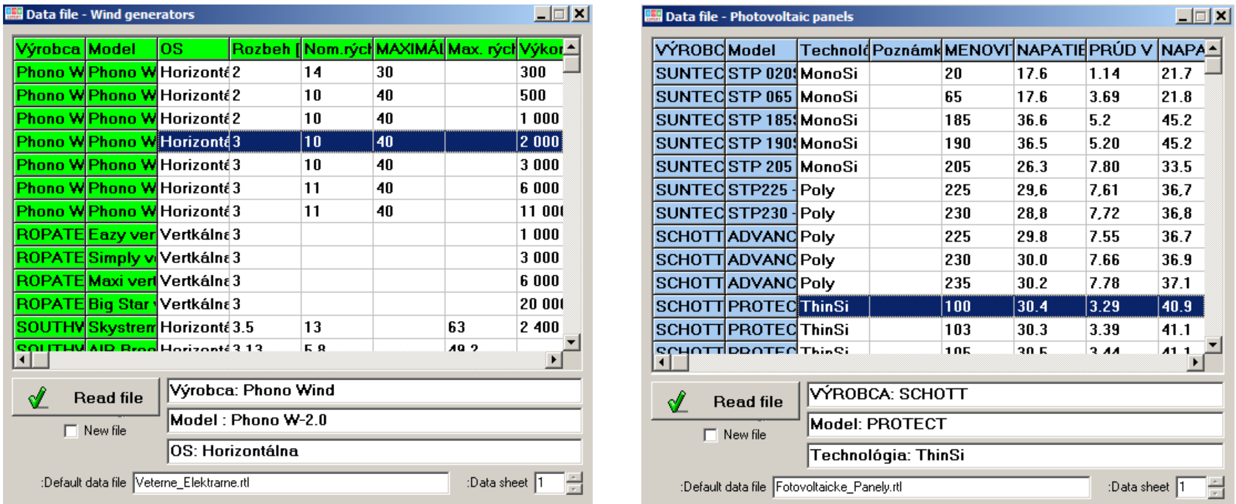


Fig. 3. Form for loads definition.

Database files are written in Microsoft Excel. Format of data sources is limited to a fixed structure of selected parameters. Examples windows database selection of energy sources are shown in Fig. 4. Data selected components of the system are written to the frame "Functional block properties " of main form (Fig. 2).



a ***b***

Fig. 4. An examples of database windows of energy sources; a) wind turbines, b) photovoltaic panels.

3.3 Using genetic algorithms to optimize the energy consumption

Genetic algorithms are numerical methods that use operations like selection, mating, and mutation to find optimal solutions in such tasks that cannot be described analytically (i.e., using derivatives of functions) or where it would be necessary to check on too many possibilities. Let such schedules be defined as *immediately neighboring* that differ only in one exchange of 1s or 0s only in one particular line of the schedules, e.g., a schedule 000011000000110000001100 of the centrifuge is changed to 000011000000110001001000 and the rest of all other lines of both neighboring schedules remain the same.

It is effective to combine the genetic algorithm with a local optimization when we are moving in the direction of the largest gradient of the decrease of quadratic deviation (QD) along such a trajectory, whose neighboring points are neighboring schedules. The original schedule is being replaced by the best schedule in its immediate vicinity until this optimization movement stops in the nearest local minimum. The first generation of schedules that satisfy conditions of their working regimes is generated with the help of a random number generator. This generation can comprise, e.g., 1000 or 1 000 000 random schedules, which are stored in a container ScheduleStash. The schedules are then sorted according to the fitness criterion, i.e., minimization of QD, and schedules with higher QD are discarded from the container (= selection). Schedules can be locally optimized before or after selection. Then every two selected schedules are connected by a random trajectory of schedules and, say, each fourth of them is locally optimized and inserted into the container (= mating). Finally, each schedule of the container randomly generates a number of trajectories starting from it and, say, every fourth schedule is locally optimized and inserted into the container (= mutation). If, say, five repetitions of a cycle of selection, mating, and mutation with a usage of local optimization does not bring a new schedule with a better fitness, the genetic algorithm stops and the best obtained solution is considered to be a global extreme.

3.4 Internet application components.

An important part of the expert system consists in application components using the Internet. Fig. 5 shows as an example the tab for the detection of local conditions for the utilization of solar panels. Over the map, you can select the location of the solar panels. On the right of the map, you can choose one of four subtabs: PV (photovoltaic) estimation, Monthly radiation, Daily radiation, and Stand-alone PV. These subtabs provide a lot of various technical parameters and computations for specified photovoltaic panels, e.g., their optimal vertical and inclined axes, PV and irradiation estimates, height of sun, etc. You can use them for the design of photovoltaic sources and their optimal utilization.

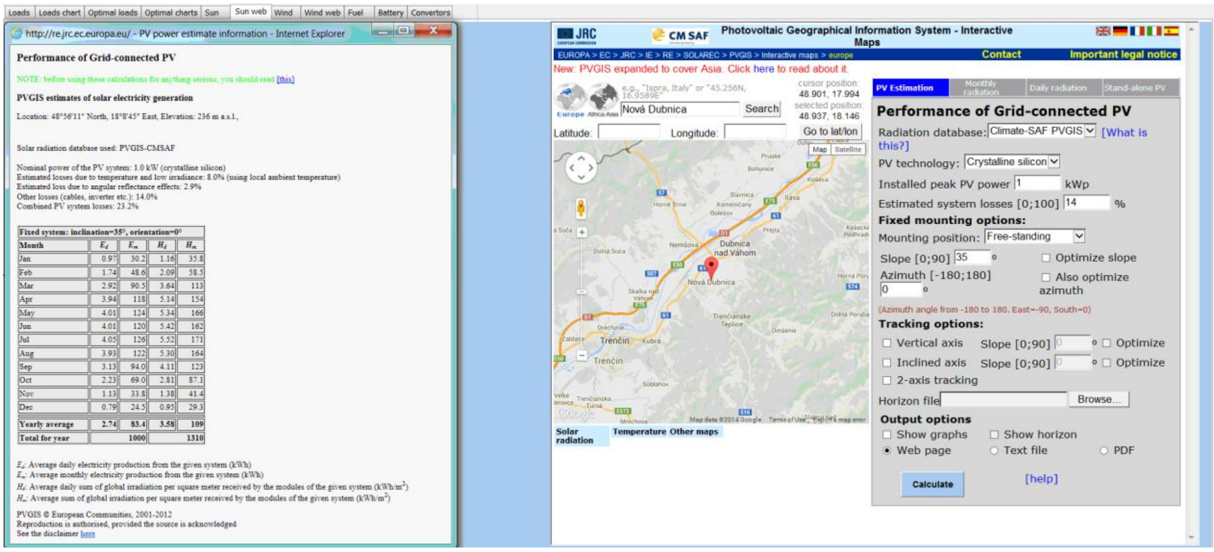


Fig. 5 An example of web components built into the expert system.

3.5 Simulation module

The simulation module allows verifying the functionality of the proposed system in an accelerated mode. In this simulation can detect critical conditions such as lack or excess energy. Based on simulation results, it is possible to correct the input data and a selection of elements in the system.

Simulation of the proposed renewable energy system is carried out using the form shown in Fig. 6. The data for the simulation consists of:

- configuration data of the appliances that are automatically downloaded from form of energy loads,
- data of energy resources that are loaded from the configuration file created at the choice of database files,
- the timing of power sources in three variants (maximum, minimum and random mode instantaneous power) and these data are read from a data file created by the application of local conditions for RES.

Simulation of system operation can be carried out in three modes, defined as the maximum, minimum and random, which correspond to the timing schedule of resources activity. Randomness is limited data on the availability of energy in that time period, for example, solar energy is available only in daylight hours and a limited period of time. The simulation process activity resources and appliances shall be carried out with 1 hour step. Instant power sources defined input data adapted from the initialization file as a percentage of the rated power of the relevant resource commitment to the current simulation run time. During the simulations, immediate information on the energy contribution of each energy source and further information about the cumulative delivered, consumed and stored energy are reported. The remaining battery power is controlled by activation of backup resources at capacity drop below a defined level. After charging the battery at the desired level, the back-up power off. Similarly, overloading the capacity of the battery is connected security burden, which again turns off after a drop of stored energy is below a defined level.

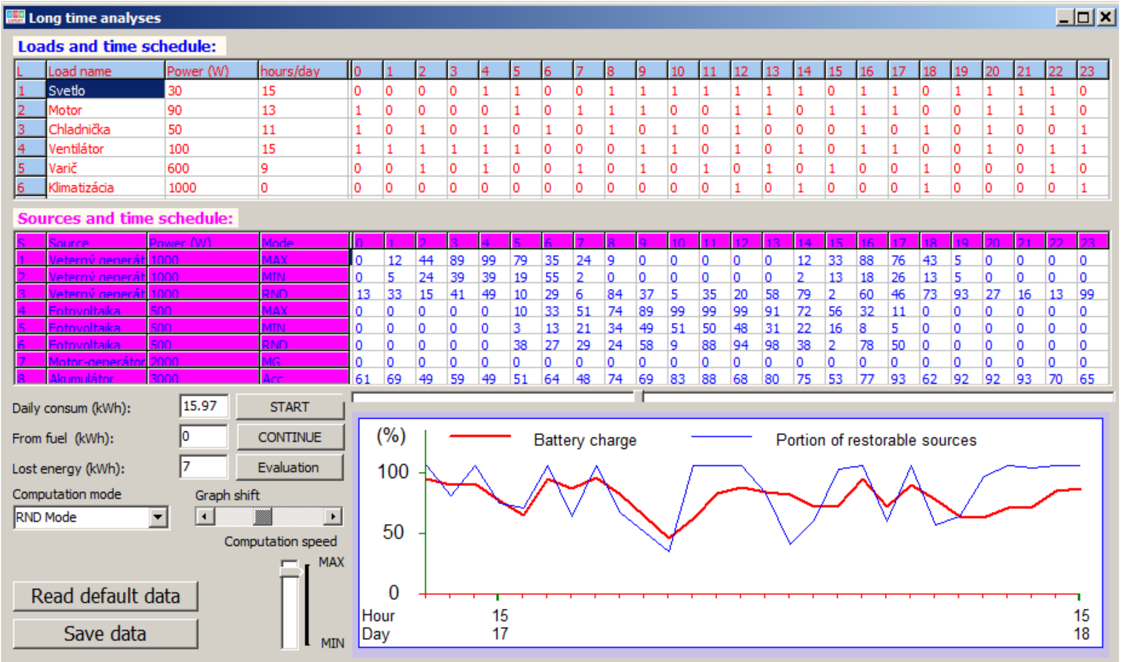


Fig. 6. Simulation form.

During the simulation, battery energy capacity is monitored and under its value is controlled switching of loads and energy sources. There are distinguishable 5 levels of energy (the absolute minimum, working minimum, the optimum operating level, working maximum and absolute maximum), 3 categories of appliances (priority, normal and emergency) and two categories of energy sources (RES and spare). Decision-making algorithm code fragment in C++ is given below:

```
bool PriorLoad, NormalLoad, EmergencyLoad; // energy loads
bool RESource, SubstSource; // energy sources
double AbsMinChLevel, MinChLevel, MidleChLevel, MaxChlevel, AbsMaxChLevel; //  defined charge levels
double AccChLevel;    // actual accumulator charge level
{   // control of energy loads
if (AccChLevel<AbsMinChLevel)
        {PriorLoad=FALSE; NormalLoad=FALSE; EmergencyLoad=FALSE};
if ((AccChLevel>AbsMinChLevel) && (AccChLevel<=MinChLevel))
        {PriorLoad=TRUE; NormalLoad=FALSE; EmergencyLoad=FALSE;}
if ((AccChLevel>MinChLevel) && (AccChLevel<=MaxChLevel))
        {PriorLoad=TRUE; NormalLoad=TRUE; EmergencyLoad=FALSE;}
if ((AccChLevel>MaxChLevel) && (AccChLevel<=AbsMaxChLevel))
        {PriorLoad=TRUE; NormalLoad=TRUE; EmergencyLoad=TRUE;}
   // control of energy sources
if (AccChLevel<AbsMaxChLevel)
         {RESource= TRUE;} else {RESource= FALSE;}
if ((AccChLevel>MinChLevel) && (AccChLevel<MidleChLevel)
         {SubstSource= TRUE;} else {SubstSource= FALSE;}
}
```

3.6 Optimization module

Optimization module is directly attached to the simulation module and allows the user to influence the selection of modules and resources of the system and also to make recommendations on the action in the optimization. The simulation process in addition to monitoring the quantity supplied and consumed energy monitors the amount of stored energy. Based on the condition of stored energy and the forecast in the supply and consumption of energy, alternative energy source as security appliance is regulated. After the suspension of the simulation can be activated evaluation of results. As part of the assessment program, the recommendations for modifying the system based on the optimal use of energy resources in defined configurations appliances energy are attached. An example of window for the evaluation of the simulation process is shown in Fig. 6. Based on the recommendations of the assessment process, it is necessary to make changes to the selection of system components. Then repeat the simulation activities RES recalculated performance parameters of the system. Finally, it is possible to generate an archive file reflecting the new selection of elements in the system for future use.

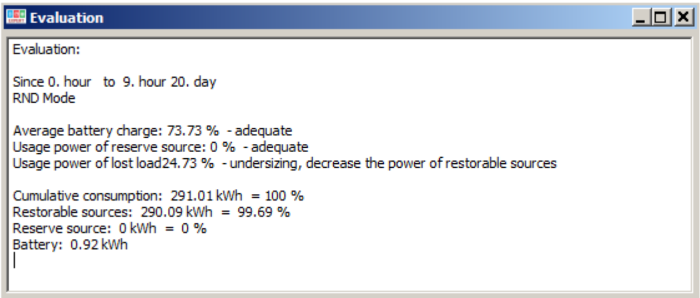


Fig. 7. Evaluation form.

4 Conclusion

The proposed expert system allows obtain the data necessary for the optimal design of the kit Off-Grid source of electrical power. The main problem that particularly affects the economics of the application is the optimal dimension of renewable energy sources in the context of local conditions to obtain sufficient energy. Linked to this is also a dimension of the accumulator and a backup power source, to meet the requirements for energy consumption. In light of the large variability in the definition of input parameters via text initialization files available to the user virtually unlimited possibilities in a variation of the configuration of resources and the variability functions appliances. This gives the opportunity for a detailed analysis of the characteristics of the proposed system in order to minimize the cost of the energy obtained in real installed power supply. The proposed expert system is currently in the validation stage of its properties. The results of simulation procedures are the source for the improvement of adding features and also optimizing its operational modes.

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