Software System for Simulation of Electric Power Processes in Photovoltaic-Hybrid System

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Abstract: *The software system for modeling and simulation of the processes of electric power conversion in Photovoltaic-hybrid energy system is described. The electrical models and characteristics of photovoltaic generator and other system components are included in the program algorithm. The application of the developed system is for research of the processes of electricity supply and is intended for agricultural farms. It can be utilized in designing of the real farms as well as in the process of students' education.*
Key words: *Programme models, PV-hybrid system, Electric Power Simulation*

INTRODUCTION

In the last years the application of renewable energy sources (RES) in electricity supply systems rapidly increase. The limited resources and high cost of conventional energy sources (oil, gas, coal), as well as the continued environmental pollution are some of the main reasons for their widespread introduction in electrical power systems. Development and usage of these alternative energy technologies are still restricted in Bulgaria. Software products (such as HOMER, PVSYST), using for projecting and research of alternative energy systems in our country are usually developed by European or American research centers or products supplying companies. The need for specific software product for projecting, analysis and simulation of electric power processes in technological buildings with specific electrical control exists. The electrical power supply in them is divided into conventional and alternative energy supply. This paper presents continuation of development of the software system for estimation of alternative energy sources (solar and wind energy) potential for the geographical region of Rousse and their utilization in photovoltaic-hybrid electric power system.

LAYOUT

The aim of present research is developing a software system for projecting, analisys and simulation of electric power processes in an investigated agricultural farm, utilizing the alternative energy sources for energy supply of some technological processes.

The following problems are have been solved:

- Choosing an appropriate electrical model and its usage in model implementation of designed photovoltaic-hybrid (PV-hybrid) system. Developing a suitable energy analysis and electric power balance;
- Developing a programme for software design of PV-hybrid system, as well as for energy analysis and simulation of electric power processes based on the selected energy model;
- Testing a software system and proving the usability of implemented algorithm for design and electrical analysis of PV-hybrid system in agricultural farm in Rousse.

o Selecting a photovoltaic system's model. Implementing an algorithm for design and energetic analysis of PV-hybrid system for electric power supply in poultry farm, located near by Rousse.

A PV-hybrid system for solar and wind energy utilization is needed. The system provides energy for electric loads, using two types of energy sources: alternative (solar energy, wind energy) and conventional (diesel generator, public power supply network). In difference with autonomous PV system, counting on solar energy, PV-hybrid system provides uninterrupted power supply, because it uses simultaneously alternative and back-up conventional energies.

A great variety of mathematical models, describing electric efficiencies of PV modules and other system components, exist.

Analytical procedures for characterizing the electrical performance of photovoltaic modules and arrays are described by D. King in the paper "Photovoltaic module and array performance characterization methods for all system operating conditions". Presented analytical procedures and performance model are results of over 15 years of experience in outdoor testing conditions, which are implemented by Sandia National Laboratories [1]. The methods allow predicting of energy efficiency of PV array. They describe the influences of solar irradiance, operating temperature, solar spectrum, solar angle-of-incidence and temperature coefficients over electrical parameters of the array. A model allows hourly simulation of electric processes in PV generator by means of using a database of basic climate parameters.

Main drawback of the electrical model, given by D. King is a need of initial testing in real operating conditions of the following PV module parameters – short-circuit current Isc, maximum-power current Imp, open-circuit voltage Uoc, maximum-power voltage Ump. Therefore the analytical procedures are suitable for performance analysis and tests of already installed PV-hybrid system at specific climatic conditions. A model doesn't fit the objects of present research, which are preliminary sizing, design of such system and simulation of energy processes.

A new model for design and electric efficiency estimation of autonomous PV electric system is developed by Prof. Andreas Wagner, a lecturer from Fachhochschule Dormund in Germany. The proposed method for design is based on statistic data of solar radiation for a given geographic region. It guarantees that 90% of electric power supply can be provided by solar energy and the other 10% are covered by wind energy or uninterrupted energy source. Each PV system component (PV module, charge regulator, battery inverter) is represented with electrical model, that describes the electric efficiency and energy losses [2].

A mathematical model of PV generator, created by Prof. Wagner, defines precisely PV module efficiency and performance characteristics, which are influenced by the air temperature and solar radiation intensity. A model doesn't require any preliminary measurements of selected module parameters. It considers a climate influences in the geographic location of a PV system installation, as well as electrical performances of system components. Before starting with PV system design and energy analysis, the input statistical data for daily amount of solar radiation, installed electrical capacities of consumers and electrical specifications of all system components are needed.

Developed algorithm for design and analysis of a PV-hybrid electrical system for additional power supply of examined farm is based on the analytical methods of Prof. Wagner. They sufficiently match the aims of present research and gives precise results in the process of design and electrical performance analysis.

Electric power, produced in PV generator, flows trough the electrical circuit of system components, which take a part in the processes of power accumulation, system defense against electric shortages and harmonization of electric performances. Each component has energy losses in a real operating conditions, that are well described with its energy efficiency parameter [2] (Fig.1).

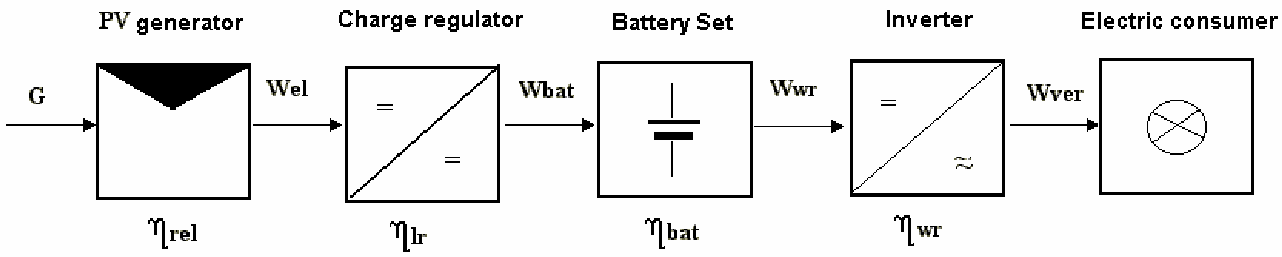

Fig.1 Energy flow in autonomous PV system

The certain aim of PV system sizing is covering the average daily energy W_{ver}, used by electric consumers. Consequently a necessary peak power P_{pk} can be expressed by the following equations:

$$P_{pk} = 1{,}2\frac{kW}{m^2} * \frac{W_{ver}}{\overline{G} * \eta_a * \eta_{lr} * \eta_{bat} * \eta_{wr}} \quad \text{or} \quad P_{pk} = 1{,}2\frac{kW}{m^2} * \frac{W_{ver}}{\overline{G} * \prod \eta_i}, \qquad (1)$$

where $\overline{G}$ is statistical estimation of solar irradiance, kW/m^2,

η_a – effectiveness of compatibility of PV module and accumulator operating performances,

η_{lr}, η_{bat}, η_{wr} – coefficients of electrical performances of the following components – charge regulator, battery, inverter.

Statistical estimation mathematical expectation of daily amount of global solar irradiance is derived trough the following dependence:

$$\overline{G} = \frac{1}{n}\sum_{i=1}^{n} G_i \quad , \qquad (2)$$

where n is a number of days in the year,

G_i - daily sum of solar radiation, kW/m^2

In case of no complicated battery charging regulation (MPPT-maximum power point tracking), considering electrical losses of incomplete compatibility of Volt-Ampere characteristics of PV module and directly connected battery, coefficient η_a is used:

$$\eta_a(U) = \frac{P(U)}{P_{p\max}} \quad , \qquad (3)$$

where P(U) is produced electric power, reaching the battery, Wh,

P_{pmax} – maximum electric power, delivered from PV module at MPP of its operating performance, Wh

Electric efficiencies of the regulator η_{lr}, the battery η_{bat} and inverter η_{wr} are expressed through the equivalent power losses of respective system component P_{eq}, which can be compensated by increasing an installed power of photovoltaic P_{pk}.

The following equation is referred to the electric efficiency of charge regulator :

$$P_{eq} = P_{pk} * \frac{U_D}{U_N + U_D} + 1{,}2\frac{kW}{m^2} * \frac{24h * U_N}{G_{\dim}} * (0{,}9 * I_{ev0} + 0{,}1 * I_{ev1}), \qquad (4)$$

where U_D is a voltage of blocking diod, V,

U_N – nominal battery voltage, V

I_{ev0}, I_{ev1} – current consumption of a regulator during normal and intensive operating mode, mA,

G_{dim} – dimensional value of solar irradiance intensity, kW/m^2.

The electric losses of inverter for an interval of twenty-four hours are expressed by:

$$P_{eq} = 1{,}2\frac{kW}{m^2} * \frac{24h * P_{ev} + k * W_{ver}}{G_{\dim} * \eta_{lr} * \eta_{bat}} \quad , \qquad (5)$$

where Pev is an energy consumption of inverter, Wh,

k – factor of the electric losses of inverter during electricity conduction process.

For the purpose of simplifying an algorithm of energy analysis and design of PV-hybrid system during charging and discharging cycle of battery, only coulombic efficiency is considered in the global battery energy performance : η_{bat} = 0,97.

The methods for produced PV power estimation, proposed by Prof. Wagner, are grounded on numerous experiments. As a result of the implemented experiments the empirical relations for estimation of electric parameters of photovoltaic modules of Si type are derived. For calculation of maximum possible electric power $P_{max}(E,T)$, delivered from

PV generator, and its relative efficiency η_{rel} only data for solar irradiance and air temperature are needed.

$$P_{max}(E,T_j) = P_{pk} * \frac{\eta(E,T_{j0})}{\eta_0} * \frac{E}{E_0} * (1 + c_T * (T_j - T_{j0})), \quad (6)$$

where E_0, T_{j0}, η_0 are solar radiation, module temperature and module efficiency at STC (standard testing conditions),

E, T_j - solar radiation and module operating temperature at different operating conditions,

c_T – coefficient of PV cell of Si type, depends on the PV power and module temperature, K^{-1}.

$$\eta_{rel} = (1 + c_T * (T_j - T_{j0})) * (1 + k_1 * \ln(\frac{E}{E_0}) - k_2 * (\frac{E}{E_0} - 1)), \quad (7)$$

where k1, k2 are factors of the equation.

During a PV-hybrid system sizing procedure a factor of system autonomy A is calculated. Factor A defines the number of days, in which electric power supply to the consumers is provided only by initially full charged battery set. A needed battery capacity C_N, that provides A days autonomously operating of the system, is expressed by the formula:

$$C_N = \frac{A * W_{ver}}{U_N}, \quad (8)$$

In the last phase of autonomous PV system sizing Prof. Wagner defines a parameter of system availability and reliability *a*. It determines the period of electric power supply of consumers from alternative energy sources without a need of providing complementary conventional energy (public electric network, diesel generator). In the developed algorithm a last phase is omitted, because of a combination of alternative and conventional energy supply.

The analytical methods, developed by Prof. Wagner, are implemented in the algorithm for design and electric analysis of PV-hybrid system, considering electrical loads in the examined poultry farm. The aim of the research is estimation of generated electric power from PV-hybrid system in depends on the climate parameters of the region. For this reason the produced energy, flowing through the system components is software modeled at intervals of 1 hour. The algorithm for simulation of battery charging and discharging processes is developed. It is based on the analytical dependences, which are derived trough the approximation of graphical, electric performances of a battery during charging and discharging cycles. The battery voltage, current and state of charge (SOC) parameters can be also observed. By means of them the control of energy flow from photovoltaic and wind turbine generator during the process of battery charging is possible. This type of control is beneficial in case of insufficiency of solar or wind alternative energy. In periods with limited amount of the alternative energy consumers are provided with electric power from the battery or public electric network.

- Explanation of the program modules in developed software system RESs v.1, based on the above described algorithm

For the development of the software system RESs v.1 the product Borland Delphi 6.0 is used [3]. A local database of type Paradox is created. A common access layer BDE (Borland Database Engine), which is supported by Delphi 6, provides communication between the records of local database and a program interface. The main advantage of the BDE is the fact that all of the data manipulation is considered "transparent" to the developer. The BDE API (Application Programming Interface) consists of more than 200 procedures and functions, which are available through the BDE unit. The developed program is for local use and it uses single-tired database. A single-tired database is a database in which any changes, such as editing the data, inserting records or deleting records happen immediately. A main drawback of single-tired database is that it is limited in how much data the tables can hold and the number of users the application can support. The amount of stored information in one Paradox table is 2 Billion Bytes. Also the number of stored records in one file is 2 Billion and the limitation for a number of fields is 255.

- A program modul 'FormConsumer' for selection the type of consumers, electrically supplied by the PV-hybrid system and for analysis of daily and yearly electrical loads.

Considering what kind of building have to be electrically supplied, the user has to choose a number and types of electric consumers – industrial or home electric equipment. The hourly energy consumption during twenty-four hours and by months can be analyzed. An electric specifications of consumers are kept as records of a database table Consumers.db. A program allows recording into database a different types of consumers or changing the parameters of existing.

A window of program module 'FormConsumer' is represented on Figure 2. On Figure 3 is given a window with tabular and graphical visualization of twenty-four hours electric power consumption by months, which depends on the selected electric equipment.

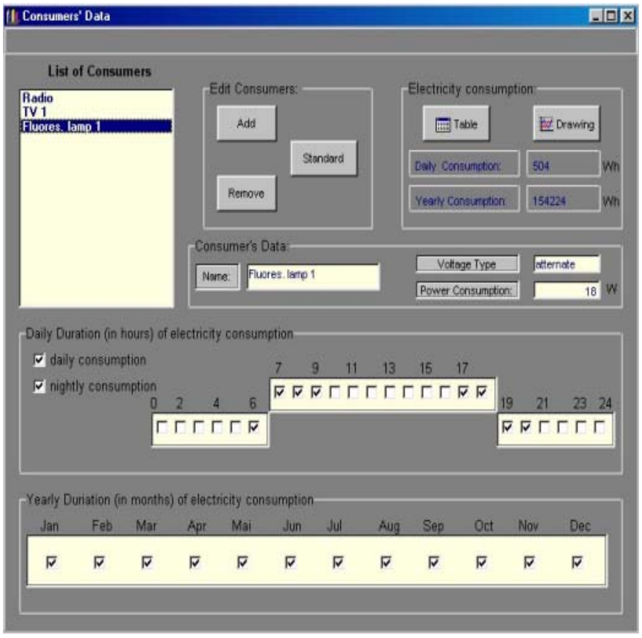

Fig.2 Snapshot of a program module FormConsumer for selection the electric equipment and its specifications

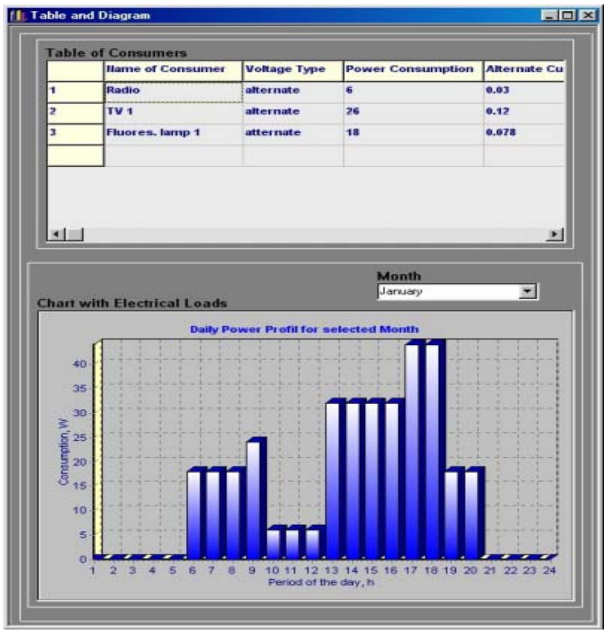

Fig.3 Snapshot of a window with tabular and graphical visualization of electric power consumption

- A program module 'PVSystem' for design and energy analysis of PV-hybrid system, based on the developed algorithm.

After the selection of consumers the user can continue with a phase of design and energy analysis of PV-hybrid system. A program proposes 'Presizing Help' to the user, guiding him during the design and energy analysis of a system. On the base of the data for daily electric consumption, statistical estimation of solar radiation and desired system autonomy, the needed PV installed power and battery capacity are calculated in the 'Presizing Help'. The user has to go through a 3 TabSheet components of a Form, when he starts with a design of a PV-hybrid system. During design process he is guided by helping messages about needed parameters of selected components or in case of incompatibility of their performances. In TabSheet1, that is named 'Solar Generator', the user has to choose a type of PV module and a number of parallel and series switched modules in a PV array. First the year with its typical climate parameters must be selected.

In a component TDBChart are graphically represented the following climate parameters, which are calculated in the other program modules – solar radiation, air temperature and wind velocity. The data are given at interval of one hour for each day of the selected year. A final result is calculation of produced photovoltaic energy from a PV generator at a given climate conditions and their graphical visualization (Fig.4).

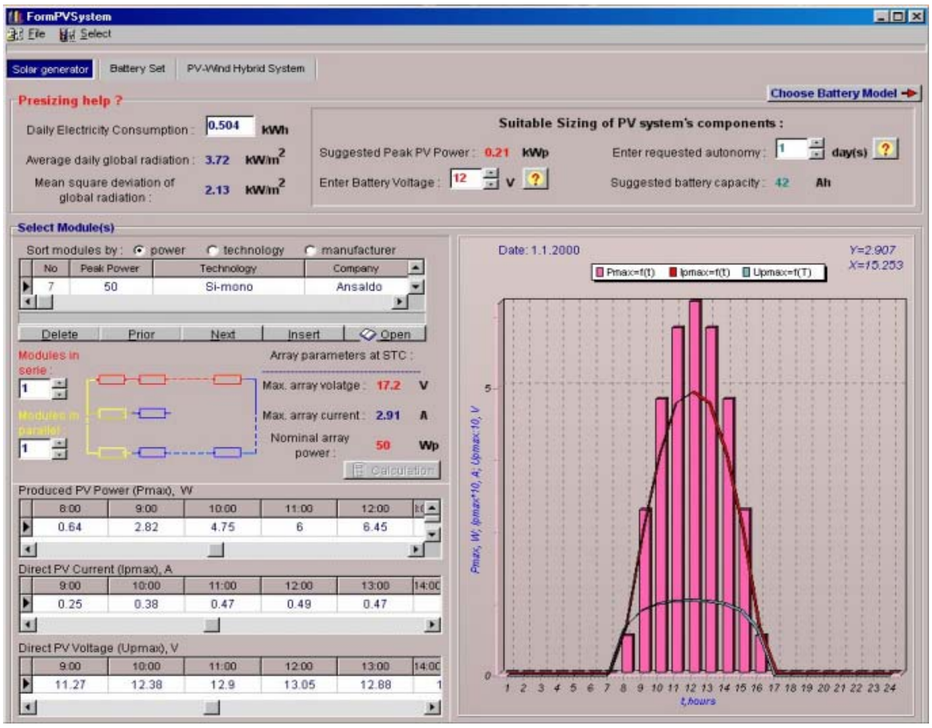

Fig.4 Snapshot of a program component TabSheet1 for software simulation of produced power from PV generator

In a program component TabSheet2 the user selects a battery type and a number of parallel and series connected battery components in one Battery Set. He also has to choose the initial battery parameters - Initial State of Charge (SOC) and Battery Depth of Discharge (DOD). In the two TDBChart components are graphically represented the hourly values of battery voltage and SOC for each day of the selected year. Before starting with a software simulation of electric charging and discharging processes the user has to go through a TabSheet3 program component, which is named 'PV-Wind Hybrid System'. It contains tables with variety models of charge regulators and inverters, accompanied by a scheme with a main electric components of a PV-hybrid system (Fig.5). After the selection of suitable charge regulator and inverter, using a button 'Back to Battery Model' a designer can return to a TabSheet2, where the simulated hourly data of battery SOC and voltage for a given day are represented (Fig.6). The full specifications of system components, which are given by the manufacturers are kept in the following database tables – PVModuleCatalog.db (for photovoltaic generators), BatteryCatalog.db (for batteries), RegulatorCatalog.db (for charge regulators), InverterCatalog.db (for inverters).

The efficiency of software system is verified with the following testing example. The power supply of home electric equipment, such as Radio, TV set and fluorescent lamp is chosen. A total installed electric power is 50 W. The user, assisted by a 'Presizing Help', selected the following electric components of a PV-hybrid system: one mono-Si photovoltaic module 'Ansaldo' with a nominal power 50 W, two series connected batteries 'Oerlikon' with total voltage 12 V and capacity 100 Ah, one charge regulator Isoler for charge control of 12 V battery and inverter with nominal power 150 W, offered by a manufacturer 'Rosendahl Energietechnik'. On the base of specifications of the selected components a program provides hourly simulation of battery voltage and state of charge, which are shown on the two charts of Fig.5.

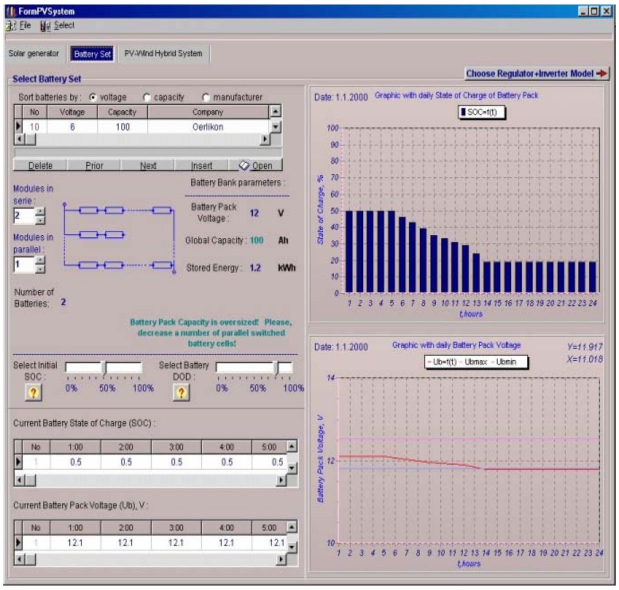

Fig.5 Snapshot of a program component TabSheet2 for simulation of electric processes in a battery

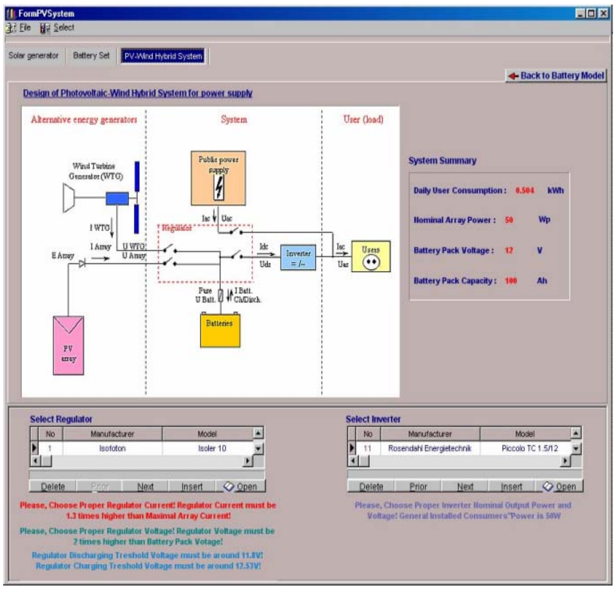

Fig.6 Snapshot of a program component TabSheet3 for selection of system components of a PV-hybrid system

CONCLUSIONS AND FUTURE WORK

The next step of software system development is considering a wind-turbine generator and conventional energy supply (public supply network) in the energy analysis of a PV-hybrid system in case of alternative energy shortages. A software module for statistical analysis and simulation of electrical consumption in a studied poultry farm is needed.

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