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SMALL PHOTOVOLTAIC POWER PLANT - MODEL, SIMULATION AND CONSUMPTION OPTIMIZATION

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Abstract: *The article deals with the possibilities of modeling and simulation of small photovoltaic power plant for off-grid houses. The article describes the optimizing methodology of photovoltaic system in terms of its design and power control appliances during the reference periods of the year. Described optimization methods - genetic algorithm - has been applied to a case study - finding an optimal control of appliance most affecting battery load of off-grid house. Optimization could reduce the required battery capacity up to 15%.*

Keywords: *photovotaic effectivness, optimization, off-grid houses*

1. Introduction

Life without electricity in "civilized" countries is almost unimaginable. In addition to the conventional energy sources are various alternative methods of electricity generation quickly developing. They often replace and reduce the use of fossil fuels (non-renewable) and they are in terms of ecology and the environment a huge step forward. Among one of the most significant alternative energy sources belong the energy production from the Sun, because the Sun is essential for the world and the most important source of all energy.

The consequences of maximizing profits and excessive efforts of increasing of living comfort as a creed and meaning of human existence are transferred to irrational wasting of energy. Wasting of energy and resources are biggest in places where are the resources are not so limited. In the case of off-grid house (house powered only by own sources) is energy wasting quickly revealed and eliminated, because is possible to spend just as much energy as we have available (this limitation does not exist in classic houses connected to the electric grid, which can provide “unlimited amount of energy”). In case when the photovoltaic power plant is main (or sole) energy source, the "intelligent" use of energy plays a very important role.

2. Photovoltaic power plant in off-grid houses

"Photovoltaic off-grid house" thus uses electricity gained only from system photovoltaic power plant – photovoltaic system (PVS) (including photovoltaic panels, batteries, controllers, etc.). Electricity is either directly spending or storing in batteries. Common sense says that if you move, as many activities associated with the spending power to the time when the sun is shining (PVS produces electricity) the less energy we have to save in batteries. This “consumption transfer” can reduce the required bat-

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tery capacity and subsequently the cost of investment. [1]
The model and simulation of photovoltaic system (photovoltaic panels, battery, etc.) is very helpful in order of consumption, charging progress optimization and in proposal process of important energy consumption scenarios – "intelligent consumption transfers of appliances". Calibrated model can predict various boundary situations (fully discharge, excess of energy etc.), which results can be used in proposal task of PVS.

3. Model of photovoltaic system

For the purposes of off-grid house is necessary to create a model of complete photovoltaic system. This model is created in Simulink (Matlab) and contains three basic elements: model of photovoltaic panel, model of battery and charge controller.

3.1. Model of photovoltaic cell

The simulation model of photovoltaic cell (PVC) is composed of several subsystems. We based PVC on the model of parallel connections diode and resistor (for model simplification), whereas PVC is also a semiconductor element and its current characteristics and behavior based on the same theory [2].

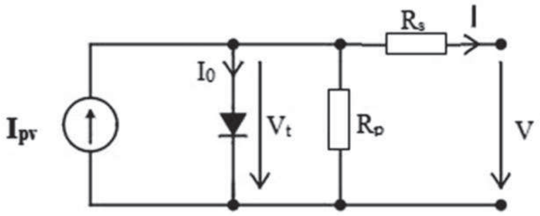

Fig.1. Schematic representation of the photovoltaic cell element

Model is based on equations for semiconductor transition adjusted for the photovoltaic element. Output current corresponds to:

$$I = I_{pv} - I_0\left[\exp\left(\frac{V + R_s I}{V_t A}\right) - 1\right] - \frac{V + R_s I}{R_p} \tag{1}$$

Where I_{pv} the photoelectric current [A], I_0 is the saturation current [A], V_t is the voltage PN junction [V], V is the output voltage of cell [V], R_s is the internal (serial) cell resistance [Ω], R_p is shunt resistor resistance [Ω], A is diode quality factor $A \in (1,2)$.
Voltage of PN junctions can be determined from the equation:

$$V_t = kT / q, \qquad 2)$$

where k is the Boltzmann constant [J/K], T is the temperature [K], q is the electron charge [C].
Saturation current is defined by the equation:

$$I_0 = \frac{I_{scn} + K_i(T - T_n)}{\exp(V_{ocn} + K_i(T - T_n) / AV_t) - 1}, \tag{3}$$

where V_{ocn} is nominal circuit voltage (no load) [V], I_{scn} the nominal short-circuit current [A], K_i is the temperature coefficient [A/K], T is the temperature [°C], T_n is the nominal temperature [°C] ($T_n = 25$).
The photovoltaic current is based on the equation:

$$I_{pv} = \frac{G}{G_n}\left[I_{scn} + K_i(T - T_n)\right], \tag{4}$$

where G is the intensity of solar radiation [W/m2] G ∈ (10 ; 1000), G_n is the nominal intensity of solar radiation [W/m2] ($G_n = 1000$), I_{scn} is the nominal short-circuit current [A], K_i is the temperature coefficient [A/K], T is the temperature [°C], and T_n is the nominal temperature [°C]
From the previous equations a parametric model of photovoltaic cell was built (Fig.2). That is a separate block ("Solar Panel" - Fig.5) with three inputs (external temperature, radiation intensity, cell voltage) and one output (current).

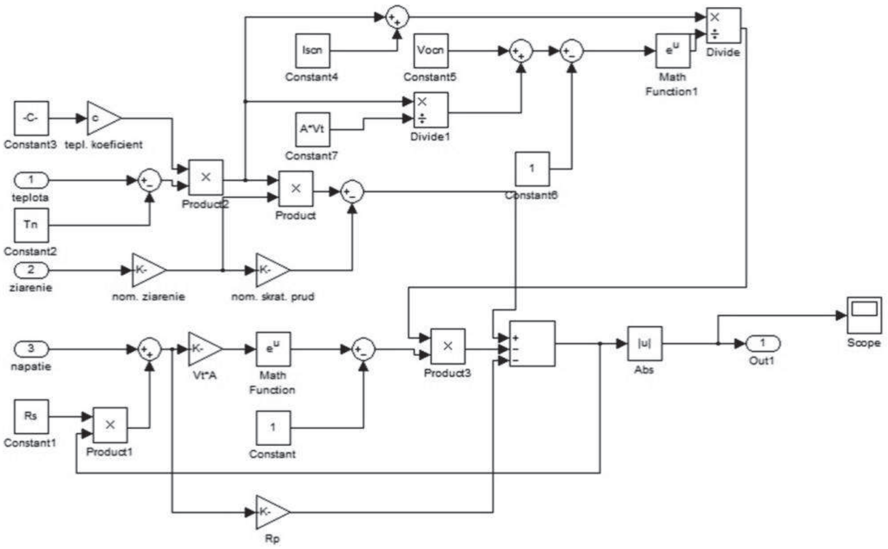

Fig.2. Model of photovoltaic cell (Simulink - Matlab)

3.2. Model of battery

Another building block of PV systems is the battery. Battery is charged during the day and it afford current when is needed. Energy is stored chemically in the form of electrical charge. For battery model can be used differential equation describing the electric current as a change of electric charge for time *t*:

$$I = \frac{dQ}{dt}, \tag{5}$$

where I is the current entering into the battery [A], Q is the el. charge which the battery is able to hold, that is, its capacity [Ah], t is the time [h]. Modifying equation (5) we obtain an equation for the model of battery.

$$Q = \int I dt \tag{6}$$

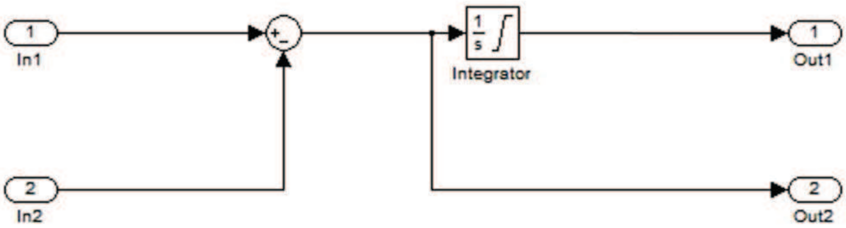

Fig.3. Model of Battery (Simulink - Matlab)

3.3. Charge controller

Charge controller was implemented as a simple PID controller, which maintains the desired charge current.

3.4. Input signals – solar radiations, temperature

PV panels are dependent on a various input signals simulating weather and climatic conditions. As we mentioned before, in a model are two inputs, which represent the intensity of sunlight and temperature. For the case study were chosen reference waveforms sun radiation intensity (Fig.4 left) and temperature (Fig.4 right) during the day for each season.

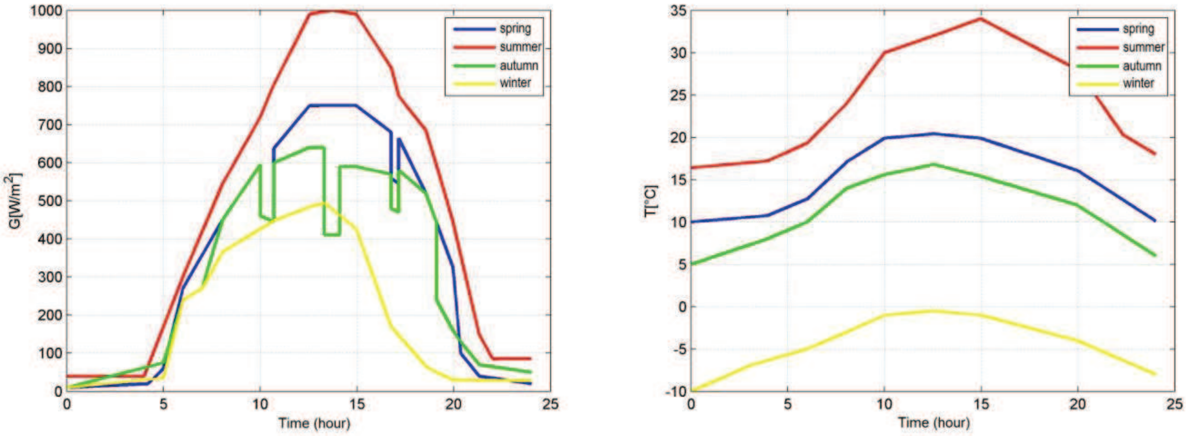

Fig.4. Left - intensity of solar radiation (during the day),
Right - temperature wave (during the day)

4. Simulation results

The final simulation model includes all described blocks and all significant inputs affecting the PVS (Fig.5).

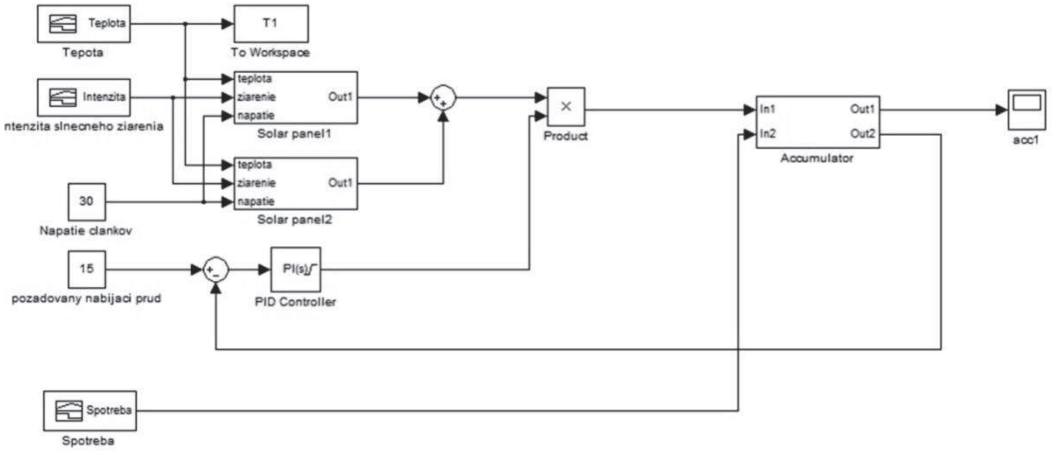

Fig.5. Simulation model of a photovoltaic system (with battery)

According to the established model and knowledge of the inputs we simulated the behavior of the PV system. Based on previous skills we set the size and type of battery and solar panels[1]. We assume the use of PVS in off-grid house firstly just for a lighting system with an estimated consumption Fig.6 left.

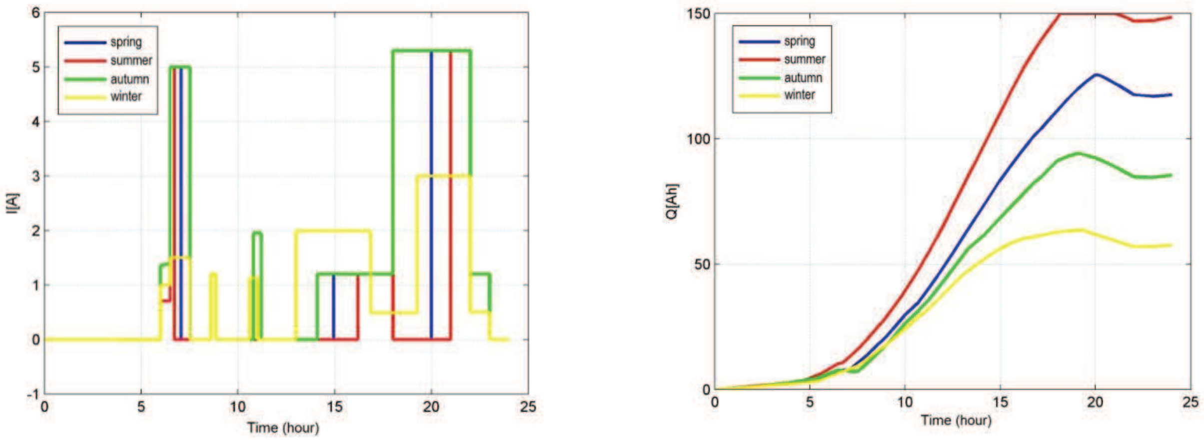

Fig. 6 Left - estimated power consumption energy (light),
Right - battery capacity (during the day)

The simulation results (Fig.6 right) shows battery charging (with capacity 150Ah) during the four reference days of the reference year periods. It is possible to determine applicability and effectiveness of the system directly from the simulation.

The simulation results show that from the state when is battery totally empty, the battery is charged enough during the day and covers the required energy for lighting (with sufficient reserve). The reserve could be used by other appliances. Due to the fact that this reserve is relatively small, its proper use is very important.

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[1] 2x panel IBC polys 240 MS (rated voltage of 30V, capable provide current: 8A, power of panels is 240W . 150Ah Accumulator - Hoppecke 150Ah

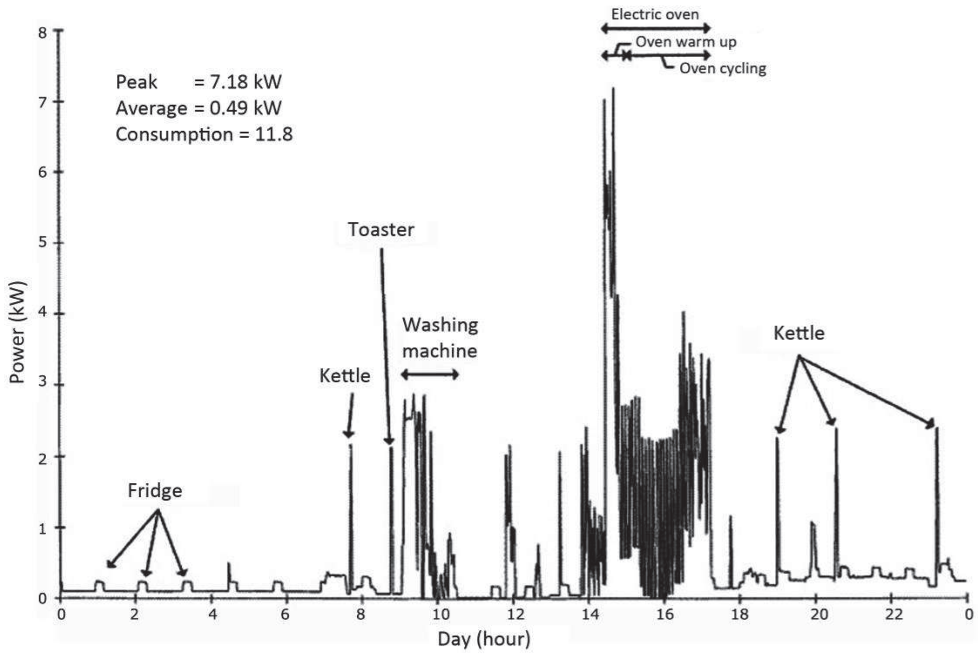

Fig.7. Measured electric consumption of a common household [3]

5. Consumption optimization

Appliances should be used especially at times when we have the largest supply of energy from the PV system, i.e. on a sunny day. Similarly, in the night, when we take energy from the battery, we should take the least. Here appears the question of transfer activities which consume energy to some “scenario” which optimally use energy from the PV system.

In many appliances (washing machine, grill, kettle, etc.) it is not a problem because we can influence on their activity, but some devices such as freezer, freezer run continuously. At first glance, it seems that we cannot influence on e.g. freezer consumption, but during the sunny part of the day can be refrigerator / freezer chilled to the maximum, so that at night it spend at least energy).

Simulation of load in case of PVS is not deterministic. Therefore is convenient to optimize the scenario by some of evolutionary techniques, which should find basic framework of optimal control of individual appliances within each reference year’s period.

We decided to use genetic algorithm to optimize the time control of refrigerator cooling system with scope of minimizing energy consumption during the night.

5.1. Genetic algorithm

Genetic algorithm (GA) is a heuristic method, which main objective is the effort to find the solution of complex problems (for which exact algorithm does not exist) by application of principles of evolution biology [4]. Genetic algorithms and all methods which belong to evolution algorithms use techniques which imitate the processes of evolution, well-known in biology – heredity, mutation, natural selection and crossing [5].

The GA is based on consecutive production of various solutions for a given problem. During the process run, so-called *population* is kept. This population consis*ts of terms and each term is one solution of given problem. As the population goes through the evolution, the solutions get better. Usually, the solution is represented by binary numbers, but it can be also found in other form (tree, field, matrix, etc.). At the beginning of GA (in the first generation), a population comprised of completely random terms is created and moving to the new generation, so-called *fitness* for each term is calculated. This fitness represents the quality of solution expressed by the resulting terms. According to this quality, the individuals are selected (by stochastic, random or another type of the selection). Consequently, they are modified (by mutation and crossing), and new population is created. This procedure is repeated iteratively and terminated either obtaining desired quality of the solution or elapsing a given time.

5.2 Process of Genetic Algorithm creation

Main goal of the process is Genetic algorithm which is able to find the best scenario of freezer cooler system control, which represents the measured object. In general, the structure of cooling steps is not known in advance. The process of genetic programming algorithm (GP) creation is harder than that of genetic algorithm [6]. It is caused by the fact that for GP a specific toolbox for each task needs to be created; on the contrary, if we had toolbox for GA it should be easily used for many similar tasks. A mentioned fact has been solved (task for GP instead of GA) prescribing the structure of minimal cooling period to 10 minutes. By considering this assumption, the task has been transformed from GP to GA (if the result does not satisfy the prescribed quality, GA is easily modified to another cooling period).

Structure of string

As mentioned before, the length of a string depends on minimal cooling interval (CI). The genes represent the sequence of CI. If CI is set to 10 minutes, it is obvious that amount of searched parameters is 144 (for 24 hours scenario) (The values of each genes can be only 0 or 1, 0-non cooling, 1- cooling)

Size of population

The size of population depends on the amount of searched Parameters and gene's structure. The population was set to 100, due to the simple gene's structure.

Mutation

Proposed GA uses two types of mutations. The first is the mutation on random value from given interval (with ratio 0.25) and the second is additive mutation (with the same rate). The rate – amount of mutations in one generation is normalized to interval <0, 1> bigger number stands for frequent mutation occurrence.

Crossing

In the algorithm, on point crossing was used and crossed strings were selected randomly.

Fitness

Fitness (quality of solution) consists of two parts. The first represents maintain temperature criteria, the second part represents the energy consumption of the solution (sum of cooling power)

Conditions of termination

GA can work in two modes; it means that we defined two conditions of GA termination:

- after reaching prescribed amount of generations
- if the value of fitness is stable for prescribed amount of generations

Syntax of GA

Mentioned GA was created in MATLAB, due to many advantages (matrix counting, etc.) of this program. The most important reason for using this tool is the existence of toolbox which involves basic functions needed for GA. This toolbox was created at our department.

6. Calculated results

Genetic algorithm found best solution of control cooling system. Fig.8 shows the gap between two cooling cycles, represents the nighttime. The temperature into freezer doesn’t exceed -15 °C (temperature condition) and the cooling cycles per day consume minimum energy from battery (energy condition). This solution in comparison with common cooling scenario saves about 14% of energy.

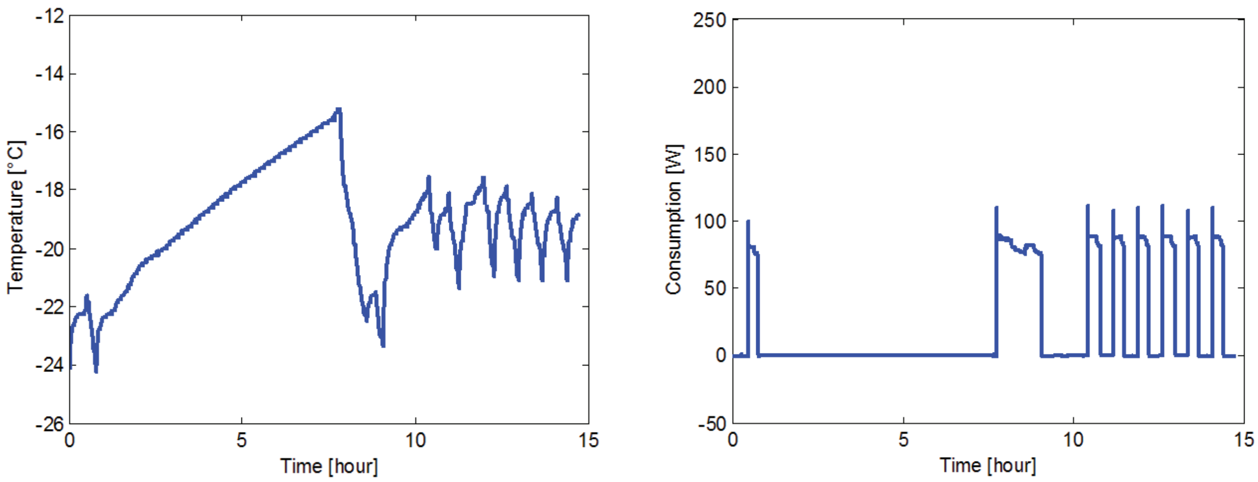

Fig.8. Left - course of temperature in the freezer,
Right - energy consumption

7. Conclusion

In this paper simulation of PV System (charging, consumption and border states) was used. It allows us to choose the optimal PV system (number of panels, batteries - the loading cycles, lifetime, etc.) which considerably reduce price of PVS. Simulation results confirmed that required capacity for lighting requirement was fulfilled and proposed system offer considerable power excess.

Power excess was used for freezer, which optimal cooling control was found by genetic algorithm. Freezing scenario proposed by genetic algorithm proved 14 % energy savings in comparison with normal cooling scenario saves. This fact is very important for off-grid houses, due to its limited energy capacity.

Off-grid homes with photovoltaic systems represent one possible realization of the idea of local energy production. Concept of energy production directly at the place of consumption forces us to think of its efficient production and necessity of its consumption. We spend energy without the consideration whether we really need it to spend. In fact we could live from 40% of the energy which we spend now, without losing anything valuable [7, 8].

Acknowledgments

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