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Dynamic model of solar photovoltaic systems

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Abstract: ***The paper deals with the simulation of the solar photovoltaic system in the Simulink program. The main purpose of the model is to analyze the dynamic operating modes. Much attention is paid to the simulation models of the battery and controller whose function is the distribution of energy flows. The paper describes consistency criteria of energy flows. The energy excess and energy deficit parameters are used as the evaluation criteria of coherence of energy flows. Graphical illustrations of simulation results are presented in the paper.***

Keywords: **photovoltaic system, simulation model of the battery, charge controller simulation model.**

I. INTRODUCTION

Optimization of operation modes and parameters of solar energy systems is one of the most important tasks when designing and implementing these systems in practice. Adapting systems to the specific climatic conditions, geographical location and requirements of the energy consumer sets a complex analysis task that is solved, as a rule, in terms of multivariate analysis methods. However the application of multivariate analysis methods requires a model that has a range of contradictory properties. Obviously, the model should accurately show the main processes in the system, but, on the other hand, be simple enough for the possibility of multiple runs while searching for the best solutions.

II. MATERIALS AND METHODS

A formal approach to simulating allows you to resolve the contradiction between the requirements for accuracy and model complexity. The example of simulating a typical structure of the solar photovoltaic system (SPVS).

Panels of photovoltaic semiconductor converters (PVSC), energy storage presents a chemical battery, management of power is carried out by a charge controller, and energy consumer is marked through the power load.

Flow capacity balance is made up according to the SPVS structure.

$$P_l(t) = F_1(t)P_{vp}(t) + F_2(t)P_{out}(t), \quad (1)$$

$$P_{in}(t) = F_3(t)P_{vp}(t), \quad (2)$$

$$P_{out}(t) = F_4(t)P_{in}(t), \quad (3)$$

где: $P_l(t)$ – power required for load; $P_{vp}(t)$ – – power generated by solar panels; $P_{in}(t)$ – power spent on the battery charge; $P_{out}(t)$ – power transferred from the accumulator in the load; functions $F_1(t)$, $F_2(t)$, $F_3(t)$ and $F_4(t)$ show different aspects of the relationship of energy flows.

The flow of energy generated by solar panels while simulating, can be determined by one of the known methods, for example [1], but it is necessary to note that both astronomical model and the model for consideration weather conditions in the place of SPV installation are required for the accurate reproduction of insulation.

The functions of interconnections of flows are built on the basis of analysis of the system operation $F_1(t)=1$ if $P_{vp}(t) \le P_l(t)$, otherwise $F_1(t)=P_l(t)/P_{vp}(t)$, the difference of energy flows is directed via channel $F_3(t)$ into the flow battery $P_{in}(t)$. Function $F_3(t)$) must also take into account the final speed of battery charge and $F_3(t)=0$, if the battery is fully charged.

Function $F_2(t)=0$ if $P_{vp}(t) \ge P_l(t)$, at $P_{vp}(t) > P_l(t)$ $F_2(t)=1$, and $P_{out}(t)=P_l(t)-P_{vp}(t)$.

Function $F_2(t)$) must take into account a final rate of discharge, and $F_2(t)=0$ when it reaches the lower border of the battery charge level.

Function $F_4(t)$ presents a formal battery model:

$$F_4(t) = E_0 + \int_0^t (\eta_1 P_{in}(\tau) - \eta_2 P_{out}(\tau) - p)\, d\tau, \quad (4)$$

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where: η_1 - parameter, taking into account the energy losses at a charge; η_2 - parameter, taking into account the energy losses at a discharge; p – battery self- charge constant; E_0 – the amount of energy in the battery at $t=0$.

Implementation of the controller model in the Simulink is shown in fig.1. Areas covering elements that implement the connection functions $F_2(t)$ and $F_3(t)$ are highlighted for illustrative purposes. Function $F_1(t)$) is implemented without computation.

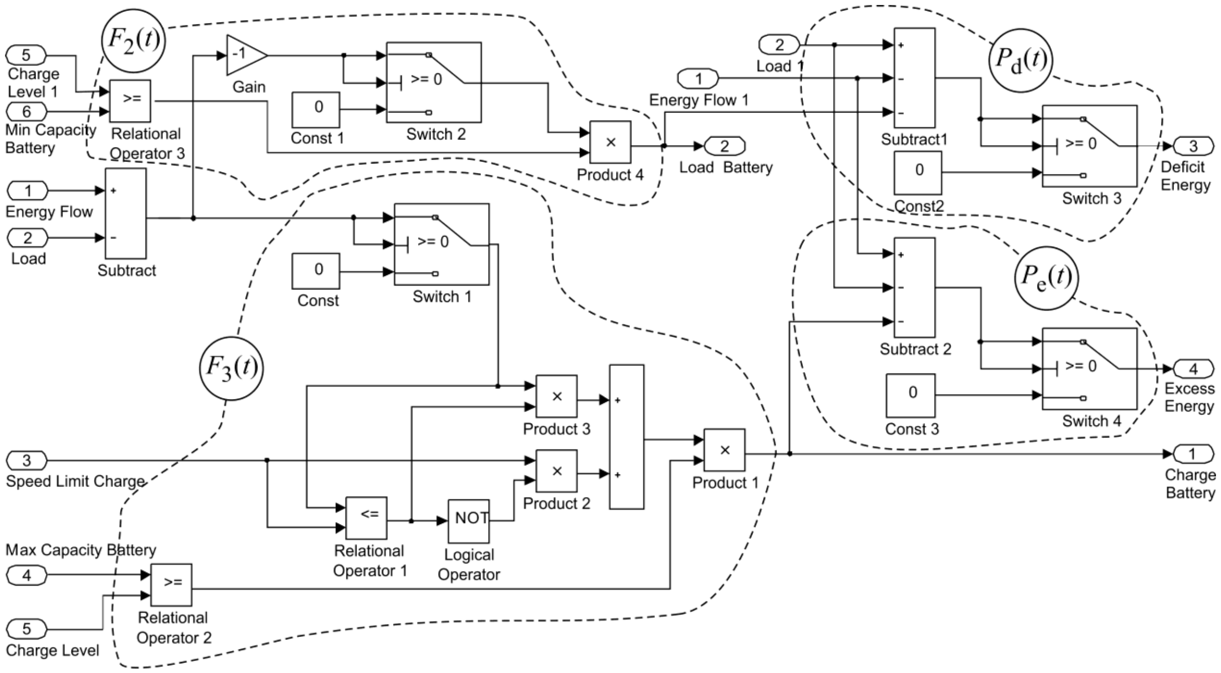

Fig.1 .Implementation of a controller model in Simulink.

In addition to the above functions $F_2(t)$ and $F_3(t)$,connecting the energy flows, additional computational parameters are introduced in the controller model which represent the following equations

$$P_d(t)=k_1\left(P_l(t)-P_{vp}(t)-P_{out}(t)\right)\text{и}$$

$$P_e(t)=k_2\left(P_{vp}(t)-P_l(t)-P_{in}(t)\right),$$

Where: $k_1=1$ if $P_l(t)-P_{vp}(t)-P_{out}(t)\geq 0$ otherwise $k_1=0$; $k_2=1$ if $P_{vp}(t)-P_l(t)-P_{in}(t)\geq 0$ otherwise $k_2=0$. In the first case the time function $P_d(t)$of deficit energy is computed, in the second case, the time function $P_e(t)$ of excess energy is computed.

The implementation of the battery model in Simulink which is based on formula (4) is shown in fig. 2. Due to the high complexity of the exact battery model the simpler version is used. While building the model the following parameter points are taken in formula (4): $E_0=0.1E_{\max}$, where $E_{\max}$ – is the maximum capacity of the battery; losses during battery charge and discharge are considered equal to 2 %, then $\eta_1=0.98$,and $\eta_2=1.02$; self-discharge constant is $p=0.1$. The assumptions in the model: the battery power is not dependent on the level of charge, the influence of temperature on the battery and solar panel is not taken into account; the efficiency of the charge controller is considered equal to one.

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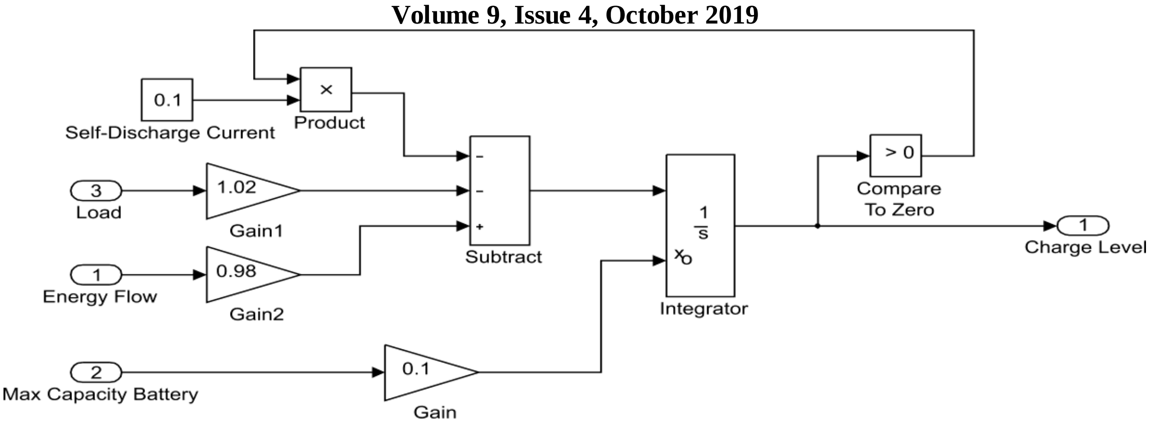

Fig.2. Implementation of a battery model in Simulink

The implementation of the general model is shown in figure 3, the following processes are visualized (Scope 1): the flow of energy generated by solar panels – $P_{vp}(t)$;required flow of energy load – $P_l(t)$; the function of energy deficit – $P_d(t)$; the function of excess energy – $P_e(t)$; in some coordinate system the charge level of the battery – $E_4(t)$is displayed.

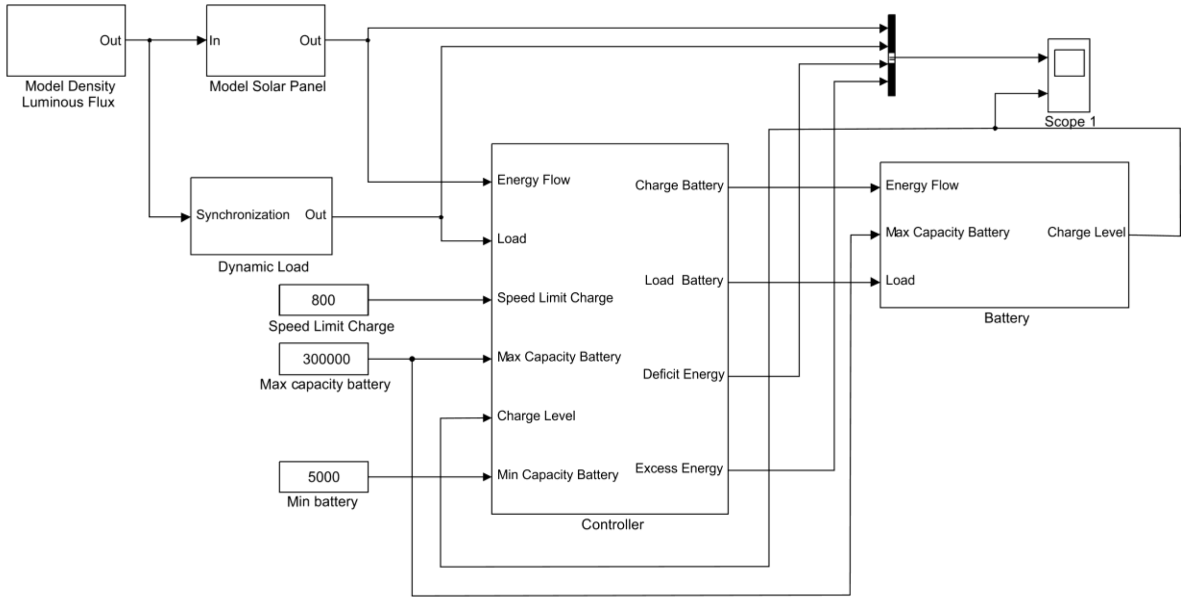

Fig.3. Implementation of a system general model in Simulink

III. RESULTS AND DISCUSSION

System simulating is carried out with the following parameters: the total area of solar batteries – $S = 5\ m^2$; SPVP efficiency – $\eta_{vp} = 0.15$; solar constant (density luminous flux) $I = 1500\ W/m^2$; maximum battery capacity $W_{vp\ \max} = SI\eta_{vp}$, $W_{vp\ \max} = 1125\ Bm$; accumulator capacity $100\ A/h$, voltage $12\,V$, V is converted into Joule $E_{\max} = 4.32\ MJ$; ; minimum battery charge level $E_{\min} = 0.15 E_{\max} = 648\ KJ$; self-charge parameter $p = 360\ J/h$.

The simulation results for the case of excess energy flow and low flow (deficit energy) is shown in figure 4 and figure 5.

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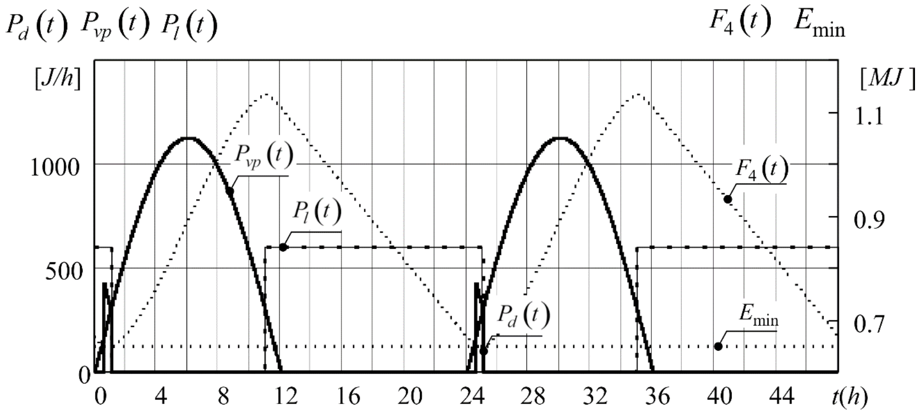

Fig. 4. Simulation results for the case of excess energy flow.

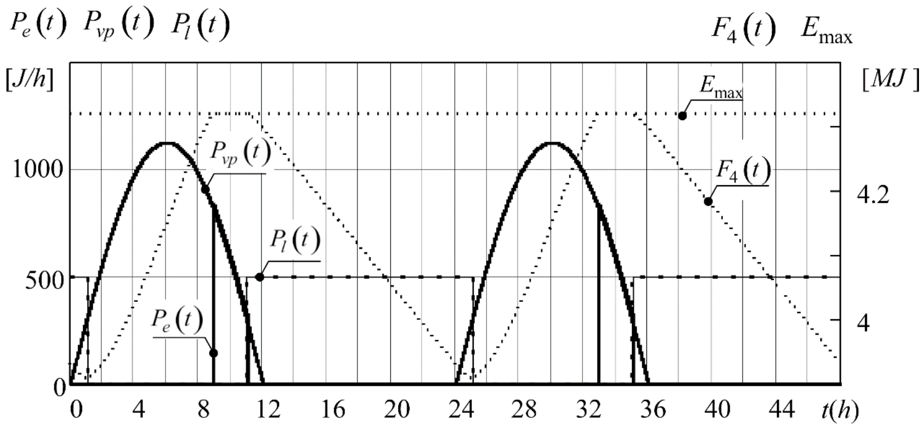

Fig.5. Simulation results for the case of deficit energy flow.

IV. CONCLUSION

The developed model allows for analysis of dynamic processes which occur in the system, comparison of energy flows by level and evaluation of losses due to their inconsistency.

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