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INCREASING THE EFFICIENCY OF A HYBRID PHOTOELECTRIC SYSTEM OF A LOCAL OBJECT WITH A STORAGE BATTERY USING FORECAST

Abstract: *The implementation of a photovoltaic system with a storage battery to meet the needs of a local object and the ability to generate energy into the grid during peak hours is considered. The principles of implementation of the planned generation of energy into the grid during peak hours with a decrease in electricity consumption from the grid have been substantiated. In this case, the setting of the SB degree charge is carried out according to the forecast of the generation of the photovoltaic battery for the next day with a preliminary estimate of the generation power to the grid. The updated value of the generation power to the grid is determined according to the forecast data by the beginning of the morning peak, taking into account the actual generation power of the photovoltaic battery. Subsequently, at the intervals of discreteness of the forecast, the value of the generation power into the grid is corrected taking into account the actual generation power of the photovoltaic battery, the load and the degree of storage battery charge. The storage battery charge mode is set taking into account the forecast data at the end of the morning peak. The corresponding algorithm of the system functioning was developed. Simulation of energy processes in the system for a daily cycle of operation with an estimation of the cost of paying for electricity has been carried out. In this case, the archived weather data were used. It is shown that with the adopted system parameters, this solution allows providing the power generation to the grid in the evening peak of 19% to the load power, and in the morning peak up to 200%. Reducing the cost of payment consumed by a local object from the electricity grid is at one tariff rate in the summer period from 1.6 times to 14 times, in winter from 1.1 to 1.55.*

Keywords: *planned energy generation to grid, storage battery degree charge, photovoltaic battery generation forecast, multi-zone tariffication, simulation.*

Introduction

The disadvantage of photoelectric systems (PES) is the uneven generation of electrical energy. The largest generation of energy from a photoelectric battery (PV) occurs at noon hours. This creates the problem of ensuring a balance between consumption and generation in the power system as a whole, as well as at the level of local microgrids with distributed generation. The energy consumption of most local objects (LO) is a general nature with peak morning and evening loads. Excess energy for generation into the grid appears only during the hours of maximum solar activity. An urgent task is the use of energy storage devices, both at the level of the power system and local grids with PES. In this case, there is an opportunity to reduce daily consumption from the distribution grid (DG) and carry out the planned generation of energy in the DG only during peak hours, which will contribute to the balance in the power system. At the same time, additional investments in a storage device (storage battery (SB)) should pay off by reducing the cost of paying for the electricity consumed by the LO from the grid. This is possible when improving the energy management of PES using the forecast of the PV generation and the possibilities of multi-zone payment.

The relevance of the issue of consumption localizing at the place of generation in world practice is confirmed by the wide proposition on the electrical market of hybrid inverters (HI) connected to a DG [1, 2]. Inverters contain of whole complex of equipment for photovoltaic (PV) and storage batteries. It is used to reduce power consumption from the grid and to implement the uninterruptible power supply function. In this case, the SB energy is used when the PV energy is insufficient for the functioning of the LO load. A numbers of HI [1] has the function of generating surplus energy in the DG, which usually takes place during the hours of the greatest solar activity and a decrease in load. The possibilities of the Internet are practically not used to predict generation of PV and control the generation and redistribution of energy.

The use of a “multiconverter” in a PES with a SB and a supercapacitor is considered in [3] with regard to local microgrids. However, its use is considered as a distributed power unit in a multi-user system under the control of a centralized smart energy management system. A similar structure, but without a supercapacitor, is shown in [4], where the problem of combining several PVs into an autonomous system is solved when the grid is disconnected. Task of energy management and grid generation is not considered.

The use of a SB imposes a number of peculiarities on PES control when the SB charge level is more than 80%. It implies the use of power regulation of PV. In [5], an option is considered with switching off the PV while maintaining the state of charge of the SB within 75-80%. Great opportunities are provided by the use of the current regulator of PV and SB [6] without additional recharge cycles of the SB.

The issue of transferring the energy, stored in the SB during the hours of the night tariff and the excess energy of the PV during the daytime, for using during peak loads is considered in [5]. It makes possible to exclude energy consumption from the DG during peak tariff hours and in the most part of the daytime. At the same time, the use of PES to meet the needs of the LO with a load schedule tied to the PV generation based on the forecast is considered. The PV generation forecast provides wide opportunities for improving the control and redistribution of energy in PES. Resource [7] provides the possibility to directly predict the PV generation but with a discreteness of 1 hour and a certain error to the actual generation. The issues of increasing the accuracy of forecasting with decreasing discreteness in time are considered in [8].

In [9] the prediction of SB charge degree using forecast of PV generation to reduce consumption from the DG is considered regarding PES with SB to meet the need of LO’s. Energy generation into the grid is not considered. Application the multifunctional inverter in PES with SB is shown in [10]. The principals of operation modes realization, including generation into grid with possibilities limitation of generation power and autonomous operation mode, are presented. However, the issues of planned generation, control of SB charge degree and using the forecast of PV generation in order to achieve concrete result, are not considered.

The effective mean for estimation of energy processes in PES in daily cycle of operation is simulation [11]. In this case, the wide opportunities to research the processes with estimation of the cost of electricity payment decreasing are appearing.

Therefore, additional study is required to ensure the planned for the day ahead, uniform in time generation of electricity into DG during peak hours (with the exclusion of generation at other times). In this case, it’s necessary to ensure the maximum cost decreasing on the payment for electricity, consumed from the GD under condition that power, consumed by the load, does not depend on weather and the season of the year.

The aim of the article is improving the principles of control of PES with SB at implementation the functions of ensuring needs of LO with the possibilities of uniform predicted energy generation into the grid in peak hours.

The main tasks of this work:

- to study the possibilities of ensuring of LO needs with uniform energy generation into the grid in peak hours with planning on the forecast a day ahead;

- to develop the principles of control of PES energy consumption and the converter unit functioning in the varies operation modes;
- to develop the simulation model to research the energy processes in system in daily cycle with estimation of efficiency at different tariff plans.

Result of research

The structure of PES with SB on the base of multifunctional grid inverter with regulation of PV generation P_{PV} is made according to the principles, presented in [10].

In PES structure the SB realizes the key function in redistribution of energy, generated by PV and consumed by load from the grid. At the same time, it is possible to compensate for the consumption of the LO load during peak hours due to the accumulation of surplus energy of the PV or cheaper electricity from the DG at multi-zone billing or at time of use payment. Generation into DG during peak hours, when P_{PV} is low or absent, is possible only due to the SB energy. Duration of evening peak is 4 hour in winter [12] (October-April) – from 17.00 (18.00) to 21.00 (22.00), 3 hour in summer (May-September) – from 20.00 to 23.00. When the LO load is the same in any season of the year, the energy W_L consumed by LO during peak hours is higher in winter than in summer. With the same energy supplied by the SB in winter, it is possible to generate surplus electricity in the DG in summer. With the correct choice of the ratio of the rated PV power P_{PVR} and the energy capacity of the SB $W_{BR} = U_B C_B$ (U_B – voltage, C_B – SB capacity (Ah)), it is possible to provide generation into DG during the evening peak and in winter. And here the question is not about a simple increasing in W_{BR}, since the SB needs to be charged by the evening peak. This requires energy, and to reduce consumption costs, it is preferable to use the PV energy and not energy from the DG. An increase in W_{BR} will lead to an increase in the duration of the SB charge and it will not have time to charge.

Based on the data [13] for PV with P_{PVR} = 1 kW in condition of Kyiv. For clear day of July the general generation is $W_{PVC} \approx$ 6 kWh, average daily power is P_{PVAV} = 250 W, recalculated to daytime (8.00-20.00) average value is P_{PVAVD} = 500 W. The length of the time to ensure a full charge of the battery is long enough. Therefore, we limit the initial value of the degree of SB charge at the evening peak Q^*_{SE} = 95% ($Q^* = 100Q / Q_R$, Q_R is rated charge (capacity, Ah)). The final value is Q^*_{EE} = 50%, taking into account the acceptable value of the degree of discharge DOD = 50% (for lead-acid SB of the OPzV12-100 [14] type at about 3000 discharge cycles).

Energy W_{BL}, transferred by the SB to the load:

$$W_{BL} = 0.01\left(Q^*_{SE} - Q^*_{EE}\right)W_{BRL}$$

where $W_{BRL} = W_{BR} \cdot \eta_C \cdot \eta_B$, η_C and η_B are efficiency of converter unit and SB efficiency.

We have two deep SB discharge cycles per day in the presence of morning and evening load peaks. Let us introduce restrictions: for winter – Q^*_{Sm} ≥ 80%, Q^*_{Em} ≥ 60% (morning peak), Q^*_{EE} = 50%; for summer – Q^*_{Sm} ≥ 80%, Q^*_{Em} ≥ 70%, Q^*_{EE} = 60%. Limitation 90% ≥ Q^*_{Sm} ≥ 80% is introduced to limit energy consumption for SB charging at night. Regarding to PES to meet the needs of the LO without generation into DG, the ratio $P_{PVR} : W_{BR}$ = 1 : 2.75 is proposed in [5]. The average value of the load power for the evening peak in summer is $P_{LPES} = W_{BL} / t_{PES}$ = 283.5 W at W_{BR} = 2750 Wh and $\eta_C = \eta_B$ = 94%. In winter, when t_{EPW} = 4 h, the value decreases P_{LPEW} = 273 W. In evening peak in winter the load is a little higher then in morning peak – we accept 1.1. We also accept the load in the morning P_{LPm} = 210 W, in the evening P_{LPEW} = 230 W with possibility of generation into DG in the evening P_{g2} = 40 W

($P^*_{g2} = 100P_{g2} / P_{LP} = 19\%$). In summer there is $P_{LPm} = P_{LPE}$ = 210 W with possibility of generation into DG in the evening P_{g2} = 70 W ($P^*_{g2} = 100P_{g2} / P_{LP} = 33.3\%$). At recalculation of PV power to P_{PVR} = 30 kW we will have: in winter P_{gw} = 1.2 kW, and energy W_{gw} = 4.8 kWh (at P_{LP} = 6.3 kW); in summer P_{gS} = 2.1 kW, and energy W_{gS} = 6.3 kWh. We accept, that average value of power of LO load is P_L = 210 W with a decrease of 15% (180 W) in the evening. Then, taking into account the fact that for summer P_{PVAVD} = 500 W, we obtain an overestimation of the PV power by 2.38 times.

In the morning peak (in summer from 8.00 to 11.00) the possibilities of generation increase since the PV energy is added (W_{PVPm} – according to the forecast data). The power P_{Lpm} value in this case:

$$P_{Lpm} = \frac{0.01\left(Q^*_{Sm} - Q^*_{Em}\right)W_{BRL} + W_{PVPm} \cdot \eta_C}{3} \tag{1}$$

Power generation P_{g1} into grid:

$$P_{g1} = P_{LPm} - P_{LP} \tag{2}$$

Diagram (fig. 1) illustrates W_{PVPm} changing depending on weather condition for May, July, September with values discreetness ΔW_{PVPm} = 100 Wh (by archive data [13] on 2015). The end value W_{PVm}, when the LO consumption without generation into grid is provided for values Q^*_{Sm} = 80%, Q^*_{Em} = 70%, P_{LP} = 210 W is W_{PVm0} = 411 Wh. At the same conditions and P_{g1} = 70 W there is value W_{PVm1} = 635 Wh. The end value W_{PVm}, when the LO consumption without generation into grid is provided for values Q^*_{Sm} = 90%, Q^*_{Em} = 70%, P_{LP} = 210 W is W_{PVm0} = 153 Wh. At the same conditions and P_{g1} = 70 W there is value W_{PVm1} = 376 Wh. When W_{PVm} = 1400 Wh there is value P_{g1} = 310 W (Q^*_{Sm} = 80%, Q^*_{Em} = 70%) and P_{g1} = 390 W (Q^*_{Sm} = 90%, Q^*_{Em} = 70%). Thus, in the period May-September the planned energy generation into the grid is realistic with a capacity of up to 1.86 and higher to the load power.

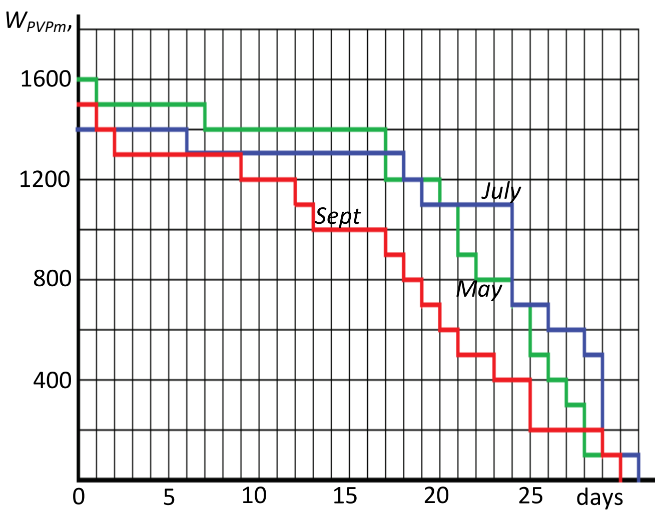

FIGURE 1. *Diagram of W_{PVPm}*

The daily cycle of PES operation were reviewed with reference to tariff zones [12] for summer season: t_1 = 7.00 – the end of night tariff zone; (t_2 = 8.00, t_3 = 11.00) – morning peak; t_4 = 16.00 – the end of the period of intensive solar radiation; (t_5 = 20.00, t_6 = 23.00) – evening peak; t_7 = 24.00 – the beginning of night tariff zone; (t_1, t_2), (t_3, t_5), (t_6, t_7) – daytime tariff zone. For winter: t_1 = 6.00, t_2 = 8.00, t_3 = 10.00,

t_4 = 14.30, t_5 = 17.00, t_6 = 20.00, t_7 = 23.00. After t_4 even in clear summer day PV energy is not enough to ensure the consumption of LO and the consumption of energy from the grid is inevitable. Charging SB characteristic of OPzV12-100 type [14] at $Q^* \geq$ 80% is characterized by a decrease in charge current (table 1, where the average value I^*_{BAV} (in intervals 0.5 h) is presented in shares to $I_{BR} = 0.1\,C_B$ and relative power value on SB charge P_B to $P_{BR} = 0.1\ W_B$). In this case, the charge from Q^* = 80% to Q^* = 95% is about 5.5 hours. In winter – $t_{45} = (t_5 - t_4)$ = 2.5 h, in summer – t_{45} = 4 h. Thus, it is necessary to ensure the value Q_4^* in winter $Q_4^* \geq 91\%$, in summer – $Q_4^* \geq 87\%$.

It is possible to exclude the consumption of energy from the DG in the interval (t_3, t_4) under the condition:

$$W_{PV34}\eta_C \geq \left(W_{L34} + 0.01\frac{\left(Q_4^* - Q_3^*\right)W_B}{\eta_C \eta_B} \right) \tag{3}$$

Table 1. *Charging SB characteristic with discreetness 0.5 hour*

Q_I^*, %	80	83.75	85	86.88	88.5	89.9	91	92	92.82	93.57	94.3
Q_{i+1}^*, %	83.75	85	86.88	88.5	89.9	91	92	92.82	93.57	94.3	95
I_{BAV}, p.u	0.075	0.045	0.0375	0.0325	0.0275	0.0225	0.0188	0.0163	0.015	0.014	0.013
ΔQ^*, %	3.75	2.25	1.88	1.62	1.375	1.125	0.94	0.82	0.75	0.7	0.65
P_B, p.u	0.375	0.225	0.188	0.162	0.137	0.113	0.094	0.082	0.075	0.07	0.065

If $W_{PV23} \leq W_{PVm0}$ even in the absence of generation to the grid, it is problematic to ensure the consumption of LO. Therefore, to limit the energy consumption for SB charging at night, during the morning peak it is possible to reduce Q_3^* to 60% while limiting $Q_2^* \leq 90\%$.

If condition (3) is fulfilled on the interval (t_3, t_4) dips are possible when $P_{PV}\eta_C < P_L$ and the missing energy is consumed from the DG. To reduce the consumption of electricity from the DG, it is advisable to exclude the SB charge, which will also ensure better use of the PV energy at other intervals. This is especially true in the case when a sharp decrease of the PV generation occurs at noon and the SB charge current is large enough. If Q^* < 80% then the SB charging current $I_B = 0.1\,C_B$, respectively, the power consumed to charge the SB P_B = 0.1, W_B = 275 W, and exceeds the load power. If the excess according to condition (3) is of the order of 5-10%, one should take into account the possible regulation of P_{PV} at intervals when $P_{PVP}\cdot\eta_C > P_L + P_B(P_B = U_B I_B / \eta_C \eta_B)$ and the actual value $P_{PVF} < P_{PVP}$ (P_{PVP} is the predicted value). In this case, a stock is entered with an overestimation of the value Q_3^* = 72%. We should also take into account possible deviations of P_L from the calculated value and P_{PVF} from the P_{PVP} forecast.

The algorithm of SB charge control is realized so. According to the $P_{PVP}(t)$ forecast on the next day (before the start of the night SB charge), the degree of charge is set depending on the W_{PV23} value (table 2) with a preliminary estimate of P_{g1}. Condition (3) is also checked and, if necessary, an overestimation of Q_3^* is introduced.

TABLE 2. Setting the SB charge degree

W_{PV23}, W	$W_{PV23} \le 153$	$153 \le W_{PV23} \le 376$	$376 \le W_{PV23} \le 635$	$635 \le W_{PV23} \le 900$	$900 \le W_{PV23} \le 1200$	$1200 \le W_{PV23}$
Q_2^*, %	90	90	85	80	85	90
Q_3^*, %	60	70	70	70	70	70

At the moment $t_i = t_2$, according to the current forecast $P_{PVP}(t)_i$ and the measured value Q_{2i}^*, the reference P_{g1i} is refined. In this case, if P_{PVFi} differs from P_{PVPi}, the forecast is adjusted $W_{PV23i} = (P_{PVFi} / P_{PVPi})W_{PV23}$. At the moment $t_{i+1} = t_2 + \Delta t$ (Δt is the discreteness of the forecast), according to the current forecast, W_{PV} generation is calculated on the interval (t_{i+1}, t_3), adjusted for the actual value of P_{PVFi+1}. Taking into account the average power value in the previous interval P_{Li} and $Q_{2(i+1)}^*$, the reference P_{g1i+1} is calculated. This is carried out until the moment t_3, when on the current forecast the generation W_{PV34} is calculated on the (t_3, t_4) with correction based on the actual value of P_{PVF3}.

The condition (3) is checked in accordance with W_{PV34} value, average value P_L on the previous interval and actual value Q_3^*. Based on this, a decision is made on the possibility of excluding the SB charge in case of generation dips in the interval (t_3, t_4). If (3) is not satisfied, at $P_{PV}\eta_C < P_L$ the SB is charged from the grid with the reference $I_B = 0.1\,C_B$. SB charge at intervals (t_1, t_2), (t_6, t_7) is not used at the daily tariff ($I_B = 0$).

The control system of converter unit is made according to well-known principles [10]. The functions of data processing, setting of modes and control of switching in the structure are performed by the program control unit (PCU). Communication with the site and conversion of the format of the received data $P_{PVP}(t)$ is carried out by the Wi-Fi module. Main operation modes:

- GM – operation in parallel with DG and with SB charge. If $P_{PV}\eta_C > P_L$, PV generation is regulated by maintaining the voltage in dc link U_d = const, the DG reference current amplitude i_g is set by $I_{gm}^1 = 0$, the SB reference $I_B = (P_{PV}\eta_C - P_L)/U_B$. If $P_{PV}\eta_C < P_L$, PV generation is maximum (set by the MPPT controller), reference SB current $I_B = I_{BR}$ and reference I_{gm}^1 is determined by the condition U_d = const. At condition (3) – $I_B = 0$;
- GM1 – operation with DG and energy generation $P_g \ge 0$ in the peak hours. PV works on the mode of maximum power, reference $I_{gm}^1 = 0$ or $I_{gm}^1 > 0$ (is determined by P_g value) sets the PCU according to the W_{PV23} forecast. Stabilization of voltage U_d is provided by regulation of SB current.

Simulation model for the study of energy processes in the system in the daily cycle

It implements the daily cycle of the PES operation without taking into account transients. Energy losses are taken into account through the efficiency. The operation of PES is considered with the use of various tariff plans. The model structure contains:

- module of PV generation forms $P_{PVP}(t)$ in accordance with forecast (archive data [13]) in tabular form, with PV generation regulation $P_{PV} = P_L + P_B$;
- module of estimation (EM) of the cost of paying for electricity consumption from DG;

- module of reference modes form variable, corresponding to time intervals. For summer period: *d* (day *d* = 1 from 7.00 to 8.00, from 11.00 to 20.00, from 23.00 to 24.00); *m* (morning load peak *m* = 1 from 8.00 to 11.00); *p* (evening load peak *p* = 1 from 20.00 to 23.00); *n* (night *n* = 1 from 24.00 to 7.00). For winter period intervals is shifted. The variables *gm*, *gm*1 is also formed for operating modes;
- load module with reference of load power $P_{LR}(t)$ in tabular form. In this case the value $P_L^1(t) = P_L(t) + P_g(t)(P_g(t) = P_{g1}m + P_{g2}p)$ is used in calculations;
- calculation module – calculates I_B, $P_B = I_B \cdot U_B$, power, consumed from DG P_g for GM, if $P_{PV}\eta_C < P_L$ then $P_g = P_L - P_{PV}\eta_C + P_B / \eta_C$ in night mode $P_g = P_L + P_B / \eta_C$.

SB model is made on data sheet. SB charge with energy taking account:

$$Q = Q_S + \int I_B^1 \cdot dt$$

where $I_B^1 = I_B \cdot \eta_B$ – when charge and $I_B^1 = I_B / \eta_B$ – when SB discharge.

I_B value is formed as $I_B(Q^*)$ in accordance with SB characteristics [14].

A "Saturation dynamic" unit is used with an upper limit $I_B(Q^*)$, and a lower one – $I_{Brc\max}$ (permissible value during discharge). The SB voltage is also set by the $U_B(Q^*)$ relationship.

EM calculates coefficient $k_E = C_1 / C_2$ [9] (C_1 is the cost of electricity consumed by the LO load at single tariff zone, C_2 is the cost of electricity consumed from the DG at the adopted tariff plan).

Results of simulation in MatLab

The model uses a PV with P_{PVR} = 1 kW, SB with W_B = 2.75 kWh, values $\eta_B = \eta_C$ = 0.94. The load $P_L(t)$ is in all cases unchanged with an increase in the evening peak in winter. The values of the degree of charge Q^*, the relative values of the generation power to the grid P_g and the values of k_{E1} (at single tariff rate), k_{E21} (at two tariff zones: day – 1, night – 0.5), k_{E31} (at three tariff zones: day – 1, night – 0.4, peak – 1.5) are given in table 3.

The oscillograms of the daily cycle of the PES operation for 1 July, 2015 at W_{PV} = 3.367 kWh with a sharp decrease of generation after lunch without SB charge form the grid is shown in figure 2. Margin (3%) for Q_3^* = 73%, Q_2^* = 86%, Q_6^* = 60%, k_{E1} = 4.132 is introduced (with connection to the grid under the same conditions k_{E1} = 2.97).

The oscillograms of the PES daily cycle for 28 July, 2015 at W_{PV} = 2.674 kWh with a sharp decrease of the PV generation in the morning and a SB charge at noon is shown in figure 3a (k_{E1} = 1.8). The dotted line highlights the fragments where the PV energy is not fully used (red), as well as the energy consumption for SB charging (blue), which is inappropriate. The exclusion of the SB charge (fig. 3b) provided an increase the use of the PV energy at k_{E1} = 2.15. The oscillogram for the clear day of December is shown in figure 4 at W_{PV} = 1716 Wh. P_{g1} = 75 W, P_{g2} = 40 W, Q_2^* = 80%, Q_3^* = 70%, Q_6^* = 50%, k_{E1} = 1.548, k_{E21} = 2.18, k_{E31} = 2.64.

TABLE 3. *k_E value for different tariff plans*

W_{PVP}, kWh	k_{E1}	k_{E21}	k_{E31}	Q_2^*, %	Q_3^*, %	Q_7^*, %	$\frac{P_{g1}}{P_L}$, %	$\frac{P_{g2}}{P_L}$, %
May-July (2015)								
6	14.66	+	+	90	70	63.3	204.8	33.3
6	13.73	+	+	80	70	63.4	152.4	33.3
6	20.3	+	+	80	70	60	152.4	47.6
4.756	6.29	+	+	85	70	63	142.8	33.3
4.756	7.39	+	+	85	70	60	142.8	47.6
4.346	6.56	+	+	85	70	62.5	143	33.3
3.751	3.167	6.32	19.3	85	70	61.9	57.1	33.3
3.367	4.132	12.21	+	86	73	60	162	33.3
2.83	2.36	3.76	5.58	85	70	61.4	33.3	33.3
2.83	2.33	4	7.13	90	70	61	57.1	33.3
2.674	2.15	3.5	5.12	90	60	60	33.3	33.3
2.021	1.733	2.37	3.43	85	70	63	85.7	33.3
1.951	1.66	2.2	2.79	82	70	62	47.6	33.3
December								
1.716	1.548	2.18	2.64	80	70	50	35.7	19
0.75	1.11	1.376	1.54	80	60	53	38.1	19
0.75	1.11	1.376	1.54	80	69	54	0	19

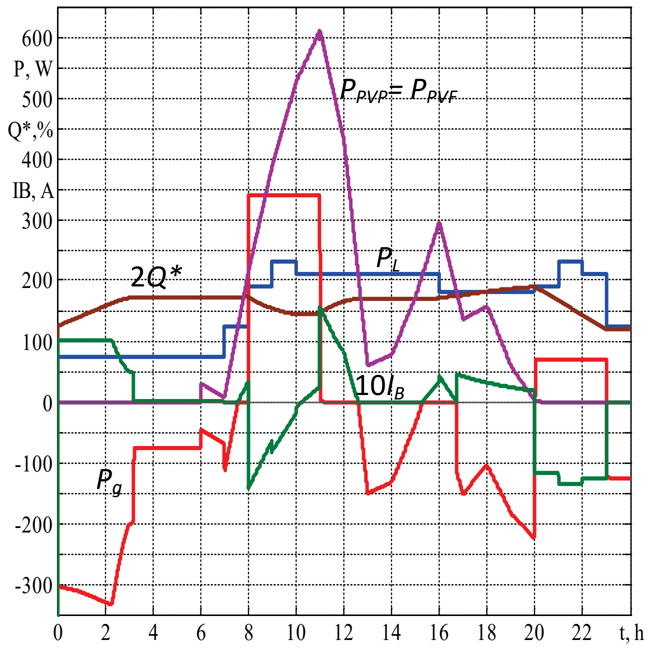

FIGURE 2. *Oscilograms of PES daily cycle at W_{PV} = 3.367 kWh*

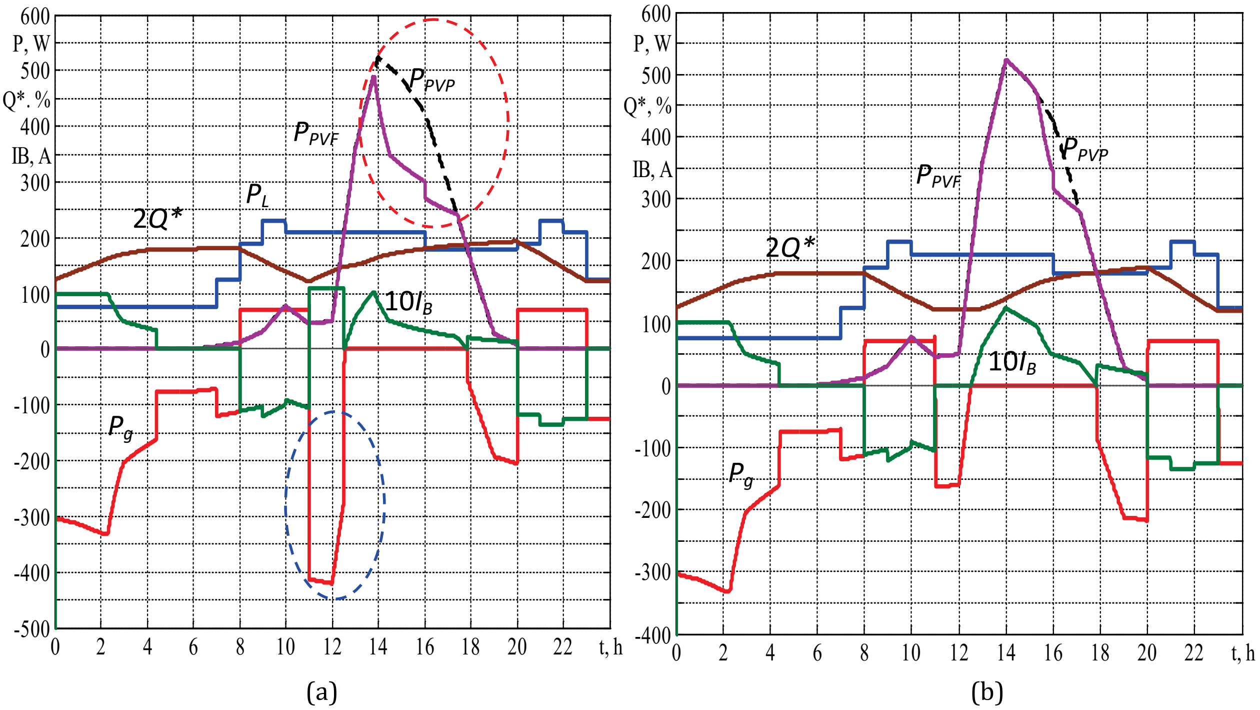

FIGURE 3. *Oscillograms of the PES daily cycle at W_{PV} = 2.674 kWh: a) with SB charge at noon; b) with the exclusion of the SB charge*

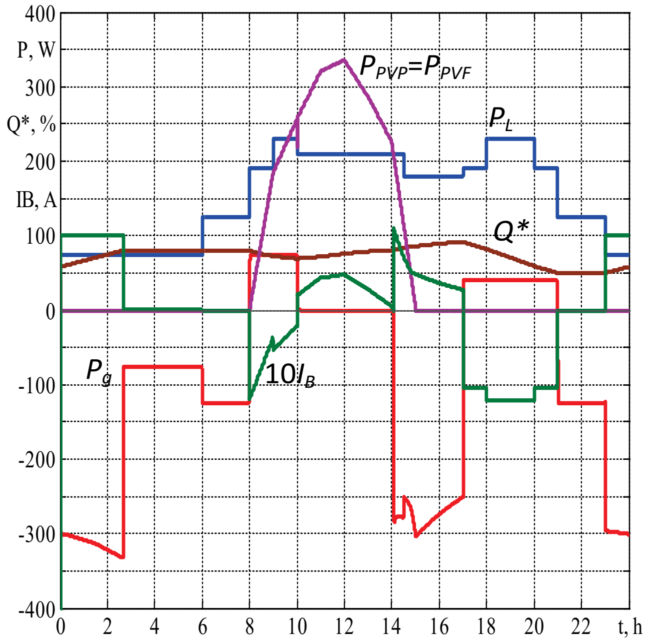

FIGURE 4. *Oscillogram of the PES daily cycle at W_{PV} = 1.716 kWh*

Conclusions

The proposed principles of the formation of the SB charge degree based on the prediction PV generation at the intervals of the PES operation ensure the planned uniform in time generation of electricity into the grid during peak hours. This is achieved while reducing energy consumption from the grid. The elimination of the SB charge in case of a sharp decrease in the PV generation allows you to reduce energy consumption from the grid with a more complete use of the PV energy. At the same time, the operation of the control system with the implementation of various operating modes is tied to tariff zones, the reference of the SB charge current and the value of the generation power is carried out by a program control unit with a Wi-Fi module.

Simulation in a daily cycle showed that with the adopted ratios of the PV power, SB capacity and load power, a decrease in the cost of paying for electricity from the grid at a single tariff zones by two or more times is possible when the power of the PV generation is more than 0.5 of the maximum value on a clear day. The exclusion of the SB charge in case of a sharp decrease in the PV generation provides a cost reduction up to 1.39 times at a single tariff rate. The value of the generation power to the grid during the morning peak for a clear day can be 2 times higher than the load power. The most efficiency is achieved with multi-zone billing. In winter, on cloudy days, the efficiency is expectedly low regardless of the tariffication.

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