An Algorithm for Photovoltaic Battery System for Energy Reduction

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ABSTRACT: *We in this work have presented algorithm for measuring the saving in electrical costs for industries that used the photovoltaic battery model. We also presented the dimensions and specification of the proposed system. Inside the demand side management program we have sued photovoltaic batter system for saving energy. We have experimented the model with real data and diagram of demand in the selected industries and the results are described.*

Keywords: Industrial Customer, Photovoltaic Battery System, Demand Side Management, Peak Shaving

Received: 1 December 2020, Revised 1 March 2021, Accepted 15 March 2021

DOI: 10.6025/jes/2021/11/2/50-56

1. Introduction

Environmental protection requirements and limited reserve of fossil fuels have led to expansion of renewable energy sources (RES) [1]. RES, including wind, solar and their hybrid systems, have become attractive options of providing energy, offering many benefits such as low cost, no pollutant emission, energy security, easy accessibility and reduction of fossil fuel consumption [2]. The increase in installed capacity of RES has a positive effect on the demand side management (DSM). The DSM can be defined as a program or activities organized by the concessionaire, that allow the control of consumer load, which affect the amount of time and energy used by consumer [3].

Solar energy is the most available type of renewable energy. The photovoltaic systems which convert solar energy into electricity are widespread due to universal availability of solar energy. In recent years, application of photovoltaic systems has spread to industrial sector. They are used in demand control management program in order to increase the energy efficiency of the plant. Increase of energy efficiency leads to the reduction of electricity consumption from the grid and the achievement of significant savings.

In this paper the emphasis is placed on brute force algorithm that calculates savings achieved by application of photovoltaic battery system for industry sector and determines its dimensions for different new power peaks. This algorithm was used in industrial sector because industrial customers pay for peak power that they have used in a period of one month along with electrical energy bill. The cost of power peak in some cases may be a third of total bill for used electrical energy per month. Therefore, it is very important to perform the cut of peak power. Presented solution for peak power reduction uses photovoltaic battery system. The system was shown in the Figure 1. Battery bank is being charged from photovoltaic array. Battery energy supplying is managed by charger controller. Battery is being discharged through inverter which converts DC to AC and supplies consumer with power peak period.

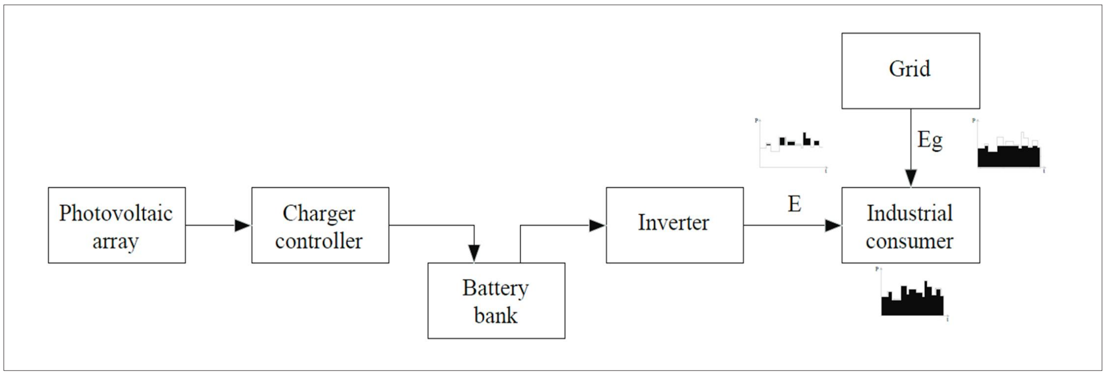

Figure 1. Photovoltaic battery system for demand control

2. Theoretical Background

DSM is the process of scheduling the loads to reduce the electrical energy consumption and/or the maximum demand [4]. There are many methods of DSM which can be followed by an industry, such as peak shaving, load shifting and valley filling.

Peak shaving is a technique that is used to reduce electrical power consumption during periods of maximum demand on the power utility. Cutting or reducing the duration of the peak can be reached by direct load control, by shutdown of consumer equipment, by diesel generator or by photovoltaic battery system.

Photovoltaic systems directly convert energy of the Sun into electricity. Electricity conversation is performed in photovoltaic cells. Photovoltaic cells are connected in serial and in parallel to make photovoltaic panel. Photovoltaic panels are connected in series to obtain the desired increase in DC voltage, such as 12V, 24V, or 48V. Series connected panels create photovoltaic array. Then, energy produced in photovoltaic array is stored in battery bank. Battery bank consists of serial and parallel connected batteries. Battery consists of serial connected accumulators. The number of serial connected accumulators depends of desired voltage of battery. It can be 24V for two serial connected accumulators or 48V for four serial connected accumulators. Electrical current from photovoltaic array is regulated by charger controller which prevents the voltage level from exceeding the maximum value from charging batteries. Then the customer is supplied with the electrical energy stored in battery bank through inverter in the period of power peak. Meanwhile, power peak is being reduced, due to change of the main energy source.

It is necessary to determine the parameters of photovoltaic battery system according to desired value of new power peak. In order to do so it is necessary to select type, power and the price of photovoltaic panel, type, capacity and price of accumulator, cost of inverter and cost of the rest of used equipment. The number of panels and accumulators can be determined by following equations.

First it is necessary to calculate the daily need for energy (Qd) that should supply customer in order to reduce power peak. This is presented by Eq. 1.

$$Q_d = \frac{E}{U_s}, \qquad (1)$$

Where E is the energy needed for reducing the power peak and Us is the battery voltage which depends on the value of E. If the reducing energy is lower than 10 kWh, the battery voltage should be 24V, otherwise it should be 48V.

The next step is calculating of the real accumulator capacity (K_n), presented by Eq. 2. This is important because battery must supply the customer during cloudy days when there is no energy production and possibility of charging battery bank.

$$K_n = Q_d \cdot N_a \tag{2}$$

Where N_a is the number of autonomy days when battery is only being discharged without the possibility of recharging.

One of the most important parameters for accumulator is depth of discharging (T_z) which limits the discharge of accumulator and determines the minimal value of real accumulator's capacity (K), presented in Eq. 3.

$$K = \frac{K_n}{T_z} \tag{3}$$

The next step calculation of the daily need for charging (Q_l) in Ah (ampere hour) taking into account accumulator charging efficiency (η) (because there are loses in accumulator contacts) and the number of days needed for fully recover of battery bank (N_e). This is given by Eq. 4.

$$Q_l = \frac{1}{\eta} \cdot \left(Q_d + \frac{K_n}{N_e} \right) \tag{4}$$

Then the value of Q_l in Ah should be converted to the value in *Wh* (*watt hour*) - Q_{lWH}, presented in Eq. 5.

$$Q_{lWH} = Q_l \cdot U_s \tag{5}$$

The number of panels (N_p) is calculated by dividing daily need for charging in Wh by average daily electricity production from the photovoltaic system (K_d), determined by calculating in photovoltaic geographical information system (PVGIS) for one panel. This is presented in Eq. 6.

$$N_p = \frac{Q_{lWH}}{K_d} \tag{6}$$

The number of accumulators (N_{AC}) is calculated by dividing minimum capacity of real accumulator by the capacity of one accumulator (AC) – Eq. 7.

$$N_{AC} = \frac{K}{AC} \tag{7}$$

The number of panels and accumulators is very important for calculating of photovoltaic battery system installation cost (CPS). The installation cost includes costs of photovoltaic panel (C_p), accumulator (C_a), inverter (C_i) and rest of equipment in photovoltaic battery system (C_o) and it is presented by Eq. 8.

$$CPS = Np \cdot Cp + Nac \cdot Ca \cdot 3 + Ci \cdot \frac{PPA}{1000} + Co \cdot \frac{PPA}{1000} \tag{8}$$

Where PPA is power of photovoltaic array.

The total cost for period of 20 years for industrial customer that uses photovoltaic battery system is calculated by Eq. 9.

$$TCPS = 240 \cdot (30 \cdot DCPS + P15PS \cdot C15) + CPS \tag{9}$$

where DCPS is daily cost for industrial customer with presence of photovoltaic system, P15PS is new power peak and C15 is power peak cost.

The total cost for period of 20 years for industrial customer that does not use photovoltaic battery system is calculated by Eq. 10.

$$TC = 240 \cdot (30 \cdot DC + P15 \cdot C15) \tag{10}$$

Where DC is daily cost for industrial customer and P15 is value of power peak.

3. Algorithm and Discussion

3.1 Algorithm

The algorithm which is used to determine savings and dimensions of system is shown in the Figure 2. It is necessary to make an assumption that daily diagram of industrial consumer is almost constant. Algorithm starts with input of all data, including: C_e - cost of electrical energy (€), C15 - cost of power peak (€), N_a - number of autonomy days, T_z - depth of discharging, η - accumulator charging efficiency (%), N_e - number of recover days, K_d - average daily electricity production from the photovoltaic system (PVS) (Wh), C_a - cost of accumulator (€), C_p - cost of panel (€), AC - capacity of accumulator (Ah), C_o - cost of the rest equipment in PVS (€), P_p – power of panel (W), C_i - cost of inverter (€) and n - number of new power peaks.

Step No. 1: Input daily diagram of demand $P(_j)$ for industrial customer.

Step No. 2: Input the first value for new power peak (Pc).

Step No. 3: Calculating the total cost of demand (TC) for period of 20 years without using PVS. It is being done by calculating hourly cost (HC) summed for a period of one day (DC). Then daily cost is used in Eq. 10. for calculation of total cost of demand (TC).

Step No. 4: Calculating daily cost with PVS (DCPS). That step starts by assigning the variable power peak with PVS (P15PS) the value of new power peak $P_c(i)$. The variable E_l and E_{cl} were used to save power which is equal or lower than new power peak and their sum represents the energy taken from the grid (E_g). Energy which is got from the PVS is denoting with E and it is the result of summing the difference (D) between daily diagram power (that satisfies the condition $P(j) \geq P15PS$) and power peak. Finally, for this step, energy from the grid is multiplied by the cost of electrical energy and makes daily cost with PVS (DCPS).

Step No. 5: Calculating the dimension of PVS (number of panels and accumulators). They are calculated by using Eqs. 1–7. Number of panels is multiplied by panel power representing the dimension of photovoltaic array (PPA).

Step No. 6: Calculating the total cost with PVS (TCPS) for period of 20 years. First, it is necessary to calculate the cost of PVS (CPS) using Eq. 8. Then, in order to determine TCPS the cost of PVS should be summed with the cost of energy usage for period of 20 years.

Step No. 7: Determining the savings (S) by calculating the difference between total cost without PVS and total cost with PVS. Finally, outputs of this algorithm are savings, dimension of photovoltaic array, energy from grid, energy from PVS and cost of PVS.

Number of new power peaks determines how many times steps 2-7 should be repeated.

3.2 Testing

Algorithm presented in previous topic was tested using program package MATLAB. The daily diagram of demand used in this paper is taken from one industrial customer in Serbia. It is approximated and shown in the Figure 3.

That daily diagram has four potential new power peaks. The input data necessary for calculating savings, dimension of

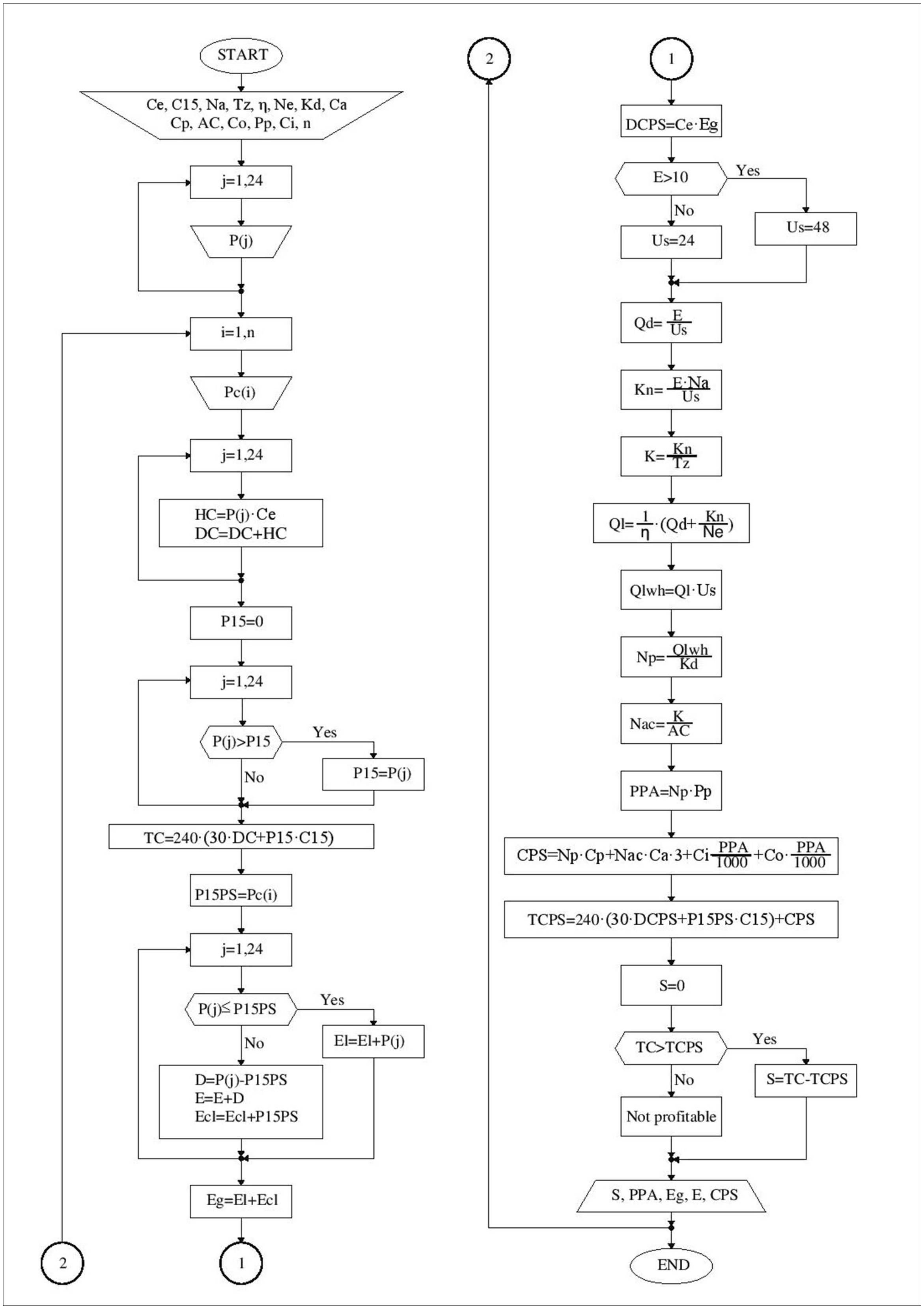

Figure 2. Algorithm

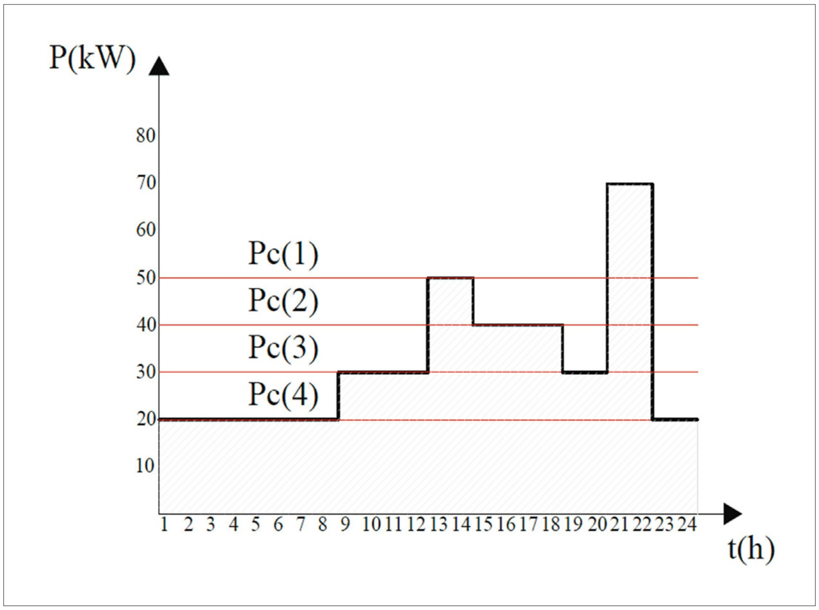

Figure 3. Daily diagram of industrial customer

photovoltaic array, electrical energy from grid and electrical energy from PVS are: $C_e = 0.2€$, $C15 = 10€$, $N_a = 2$ days, $T_z = 0.5$, $\eta = 0.9\%$, $N_e = 10$ days, $K_d = 800W$, $C_a = 250€$, $C_p = 220€$, $AC = 200Ah$, $C_o = 30€$, $P_p = 250W$, $C_i = 150€$ and $n = 4$. Results for each new power peak are shown in table 1.

The selection of most favorable solution is being made after getting results, according to investment capabilities and size of the area predicted for installation of the system.

P_c (*kW*)	*S* (€)	*PPA* (*W*)	*CPS* (€)	E_g (*k Wh*)	*E* (*k Wh*)
50	83542	15208	22058	740	40
40	142697	30486	44503	700	80
30	237008	61042	89392	620	160
20	384053	114515	167947	482	300

Table 1. Results for each new power peak

4. Conclusion

The algorithm for calculating savings in electrical bill for industrial customers with the presence of photovoltaic battery system was analyzed in this paper. This algorithm can be applied in different daily diagrams of demand, whereby benefits of the presence of photovoltaic battery system can be more or less significant, in dependence on the value of power peak.

With current electrical energy price, significant savings by using photovoltaic system are obtained. The price of electrical energy from grid will increase and the price of the photovoltaic equipment will be lower, so these applications will be used for all greater savings. In addition, application of photovoltaic system reduces the pollution and reduces the demand for non-renewable sources.

In future investigation accent can be put on optimization methods for costs minimization for industrial customers.

Acknowledgement

The paper is a part of the research done within the project III 44006, supported by Ministry of Education, Science and Technological Development of the Republic of Serbia within the framework of technological development.

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