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Calculation of accumulation unit for renewable energy source system

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ABSTRACT

The article deals with the accumulation unit calculation deployed in renewable energy sources system. It is assumed that accumulation unit consists of a defined number of batteries. There are two cases which are analyzed and discussed in this article. The first case determines how many batteries have to be connected to store input energy. The second one determines how many batteries have to be connected to provide output energy to connected electronic devices.

1. Introduction

Except for special cases, each system comprises an accumulation unit (AU) to operate properly. Both short-term and long-term AU balances difference between input and output energy. In renewable energy sources (RES) system, there are also AUs installed to support this operation. These energy sources are usually referred to as renewable sources of energy, as they depend directly or indirectly on sunlight.

In RES systems, different energy sources are implemented to generate electrical energy: solar cells, concentration cells, solar collectors, as well as indirect utilization of solar energy through biomass, water resources, heat pumps, wind power, marine energy, etc. [1–3]. Specific role have geothermal resources.

Different types of AUs can be implemented in RES systems: electrochemical batteries, supercapacitors, superconducting units, rotary, pneumatic and other. These types are referred to as short-term. Except for these, there are also long-term storages available. However, they operate on different principles.

The most accessible solution for users are electrochemical accumulators [4–7]. However, it is always necessary to design a size of AU to provide short-term storage of required energy amount to balance production and consumption during short periods of time.

2. Accumulation unit as key element of RES system

Electricity, which is generated by using photovoltaic panels, wind generators or other sources, is limited by an availability of input energy in different forms. The rate of incident global radiation varies according to the meteorological situation, namely the degree of cloud cover. Energy of wind depends on the current meteorological situation, thermal conditions in the atmosphere, land surface or sea level.

At the same time the energy consumption profile is defined. Consumption of energy is different during the nights, days, working days, weekends or holidays. Energy consumption profile also varies according to specific interests of the consumers. The reader and handyman have different energy requirements.

2.1. Ways of solutions of accumulation unit for RES systems

It is necessary to include an element to balance energy production and consumption over time. Any kind of RES system includes AU to balance energy production during short time periods. The AU is usually formed by serial-parallel connection of batteries. The most commonly used type of batteries is lead-acid batteries.

To determine the capacity of AU, there are two types of tasks to calculate:

- In the first case, total energy amount and production parameters are defined. Overall number and type of batteries connection can be calculated and determined. Afterwards, we can determine total output energy for connected devices.
- In the second case, consumption profile of connected devices is defined. Based on these values, we can determine type and amount of batteries to supply required energy into connected

device
profile

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Even it is possible to calculate the stored energy amount, this task is quite complicated. A complication causes a relatively large variance of input data of insolation at a location and position. This factor depends on type of the weather. Sometimes are insolation values more favourable, but sometimes worse. Another difficulty is the energy consumption profile, as it differs all over the day according to the user activities. Therefore it is recommended to overrate the calculated system to satisfy the user needs during peak period.

2.2. Proposed solutions

We assume that the AU stores energy produced during the day. This energy has to be stored and supplied later to the devices. The AU has to be able to both receive and store the produced energy. At first, it is necessary to select the type of batteries. For RES systems lead-acid batteries are the most suitable solution. User is usually interested in overall voltage, capacity and price. It is recommended to use batteries with a voltage of 12 V and capacity of 100Ah. This kind of battery is easily transferable and is able to form an AU with a voltage of 12 V or multiplies of 12 V.

For this type of battery we determine overall voltage U_S, depth of discharge H_V, expected lifetime Z_{AKU}, efficiency η_{AKU} and decrease in capacity PK_{AKU} when a battery has to be removed from the AU. Based on calculations, it is necessary to estimate the number of days to discharge the set when weather conditions are not favourable to fully recharge AU.

For the calculation it is useful to determine the number of batteries in one branch. This number can be determined using a battery voltage U_{AKU} and AU voltage U_S:

$$N_A = \frac{U_S}{U_{AKU}} \quad \text{(pieces)} \tag{1}$$

At first some constant values must be determined for the selected type of battery. We calculate the amount of energy that is stored in the fully charged battery. To calculate the energy amount W_{1AKU}, we define battery capacity $C_{AKU,}$ battery voltage U_{AKU} and the time interval $T_1 = 1$ h:

$$W_{1\mathrm{AKU}} = C_{AKU} U_{AKU} T_1 \quad \text{(Wh)} \tag{2}$$

The stored energy in the AU is divided into instantly usable and a reserve energy. The rate of usable energy is determined by the battery type. This rate should not be low as it reduces the battery lifetime. For lead-acid batteries manufacturer recommends a maximum discharge rate of 30%, as the remaining 70% of stored energy should not be used.

Usable energy W_P and reserve energy W_R stored in a battery are calculated from the stored energy W_{1AKU} applying a selected parameter – depth of discharge H_V:

$$W_P = W_{1\mathrm{AKU}} H_V \quad \text{(Wh)} \tag{3}$$

$$W_R = W_{1AKU}(1 - H_V) \quad \text{(Wh)} \tag{4}$$

Energy provided from the battery W_{1AKU3} is usable energy stored in the battery W_P reduced by efficiency coefficient η_{AKU}:

$$W_{1\mathrm{AKU3}} = W_P * (1 - 0{,}5 * (1 - \eta_{AKU})) \quad \text{(Wh)} \tag{5}$$

Energy received by the battery $W_{1\mathrm{AKU1}}$ is usable energy stored in the battery W_P multiplied by efficiency coefficient η_{AKU}:

$$W_{1AKU1} = W_P * (1 + 0{,}5 * (1 - \eta_{AKU})) \quad \text{(Wh)} \tag{6}$$

Overall energy stored in the battery at the beginning of installation is equal to the energy stored in the battery W_R. At the end of battery lifetime, this values decreases to W_{RKZ} by difference in battery capacity C_{EX}:

$$W_{RKZ} = W_{1AKU} * (1 - (1 - C_{EX}) - H_V) \quad \text{(Wh)} \tag{7}$$

3. Defined amount of produced energy

In this case, it is assumed that power unit produces and supplies input energy to the AU. This energy must be stored and later supplied to the connected devices.

RES is an important source of electric energy, which is also used as source of energy for other devices, providing different types of energy, e.g. thermal or mechanical.

In addition to the amount of energy necessary for day consumption, it is necessary to determine energy peak value. The peak value is measured to satisfy higher power consumption during peak periods.

The time interval of one day is a parameter that reflects the daily cycle of both energy production and energy consumption. The day begins and ends at midnight, when people sleep and power consumption is at minimum level. Energy consumption is higher during the day, but the profile of the energy consumption varies.

We assume that the generated electric energy is supplied and stored in the AU. Afterwards, AU supplies connected devices. The main problem is that the profile of energy production varies from the profile of energy consumption. Energy is often needed when production is not possible.

The number of branches of the battery unit N_V is determined by the input energy W_{11}, usable energy W_P, the number of batteries in one branch N_A and the charging time T_{HD} (per day) when charging is possible:

$$N_V = \frac{W_{11}}{W_P T_{HD} N_A} \quad \text{(pieces)} \tag{8}$$

The calculated number of branches N_V is usually rounded up.

The total number of batteries in the battery unit N_{AKU} is given by the number of all branches N_V and number of batteries in one branch N_A:

$$N_{AKU} = N_V N_A \quad \text{(pieces)} \tag{9}$$

Usable output energy W_{22} from the AU will be given by energy provided by a battery W_{1AKU3} and total number of batteries N_{AKU}:

$$W_{22} = W_{1AKU3} N_{AKU} \quad \text{(Wh)} \tag{10}$$

Reserve energy of the AU in the last year W_{R2N} life will be determined by the reserve energy of one battery W_{RKZ} at the end of battery life and a number of batteries in an AU. Reserve energy of the AU in the first year W_{R1N} of battery life will be defined by the reserve energy of one battery W_R in the first year and a number of batteries in an AU:

$$W_{R2N} = W_{RKZ} * N_{AKU} \quad \text{(Wh)} \tag{11}$$

$$W_{R1N} = W_R * N_{AKU} \quad \text{(Wh)} \tag{12}$$

To calculate overall price of the AU in crowns ($CENA_{Kc}$) or euros ($CENA_E$), price of one battery in crowns (PR_{Kc}) or euros (PR_E) must be known:

$$CENA_{Kc} = PR_{Kc} N_{AKU} \quad \text{(Kč)} \tag{13}$$

$$CENA_E = PR_E N_{AKU} \quad \text{(EUR)} \tag{14}$$