RESEARCH IN CHARGING PARAMETERS OF BATTERIES FOR TWO-WHEEL ELECTRIC VEHICLES

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Abstract. Battery charging parameters and their changes in time are important in charging a battery for a two-wheel vehicle. A research has to be conducted in order to choose a proper charging device, to optimally load the electric wiring network as well as to choose power and other parameters for alternative energy devices in order to ensure the charging process. The present research involves 5 various electric bicycles. The research also involves battery systems with a total voltage of 24 V, 36 V, 48 V and 60 V. For the research, both a data collection system and a battery discharging system were developed, which were successfully approbated.

Keywords: electric vehicles, charging time, current, voltage, battery charging equipment, battery discharging

Introduction

Every year the exploitation of electric vehicles expands in Latvia. Electric bicycles are the most popular. The possibilities for charging these vehicles have been considered as well. To provide a sufficiently fast, quality charge of an electric vehicle both, the charging parameters that depend on the particular charging device and its algorithm and the parameters of the electrical wiring network or another, for instance, alternative energy source are important.

If electric vehicles are not widely used and if several electric vehicles are not simultaneously charged at a charging station, no problems with the electric wiring network will arise. However, in case if the number of electric vehicles increases, the electric capacity of an initially planned charging station will be insufficient. This factor may be attributed to charging electric vehicles at public pay parking lots where they are parked overnight. In case if the parking lot has a 3-phase 16 A connection, a slow charge will be available to only 3 electric automobiles. In the case of a one-phase connection, only one electric vehicle may charge its battery.

As regards the total load of the electrical wiring network, charging at night is preferred, as during night hours when the overall consumption of electricity is low, the consumption of electricity could become balanced and more even.

Current parameters during charging are of great importance in designing alternative energy charging stations. By precisely forecasting the power capacity of a charging station, it is possible to reduce the cost of the alternative energy charging station.

Electric vehicles are designed with the capability to be charged according to several algorithms. All electric vehicles are designed for a slow charge at a relatively low power. A slow charge takes 6-9 hours, and it may be done from a regular 16 A outlet socket. The owner of an electric vehicle may rely on a slow charge at a parking lot for electric vehicles when the charging time is not essential. All low-speed electric vehicles usually use this way of charging, especially those with lead batteries. The charging process might be medium fast when a charge takes 5-6 hours. Such a charge is appropriate for some electric vehicles, but this kind of charge may use a 16 A direct current connection.

A fast charge of a battery takes 30-40 minutes, and the battery is charged up to 80 % of its capacity. For such a charge, a special direct current charging station with a power capacity of 40-50 kW is needed. A fast charge is mainly intended for electric vehicles equipped with a lithium battery [1]. Battery exchange stations are intended for only certain makes of electric vehicles. A detailed analysis of slow charge possibilities for only low-speed electric vehicles is performed in the present research.

It is especially important to know the characteristics of batteries to be charged and the parameters of small-capacity charging stations, for instance, charging stations powered by alternative energy. If the charging parameters are precisely known, the construction cost of a charging station powered by alternative energy may be considerably reduced. Kinds of charging stations powered by alternative energy for electric vehicles are shown in Fig. 1.

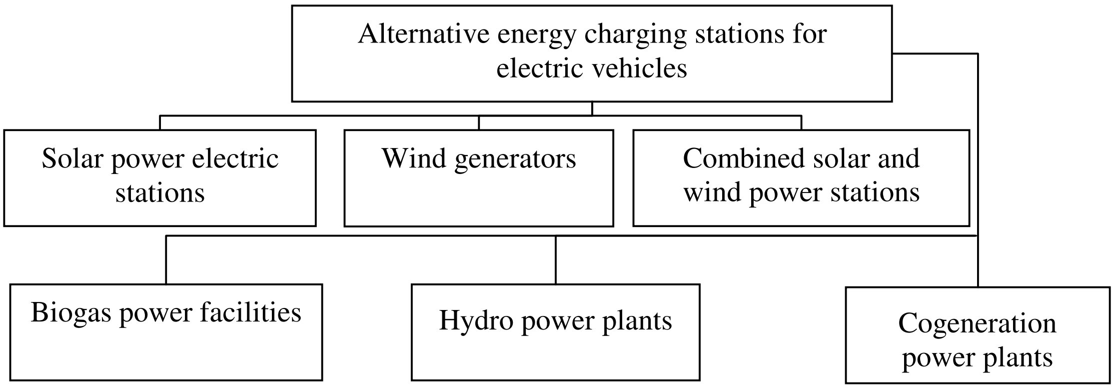

Fig. 1. **Kinds of charging stations powered by alternative energy for electric vehicles**

It is convenient to use solar power electric stations for charging electric vehicles. If such stations are used for charging small-capacity electric vehicles such as electric bicycles, the construction of these stations is not complicated and their cost is not high. The bicycle season usually also coincides with the highest solar radiation level – in spring, summer and autumn. Such electric stations may be designed and constructed especially for small-capacity electric vehicles.

Wind generators can also be used for charging electric vehicles, yet, in Latvia wind energy not always is available in necessary amounts. Accordingly, the use of such equipment is not always possible and the cost of this equipment is higher than that of solar photovoltaic power stations. In order that an alternative energy electric station is suited for various weather conditions, combined solar and wind power stations are used. The control system of such power stations is complicated and their cost is high.

The bottom of Fig. 1 shows alternative energy power plants, the construction of which for charging only electric vehicles is not reasonable. The use of such power plants for charging electric vehicles is efficient only if the electricity generated is used for other purposes. In this case, the charging capacity needed for small-capacity electric vehicles is not important, as the power capacity of biogas, hydro or cogeneration power plants significantly exceeds the power capacity needed for charging electric vehicles. Based on the previous analyses, one can conclude that among the given kinds of alternative energy power plants, the most convenient way is to use solar photovoltaic panels for charging small-capacity electric vehicles.

Research of the $LiFePO_4$ batteries has gained a lot of attention in the last 10 years. Wide research has been done about these battery charging and draining control systems, evaluating battery charging state depending from battery voltage. Data samples are stored with 2 sec intervals [2]. Research is also carried out in separate battery element balancing, which can lead to important improvement in battery operation time [3]. Research in $LiFePO_4$ battery charging has been done also by the LUA scientists, gaining charging voltampere characteristics depending on the charging time [4]. Lead acid battery research for electric vehicle drive has been done in previous experiments. There is 12 V battery charging studied with different charging currents and battery charging level, depending on the battery voltage [5]. However, research in electric bicycle battery pack charging characteristics for different voltage systems, using original vehicle charging devices, has not been done, that is why this research is topical.

The aim of the present paper is to determine and analyse the charging parameters of batteries for various electric vehicles. The findings can be used in designing small-capacity electric stations powered by alternative energy that are intended for charging batteries of electric vehicles.

Materials and methods

Research methodology. Experimental research was conducted on the batteries of electric bicycles and on the original chargers supplied with them. Battery charging voltage, V, and current, A, were measured by a data logger WINDAQ DI 145. The experiments were repeated five times for each set of batteries and a charger. After processing the experimental data, 3 most precise readings were selected and the average charging parameters were calculated. The following research objects – batteries – were used in the experiments:

- battery system with 2×12 V (24 V) 12 Ah batteries;
- battery system with 3×12 V (36 V) 10 Ah batteries;
- battery system with 3×12 V (36 V) 12 Ah batteries;
- battery system with 4×12 V (48 V) 12 Ah batteries;
- battery system with 5×12 V (60 V) 12 Ah batteries.

In all the cases, the duration of exploitation of batteries was two summer seasons, and the batteries were used on various electric bicycles. The batteries were discharged under load before their charging. Connected in a parallel or series circuit, 36 V 100 W incandescent bulbs were used as load. The discharging process was persistently controlled by the brightness of the incandescent bulbs, while multitesters were used for precise control. The discharge was performed based on a consideration that the voltage of each discharged battery has to be within a range of 11±0.1 V.

The charge was performed by a charging device supplied with each battery pack. The charge was performed until the batteries were fully charged. The average battery charging time in the experiments was 7-9 hours. The end of charging was indicated by a disconnection of the charging device, an automatic interruption of the charging process and the charging system transition to maintenance mode. In the experiments, the data logger recorded changes in voltage and current in the entire charging period. In the initial stage of data reading, the voltage was measured with a multitester and the data were compared with the logger readings on the window of its program. If the readings deviated by more than 5 %, calibration of the logger was performed. The information recorded by the logger was saved in a computer connected to it.

Equipment used in the experiments. The data logger WINDAQ DI 145 connected to a laptop computer Lenovo T60 was used to record the data. The key characteristics of the logger are as follows:

- 4 fixed differential analog inputs protected to ±150 V;
- two dedicated digital I/O ports for Remote control protected to ±30 V;
- ±10 V full scale measurement range;
- 240 samples per second maximum sampling rate;
- three status LEDs for easy notification of system status [6].

For operational control of the discharge and charge processes, a digital multimeter RMS FLUKE 87 was used. The multimeter key characteristics are as follows:

- VAC max. 1000 V;
- VDC max. 1000 V;
- ADC max. 10 A;
- resistance max. 50 MΩ;
- VDC resolution 100 μV;
- VAC resolution 100 μV;
- bandwidth VAC 20 kHz;
- bandwidth AAC 2 kHz;
- AAC max. 10 A.

Results and discussion

After the data on the charging process were collected, they were selected and processed. Out of the 5 repeated measurements, the data to be most mutually compatible were selected. The criteria for data compatibility were as follows: charging time and initial voltage before charging [7]. In order that the battery packs have an equal voltage at the beginning of charging, they were held for 10-15 minutes after the end of discharging and only then charging began.

Fig. 2 shows the experimental results for charging the battery system 2×12V (24 V) 12 Ah. From the perspective of exploitation, these batteries may be characterised as being in good condition.

The full charge time for the 24V battery system was 7.53 h. A sharp increase in voltage and a corresponding decrease in current were observed in the first 10 minutes of charging. The charger retained constant charging current within a range of 1.70±0.02 A until the 5th hour of charging. After 5.6 hours, the current started gradually decreasing, whereas the voltage increased faster than before. In the final stage of charging, the current decreased to 0.4 A. The voltage reached 29.50 V in this period. After the charger disconnected, the voltage stabilised at 28.2 V (14.1 V per each accumulator if equivalent charge). Even though the charger retained a charging current of 0.2 A, the charge indicator indicated that the batteries were fully charged and the charge was stopped. The charging power did not exceed 48 W in the experimental period.

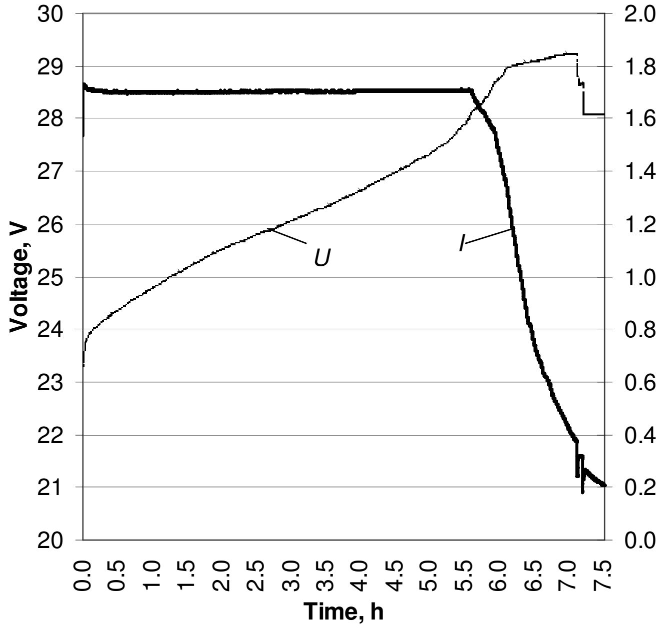

Fig. 2. **Charging voltage and current for the 24V battery system**

The next series of experiments were conducted on the 36 V battery system (Fig. 3). These batteries were also in good condition. The curves similar to those for the 24 V battery system were obtained.

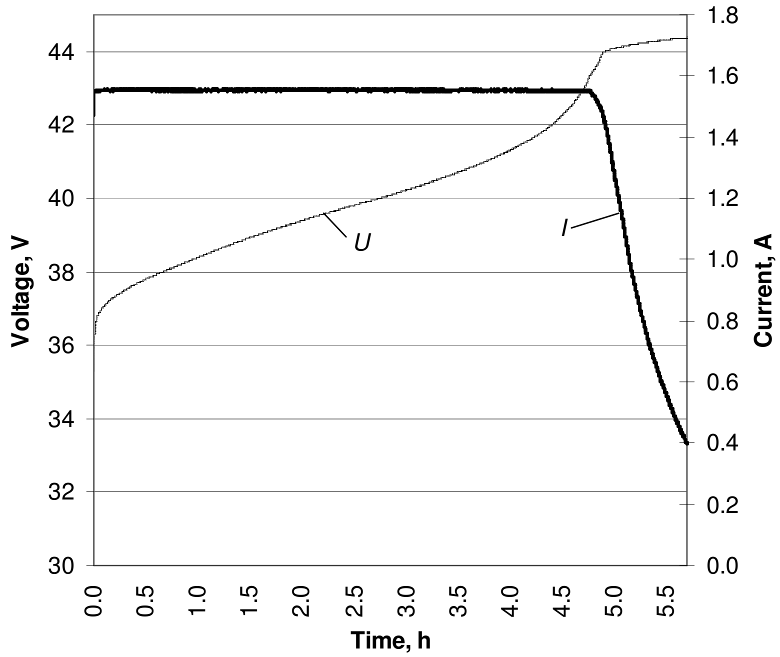

Fig. 3. **Charging voltage and current for the 36V battery system**

The average full charging time was 5.7 h. In the first 7 minutes, the voltage increased from 35.3 to 37.1 V. The charging current in the first 4 hours was stable, within a range of 1.55±0.02 A. After a charge of 4.4 hours, the voltage started increasing very fast and in 30 minutes increased from 42 V to 44 V. Beyond this level of voltage, which corresponds to a charge of 4.9 hours, the voltage evenly increased to 44.4 V (14.8 per each accumulator) and the current gradually decreased to 0.4 A when the charger disconnected. The charging power did not exceed 66 W.

The experiments were also conducted on the 48 V battery system (Fig. 4), the batteries were in good technical condition. The capacity of each of the 4 batteries was 12 Ah. At the beginning of charging, the voltage was equal to 48.3 V. The average charging time was 5 h. The battery voltage gradually increased to 56.6 V in 3.4 h. In the first 3.4 h, the charging current was steady and did not exceed 1.81±0.02 A. After a charge of 3.4 hours, a decrease of the charging current was observed, reaching 0.2 A at the end of charging. The voltage continued rising up to 58.8 V (14.7 V per each accumulator), yet, during the charger disconnection process (the charging current was decreasing) it decreased and stabilised at 55.3 V. The charging power was less than 99 W.

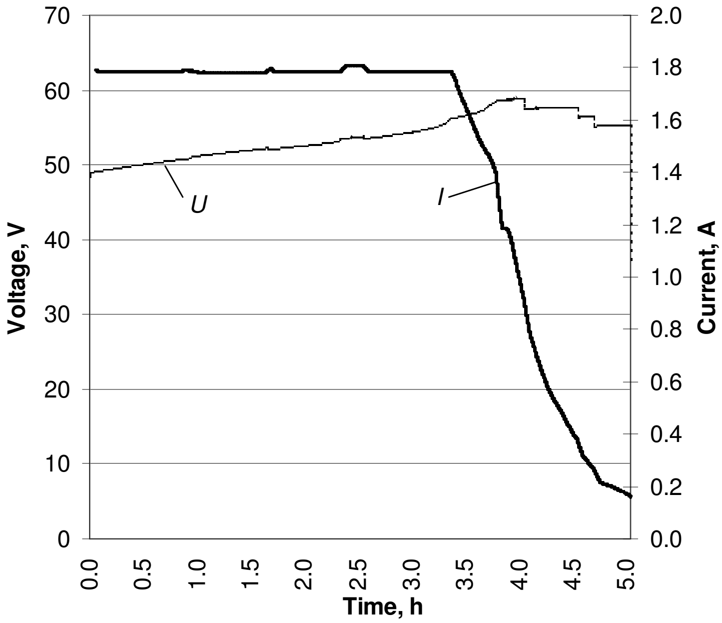

Fig. 4. **Charging voltage and current for the 48V battery system**

In the experiments on the 60 V battery system, the average charging time was 11.26 h (Fig. 5). The battery pack consisted of five 12 V batteries. In the first 8 minutes, a fast increase in the charging voltage occurred, rising from 57.6 to 60.8 V. Afterwards, the charge was steady, with the voltage gradually climbing to 72.4 V.

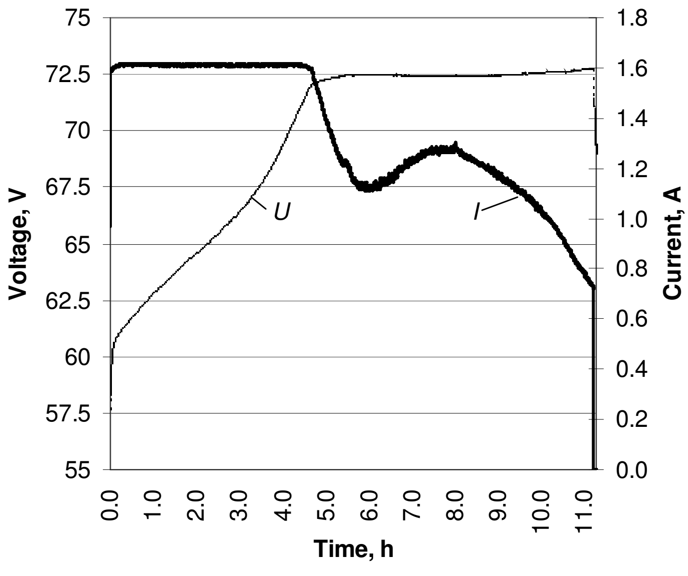

Fig. 5. **Charging voltage and current for the 60 V battery system**

The average charging current was within a range of 1.54±0.3A in the first 5 hours. Reaching a voltage of 72.5 V (14.5 V per each accumulator), the charger gradually started disconnecting. The disconnection lasted for 0.6 hours and the charging current decreased from 1.50 to 0.72 A. The maximum charging power for the 60V battery system reached 115 W.

Experiments were also conducted on a battery system in which one battery was defective. The curves of charging, in this case, were different from the above analysed curves; besides, the maximum voltage was not reached by the battery pack and the charging process did not stop automatically.

Conclusions

1. The curves of experimental charging were similar for all the battery systems. The curves suggest that a special charging algorithm has not been used for all experimental vehicle chargers.
2. The experimental chargers were developed to be able to retain the same current in the entire charging period. Regardless of the battery system, the current was 1.51-1.83 A.
3. The batteries disconnected in the moment when, on average, the voltage of each battery reached 14.1-14.8 V. In designing a charging device powered by alternative energy sources, for instance, solar cells, an algorithm for interrupting the charging of a controller has to be similar.
4. According to the experimental data, charging one two-wheel electric vehicle requires a solar cell with a power of at least 120 W. If using smaller power solar cells than would be required, charging batteries will take longer than from a standard charger powered from the electrical wiring network.
5. Electric bicycles are most often equipped with a battery system of 36 V. In designing an alternative energy charging device, the solar cell power of 80 W is sufficient for electric bicycles of this type.
6. The disconnection process of a standard battery charger may take even an hour. In this period, the current gradually decreases up to 0.20-0.72 A.
7. In case there are suspicions that some battery in the pack is not in good technical condition, it is advised to use a timer in the charging process, setting the disconnection time based on the nominal charging time of the particular battery pack. Otherwise, the other batteries may be damaged.

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