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Test bench for battery energy storage selection for use on solar powered motor yachts

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Abstract

An increasing number of transport vehicles, including vessels, are powered by electric engines supplied by batteries. Warsaw University of Technology, together with the Maritime University of Szczecin and industrial partners, is involved in the "Innovative yacht with hybrid drive, fueled by renewable energy sources" project, focused on the construction of a yacht driven from such a source. The biggest challenge in this field of technology is represented by the batteries. Proper assortment and exploitation can significantly extend their life cycle. For this reason, the interest in forecasting battery life cycle in specific applications has increased. In this article the authors review the types of batteries used in transport and present the design and realization of a laboratory workstation developed to test battery parameters in the context of the project. The process of gathering parameters and the testing conditions are also presented. An original IT system manages the progress of the experiments. Logged cell operating parameters will be presented along with the real, measured data.

Introduction

An increasing number of devices of daily use are powered by electricity from batteries. The most popular are mobile phones, laptops, or portable music players. In time, even individual and collective means of transport using battery power are becoming more popular. A significant increase of interest in electric drive is also prominent in seafaring. Yachts driven by electric motors are already available on the market as well as kits to perform the conversion to electrical drive in already existing units. In the sphere of interest, there are also hybrid designs, where the necessary energy is obtained by an electric motor, internal combustion, or both, depending on the situation. This solution allows for limiting fuel consumption, that is, the reduction of unit operating costs while maintaining the range. Many projects are currently being carried out regarding electric water transport; this is due to the desire to reduce air pollution, noise, and the costs associated with the operation. One of these projects is the "Renewable Energy Powered Innovative Hybrid Sailing Yacht" project.

Types of chemical battery cells used in transport

The first, and still used, chemical cell for electric motors is the lead-acid cell. Despite its disadvantages, such as short life span, sensitivity to temperature, a small number of life cycles, and large weight, it is still used because of its availability and attractive price.

Nickel-metal-hydrogen cells, initially introduced to replace the toxic nickel-cadmium technology, are in competition with lithium-based batteries. The energy density of these nickel cells is about 120 Wh/kg and rated voltage is 1.2 V (Riezenman, 1995).

The lithium-ion batteries are among the most commonly used cells and they are characterized by high energy density of 160 Wh/kg and high nominal voltage of 3.6 V. An additional advantage is the large number of life cycles and slow self-discharge process. The disadvantage of the lithium-ion battery is the lack of resistance to voltage drops below 2.4 V, resulting in loss of the functionality of the cell, which may in turn lead to its destruction. In order to eliminate this drawback, a control system is used to protect the battery against excessive voltage drop.

The main difference between lithium-ion battery cells and lithium-polymer ones involves the use of solid electrolytes, where conductive polymers with dissolved lithium salt are used. This solution eliminates the possibility of leakage. Unfortunately, these cells are very sensitive to overload, which can lead to damage and, in extreme situations ignition. For this reason, it is necessary to strictly control the use of the system's charging process (Binkiewicz, 2009). The main application of this technology is modeling, but adaptation to transportation needs is in progress. Rated voltage is equal to 3.3 V, and the energy density reaches up to 250 Wh/kg.

Lithium-iron-phosphate battery cells are currently gaining popularity due to the high degree of security provided by this technology and their long life; however, they are characterized by lower energy density, about 110 Wh/kg, than conventional lithium-ion battery cells and a rated voltage of 3.2 V. They are used in transport, particularly if there is a possibility of placing a larger battery pack, for instance in electrically powered boats (Jiayuan, Zechang & Xuezhe, 2009).

The main goal of the laboratory workstation project

Often the correct prototype battery pack determines the fate of the entire project. In order to properly select the cell type and the model to be used in the battery pack, it is necessary to perform a thorough analysis of its performance in a particular application. The choice of the right cell is based on the analysis of the technical specifications provided by the manufacturer. An evaluation of the cells that meet the requirements of a given application may be carried out on the basis of parameters such as:

- operating temperature range;
- permissible operating currents;
- safety requirements;
- service requirements;
- deemed storage tank cost.

Usually, after such an analysis, it is possible to determine the types of cells that can be used to build a package in accordance with the expected criteria. A specific selection must then be made based on the analysis of the following parameters:

- the impact of charging and discharging current on the available storage capacity;
- effect of temperature on the available capacity;
- dependence of lifetime on the number and depth of work cycles performed (Guena & Leblanc, 2006).

A set of data needed to complete these steps is not widely available and missing data can only be obtained by experimentation. The amount of information needed to carry out the selection tray is significant, and its collection must be performed on a specially designed computer-controlled station.

Workstation technical requirements

To obtain data useful for the creation of models of individual cell types it is necessary to conduct a series of measurements, which must meet the following criteria:

1. Time constant of each measurement for every cell must be the same.
2. Equal step change of the value of charge and discharge current between each measurement for every cell.
3. Every measurement must yield the following dataset:
   - timestamp;
   - cell temperature;
   - cell current;
   - energy sent/received;
   - cell voltage.

The equipment must enable the execution of the process in the conditions needed for a given cell and the recording and archiving of the above parameters. In addition, it must be possible to control and preview the process from a PC, including remote viewing via the Internet.

The number of work cycles performed must also be recorded, because each type of cell will be tested with the aim of determining its actual durability. Such tests will consist of a series of charge and discharge measurements with a specific current, until the loss of capacity equals 30% of its initial value. These experiments are planned for specified discharge factors corresponding to operation at full capacity, half capacity and in so-called microcycles.

The conditions in which the tests are conducted also play a key role. The basic parameter that needs to be controlled is the ambient temperature. All tests will be conducted in a thermo-stabilizing chamber ensuring a constant external temperature of the cells at 21°C.

Measurement system

The workstation setup requires the following devices:

- an actuating system enabling simultaneous testing of four cells;
- a measurement system for collecting and archiving the parameters;
- a power supply for the testing equipment;
- the thermo-stabilizing chamber;
- a controlling computer.

The following actuating and measurement setups were envisaged:

1. A workstation based on separate modules: a programmable power supply, programmable load, electrical and temperature recorders.
2. An integrated measuring system enabling charge and discharge of the cells and measurement of the required values.

A workstation built based on the first principle would allow testing in a wide range of operating currents with a degree of accuracy sufficient for the project; however, such an approach suffers from the following disadvantages:

- the need to control each system separately using different software;
- large dimensions of individual elements;
- complicated composition of the workplace;
- acquiring a large number of parameters from different processes simultaneously using the same recorder increases the risk of losing significant amount of data in case of failure;
- high price;
- in case of failure of one or more elements of the workstation the repair procedure would be complicated due to the fact that every element comes from a different manufacturer.

Following the market research and taking into account the specifications, an integrated charger Pulsar 2 from the Polish company Elprog, has been selected. The possibility of adding customized functions to the charger software and of controlling the device via the serial port has been arranged with the producer. Pulsar combines an actuating system (programmable power supply, programmable load) and measuring system, which further reduces the project's costs.

Pulsar 2 additionally allows:

- saving the settings for the process in one of 8 memories;
- working with the following cells: Ni-Cd, Ni-MH, Li-Ion, Li-Pol, Li-Ta, Pb-bat, RAM, Li-Ph ($FePO_4$);
- forming and regenerating cells;
- measurement of the internal resistance of cells and packets;
- returning energy to the battery power supply unit;
- charging and discharging current in the range of 0.2 A – 9.9 A;
- charging voltage in the range 0.5–60 V;
- temperature measurement and thermal protection of the charged battery;
- recording of the process on the SD card and data transfer to the controlling computer.

Each of the four chargers is supplied with an individual set comprised of laboratory power supply and a 12-volt lead-acid battery. The use of the battery in the power supply not only allows the power return but also acts as a backup in case of power outage in the laboratory.

To maintain a constant temperature during the test it was decided to use the electronically controlled refrigerator with Peltier cells. This makes it possible to maintain a constant, predetermined temperature at which the cells are tested. A visual inspection of the cells is possible without opening the unit. All data on cell temperature and ambient temperature are recorded by the measuring system.

The computer is used to control the charging/discharging process of the battery via a programmable Pulsar charger. Due to its built-in battery, it was decided to use a laptop type computer, which can continue the measurements even in the event of a power outage. Another important requirement for computer is that it needs to be equipped with at least 4 USB ports, allowing the control of four chargers. CPU and memory simply need to meet the requirements that allow comfortable work in Windows 8.x, so that consecutive measurements are not slowed down by a lack of memory. The computer should run a remote access service through the network to view the current measurement results. The constructed and operated test setup is shown in Figure 1.

During the measurements, the system's storing capacity as a function of the current's discharging

Figure 1. View of test setup

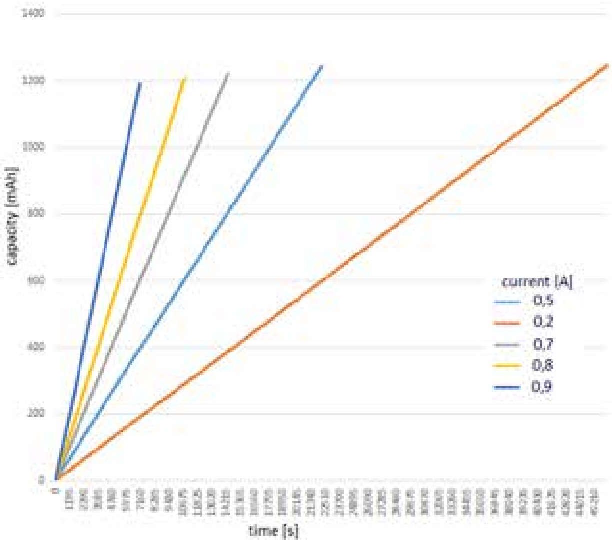

Figure 2. Capacity dependence characteristics of the charging current

and charging characteristics were studied. Sample characteristics are shown in Figure 2.

Software

The basic process carried out in a measurement system consists in charging and discharging the cell, connected to the Pulsar charger and controlled by a computer (Figure 3). Data transmission takes place via a physical link USB 2.0 running in emulation mode RS 232. Control commands for charger operation are sent from the computer to the Pulsar charger. The charge cycle begins by sending the appropriate commands, after which the application reads the measurement data on the COM port. Depending on the acquired information, the application decides whether to continue the charging/discharging process or to interrupt it due to error, e.g. loss of power, complete discharge of the battery, exceeding the limit values. The control process also takes place visually through a screen built-in charger.

The data received from the Pulsar charger are stored on the computer as CSV files, each file corresponds to one cycle. Files are sorted according to the charger operating mode. The computer is controlled locally or remotely using Microsoft Remote Desktop Protocol.

Computers constituting the system are connected in a local area network LAN. Communication between computers on the network takes place via TCP/IP protocol. The measurement data are stored in a Microsoft SQL Server relational database running on the server. The server is controlled by the operating system Windows Server. The server also provides WEB applications services. REPSAIL database contains information about cell charging or discharging processes, types of cells, power sources providing energy supply, and loads with demand timetables.

Importing measurement data from CSV files into the database is done using ETL (Extract-Transform-Loading) application running on Windows Server. The application allows loading measurement data from the files in the specified directory. The application realizes all stages of the ETL process (Czerepicki & Góralski, 2012). Data extraction is understood as reading of CSV files. The errors occurred during measurement should be detected. The data containing errors are not loaded into the database. If such a situation is detected the application prepares an appropriate report as a text file, allowing the local operator to repeat the charging or discharging of the battery. At the stage of the transformation of linear data loaded from the CSV files, these are divided into categories: charging cycles, detailed measurements parameters, batteries, etc. The stage of loading data into the database consists of saving a set of tables to the relational database.

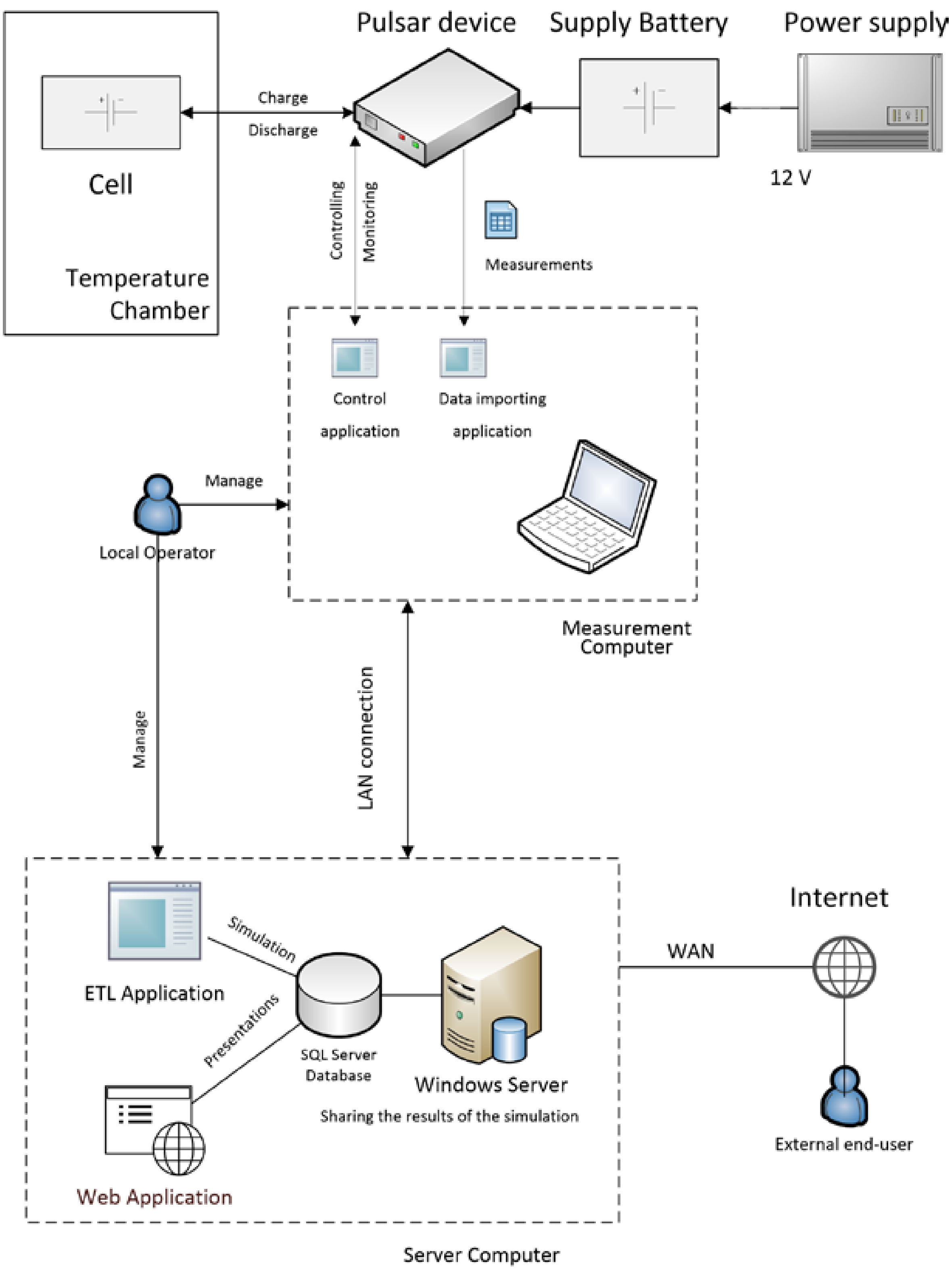

Figure 3. Measurement and software system diagram

The application can also be started from any computer on the network. However, due to very large capacity of input data the transfer in the local network may take a long time, much longer than copying the CSV files to the server and running the application from a local user account. The server is managed remotely. The local operator uses a remote desktop application to perform ETL operations.

The end user has access to the collected information in the database through Web application using the .NET Framework. The application is hosted on Microsoft Internet Information Server and can be shared with Internet users.

Conclusions

The proposed workstation for the study of operating characteristics of chemical cells allows for testing, registration, control and communication with the user. Communication is provided from both the Pulsar equipment and control computer, plus it is possible to connect to the workstation through the Internet. The workstation was used to collect data links in the framework of the "Innovative yacht with hybrid drive powered with renewable energy sources" project, carried out at the Department of Transport at Warsaw University of Technology. The collected data will be used to build computer models of chemical cells for the purpose of selecting the battery pack, and an analysis of their work for the defined voyage cycles.

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