Wireless System for Battery Cell Voltage Monitoring

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Abstract – **The subject of this article is the development and the testing of a wireless battery voltage monitoring system. A smart device using Wi-Fi interface is developed to measure the voltage and temperature of each cell of a battery. This device makes possible the construction of a smart battery monitoring system for control and optimization of the charge/discharge cycles of a battery.**

Keywords – **Battery monitoring, Smart sensor, Data acquisition, Wi-Fi interface, Internet of Things.**

I. INTRODUCTION

Most of the batteries consist of a number of cells connected in series. Usually in the process of charge and discharge the voltage of the whole battery is monitored but not that of the individual cells. This principle relies on that all cells from the same battery are with identical parameters and are always in an equal state of charge. When the battery gets older, the cells change its parameters. The capacity of some cells drops more than others and the internal resistance of some cells is getting higher than others. These differences are leading to a non-equal state of charge of the different cells. The weaker cells go into a deep discharge and overcharge frequently. At the same time the stronger cells stay undercharged. This puts the cells into a non-optimal mode of operation and the asymmetries are getting worse with time and soon the battery reaches its end of life [1].

For the purpose of the battery monitoring a cheap device with small size and Wi-Fi interface is developed. The device is mounted on each individual cell of the battery and monitors the voltage and the temperature of the cell. The current through the battery is monitored also. All the data is sent through a Wi-Fi interface to a central station where the data from the whole battery is collected and processed. This gives information for actual parameters of each individual cell and can be used to optimize the mode of operation of the battery. With this methodology one can provide the required measures to counteract the cell degradation in the exact time and prolong the battery life.

II. STRUCTURE OF THE CELL VOLTAGE MONITORING MODULE

The structural diagram of the cell voltage monitoring device is represented in Fig. 1.

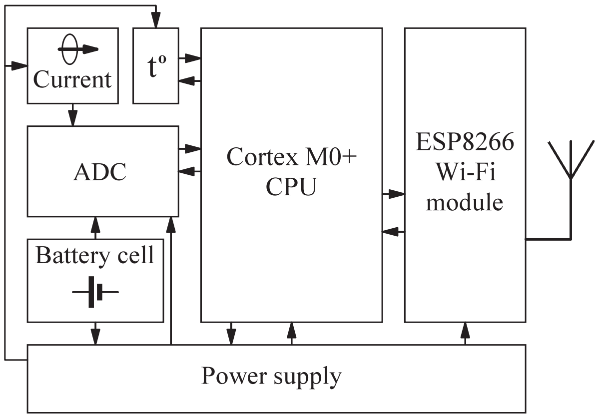

Fig. 1. Structural diagram

It consists of a power supply module, Wi-Fi interface module, CPU module and some peripheral devices like Analog-to-Digital Converter (ADC), sensors etc. The microcontroller Cortex M0+ is a low power microcontroller which controls the whole measurement process and communication through the Wi-Fi interface. The used Wi-Fi interface module is based on ESP8266 device and has serial interface for data transfer and Printed Circuit Board (PCB) antenna [2]. The cell voltage monitoring module also incorporates Analog-to-Digital Converter, digital temperature sensor and current sensor.

The microcontroller program algorithm does the measurements, sends the data through the Wi-Fi, receives control packets of data from the central station and puts the microcontroller and all peripheral modules to low power mode, called ‘Sleep’. A wakeup timer is started and when it counts to zero the microcontroller wakes up and does the routine again. This is a key measure to reduce the power consumption of the module and the self-discharge of the cell.

III. POWER SUPPLY

The power supply module generates all of the supply voltages needed for the system from the voltage of the battery cell itself. The voltage of the cell varies in a wide range based on the type of the battery and the state of charge. The DC-DC converter uses TPS61200 device. Its input voltage interval is from 0.5 to 5.5V which covers almost every battery cell voltage and state of charge. The DC-DC converter features reduced idle power consumption and high efficiency by using synchronous rectifier. The specific application requires the

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power supply to withstand significantly higher voltage than the standard cell voltage in case of open circuit into the battery cell. In such scenario the whole battery voltage can appear over the cell terminals with the reverse polarity [3]. In such case the power supply should shut down safely. The power supply can shut down also in case of deep discharge of the battery cell. In these cases the central station loses connection to that cell which is interpreted as failure in the cell.

IV. COMMUNICATION PROTOCOL

The data transfer through the Wi-Fi is organized in *64 bit* packets Fig. 2. Every packet starts with the *16 bit* battery identification number followed by *4 bit* cell number. The next information transmitted is the *12 bit* temperature value followed by the two *16 bit* values for the current and the voltage. As the current is equal for all cells in a battery only one module measures the current. This is either the module of the first or the last cell. The current value transmitted from all other cell modules is 0x0000.

Battery ID	Cell number	Temperature value	Current value	Voltage value
16 bit	4 bit	12 bit	16 bit	16 bit

bit 0 *bit 16* *bit 20* *bit 32* *bit 48* *bit 64*

Fig. 2. Structure of the data packet

The power consumption of the module is proportional to the frequency of the measurements, Fig. 3.

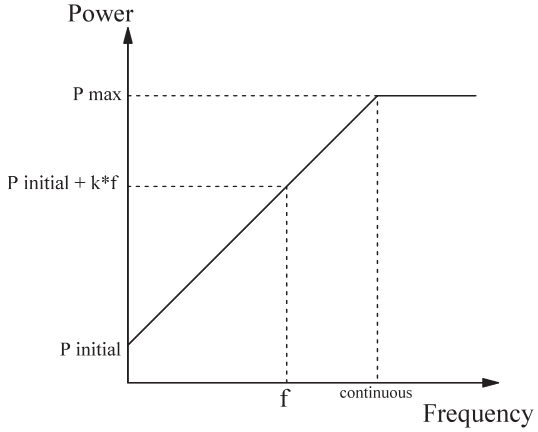

Fig. 3. Power-to-frequency relation

A two-way communication protocol is developed for self-discharge reduction. If the cell module cannot connect to the central station the turn on frequency is low - one turn on per minute. This reduces the power consumption and the self-discharge When the connection with the central station is established the station responds to the cell module with a data packet which contains the desired frequency of measurement in the form of a value for the sleep timer of the microcontroller. If needed a continuous mode of measurement can be activated.

The program algorithm of the cell module is represented on Fig 4:

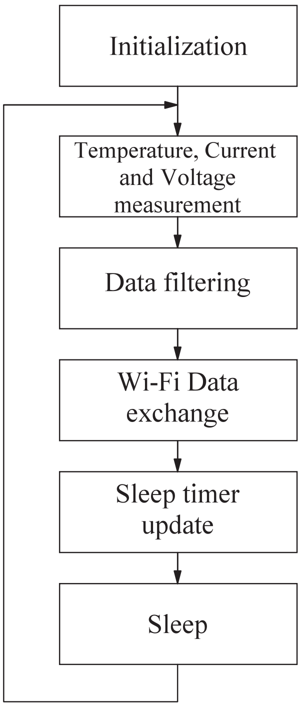

Fig. 4. Cell module program algorithm

After a restart the microcontroller performs initialization of all peripheral modules. Then it measures the temperature, current and voltage and filters the data to eliminate the noise. After that it sends the processed data to the central station and receives the control data packet. From the packet it extracts the sleep timer value, loads the timer and puts the peripheral modules and the processor to sleep. When the sleep timer expires the processor wakes up and repeats the algorithm.

V. DATA FILTERING

In the process of battery usage electromagnetic interferences are generated either from different loads or from a charging station. This interference can affect the accuracy of the measurements and introduce significant error.

In the process of the DC voltage and the current measurement a simple averaging on *n* samples can be performed to eliminate the noise influence. In some cases when a lower data delay is required, more complex algorithms as moving average can be implemented.

The microcontroller in the module does the moving average on *n* samples before sending the results to the central station.

VI. CENTRAL STATION

The central station consists of a Wi-Fi server and a microprocessor system with a user interface. It performs all of the control and communication with the cell modules and collects the data. Based on the information for the cell voltages, currents and temperatures it can calculate the best mode of operation for the battery at the exact time and send it to the charge/discharge controller for correction.

The information for the voltage of each cell along and the current through the battery can give various different parameters for the battery. When the data is collected and processed the state of charge, capacity and the internal resistance of each cell can be determined in a random moment of time. This information may be very useful for determination the optimal time of performing the charge or the corrective service to the battery. Estimation for the end of life can also be prepared.

The central station program algorithm is represented in Fig. 5.

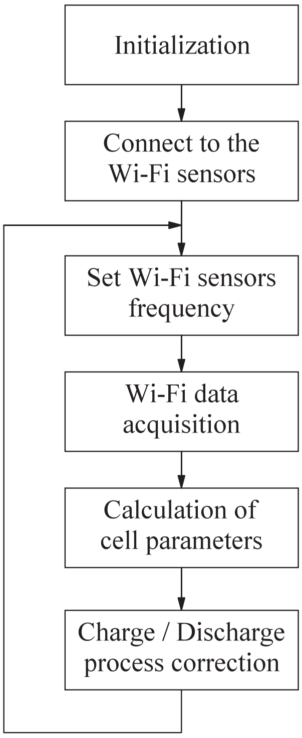

Fig. 5. Central station program algorithm

After a restart initialization of the peripherals is performed. Then a connection is established with all of the cell modules. The desired frequency of measurement is sent to the cell modules and the data from the modules is received. The received data is processed and the parameters are calculated. Based on the calculations the optimal mode of the battery is determined and the mode is corrected. Then the algorithm is repeated.

VII. MATHEMATICAL CALCULATIONS

When the data is collected in the central station the following parameters of the battery cells are calculated:

- Cell capacity. The capacity of the cell of a battery is calculated by integrating the current through the cell in the time of discharge when starting at a fully charged cell and finishing at fully discharged.

The capacity of the lead-acid batteries decreases as the discharge current increases [4]. In this case the capacity calculation is corrected according to Peukert's law Eq. (1):

$$It = C\left(\frac{C}{IH}\right)^{k-1} \tag{1}$$

where:

It is the capacity for the actual discharge current I,
C is the standard capacity for the discharge time H in hours,
k is the Peukert's constant for the battery.

The equation is applied to every time interval with relatively constant discharge current.

This method is fairly accurate but it is inapplicable in some cases because of the required starting conditions of fully charged battery and the required full discharge. These requirements are not fulfilled every discharge cycle because the lead-acid batteries are usually recharged before full discharge.

An alternative method for capacity measurement is proposed using the voltage versus state of charge curves for the battery Fig. 6.

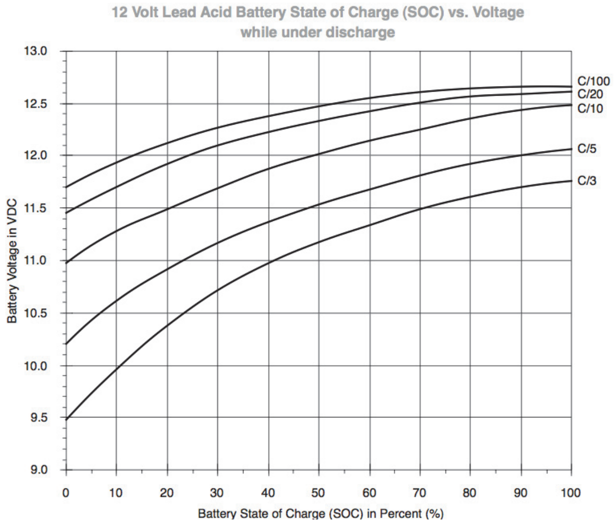

Fig. 6. Voltage versus State of Charge curves

The state of charge is determined according to the standard curves for the battery in the beginning and the end of the measurement period. The current is integrated in the time of the measurement period. The capacity is calculated according to Eq. (2):

$$C = \frac{\left(\int_{t=0}^{t=n} I.dt\right).100}{SoC_{t=0} - SoC_{t=n}} \tag{2}$$

where:

$t=0$ is the beginning of the measurement interval,
$t=n$ is the end of the measurement interval,
$SoC_{t=0}$ is the State of Charge in percent at the beginning of the measurement,
$SoC_{t=n}$ is the State of Charge in percent at the end of the measurement interval,
C is the approximated capacity of the cell.

For lead-acid batteries the calculated value C is corrected using the Peukert's law to get the standard 20h discharge capacity.

These capacity measurement algorithms are not so accurate in comparison to the measurement using a constant discharge current. However, these algorithms give a rough idea for the capacity of each cell.

- Static internal resistance of the cell. The static internal resistance of a battery cell is important parameter. It is used for determining the state of charge, the aging of the cell and the optimal charge/discharge current. It is calculated from the variation of the cell voltage versus the variation of the current through the cell and is given by Eq.(3):

$$R_i = \frac{\Delta U}{\Delta I} \tag{3}$$

where:
R_i is the internal resistance of the cell,
ΔU is the variation of the cell voltage,
ΔI is the variation of the current through the cell.

The internal resistance is calculated every time when a load current variation occurs. The natural wide interval of load current variations allows the building of a load curve for each cell of the battery and also a curve of the static internal resistance versus the load current.

- End of life prediction. Based on the above calculations the end of life of the battery can be predicted. A rapid increase of the internal resistance of one of the cells or rapid decrease of the capacity is sign for a problem with the cell. The cell can be serviced accordingly or a corrective charge can be applied. This way the life of the battery can be extended [5].

The method of equalizing charge can be applied if the state of charge of the different cells of a lead-acid battery differs too much. The equalizing charge is applied until the state of charge is equalized. The usage of the data from the cell modules can help determining the exact moment of application of equalizing charge as well as the application period. This extends the life of the battery [6].

VIII. CONCLUSION

The developed battery cell voltage monitoring device helps gaining much information about the battery in the field of application. This information can be useful as for better studying the processes in the battery, as for optimizing the battery usage to extend its life.

The calculations for the different battery parameters are done in the software of the central station and can be modified according to the type of the used batteries. A new parameters can be added any time based on the existent data from the battery modules. This makes the developed system very flexible.

Wi-Fi interface is chosen for communication between the modules and the central station despite its higher energy consumption due to the lower cost of the commercial Wi-Fi modules and for the flexibility which gives the interface. For example when using Wi-Fi any standard laptop or tablet with appropriate software can be used for central station instead of a dedicated device. The usage of standard Wi-Fi interface also gives the opportunity to use already existent Wi-Fi networks to exchange the data with the central station. This is useful if the battery is mobile for example on a forklift or another electric vehicle which has a several hundreds of meters working field. An individual static IP address can be defined for every group of cell modules and the central station can recognize the group based on the IP address. This way it is possible to connect the cell modules to the central station through the internet using a mobile internet modem. This can extend the working range of the system even more. In all cases the monitored batteries should be pre-defined manually with their unique numbers in the central station in order to recognize them and to collect the data which they are sending.

The developed two-way communication protocol between the central station and the battery modules reduces the power consumption of the modules. The frequency of turning on and sending data over the Wi-Fi is changed dynamically on demand which reduces the consumption in the time the battery is not in use.

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