Design and analysis of battery management system

Dragana Petrović, Miroslav Lazić, Milan Pajnić, and Ivo Marković

***Abstract*— Rechargeable batteries are most important part in uninterruptible power supply system in telecommunication centers. Value of stored energy is reversible process, but capacity is highly dependent of charging and discharging process, temperature and other factors. Depending on application, rechargeable batteries can be connected in series, parallel or series/parallel string. With series connected battery string, higher voltage can be achieved, but unequal cell voltage balance can lead to accelerated aging of connected batteries. In parallel connected string, higher current capacity can be achieved, but due to unequal resistance of installations, internal discharging represents serious problem. Advantages of accurate charge equalization are very substantial and include reduced damage to battery cells in the stack, and dramatic increase in battery life. Realization of battery control system with bi-directional DC/DC converters is presented and described..**

***Index Terms*— Uninterruptible power supply, batteries, state-of-charge.**

I. Introduction

To ensure uninterruptible power supply of telecommunication centers, it is necessary to provide multiple sources of energy. Energy system with multiple sources of energy is considered reliable, but it is more complex and costly. It is widely accepted that primarily source of energy is electro-distributive network, which is considered as source of energy that is most accessible. As back up energy source, battery cells and/or power generators are used. Electro-chemical sources are capable of accumulating energy from primary source, but amount of stored energy is fairly limited.

An accumulator (rechargeable battery) is an energy storage device. Change in value of stored energy is reversible process, but capacity is highly dependent of charging and discharging process. Basic element of battery is battery cell with nominal value of 2V. Battery cells are usually connected in series to produce commercial rechargeable batteries with nominal voltage value from 6V to 24V [1].

Accumulator (rechargeable battery) is the only source of energy that is entirely under control especially in mobile telecommunication centers [2]. However, value of stored energy is fairly limited. That is why power supply of mobile telecommunication center needs to be organized in such way to completely utilize all available energy from rechargeable batteries. If possible every conversion of battery string nominal voltage should be avoided and energy directly supplied to the load. During each conversion, energy loss could vary from 6 to 25 percent [3].

Accumulator charging process is highly dependent on cell type, capacity and other factors. Slow charging process is considered time consuming, but fast charging processes are reducing battery capacity and are considered destructing and surely must be avoided.

Small nominal voltage of battery cell causes their series connections. With series cell connection, characteristic of battery string is defined by the worst cell in string. Cell voltage imbalance within a series string can be attributed to the differences of cell internal resistance, imbalanced state-of-charge (SOC) etc.

In section II, characteristics of series and parallel connection of battery string and common cases of voltage imbalance during charging and discharging process are described. Also series-parallel connection of battery string is presented as an alternative. Principe of equalizing state-of-charge (SOC) in battery string is presented in section III. The charge equalization concept in this paper is based on battery cell voltage having values dependent on battery chemistry, temperature and other related parameters. Advantages of accurate charge equalization are very substantial and include reduced damage to battery cells in the stack, and dramatic increase in battery life. Bi-directional DC/DC converter for capacity equalization is described in section IV. Finally conclusion is drawn in section V.

II. Connection of Rechargeable Batteries

Basic element of battery is battery cell. Nominal voltage value of battery cell is in range from 1.4 to 2.3V. Nominal cell voltage is highly dependent of manufacturing process and SOC. Battery cells are usually connected in series to form commercial rechargeable batteries with nominal voltage value from 6V to 24V. Difference in cell chemistry, and normal difference during repeated cycles of cell charge and discharge, leads to large no uniformities in cell charge levels and correspondingly differences in cell terminal voltage. Depending on application, rechargeable batteries can be connected in series, parallel or series/parallel string.

A. Series connected battery string

Series battery connection is used to achieve higher voltage of battery string. Current capacity of series battery connection is equal to current capacity of individual battery in string and

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can be expressed in term of capacity.

Battery capacity is a measure (typically in Amp-hr) of the charge stored by the battery, and is determined by the mass of active material contained in the battery. Current capacity of battery string is equal to capacity of individual battery (or cell), and current through each individual cell is equal during charging or discharging process. Difference in characteristic are manifested as cell voltage imbalance within a series string. Battery life is affected with cell voltage variations out of the range of the recommended values. Cell with smaller capacity or larger internal resistance can be charged and discharged faster than other cell in the string. This means that bad cell could experience higher voltage than recommended, and other cell could remain uncharged. During discharge cycle, voltage on bad cells could drop below recommended range. Worst cell in string determines characteristic of whole battery string.

Depending on the failure type of battery cells, we distinguish between two situations:

- Battery module is short circuited, battery string nominal voltage is smaller, under voltage protection in devices are active.
- Battery module is presented as open circuit, battery string is disconnected.

Due to unequal internal impedances of batteries in series connected string, following cases can be distinguished and manifested as cell voltage imbalance. In Fig. 1, string of four batteries connected in series. All individual batteries have same internal impedance, consequently voltages are same. All batteries in this situation are charged to 100% of initial capacity.

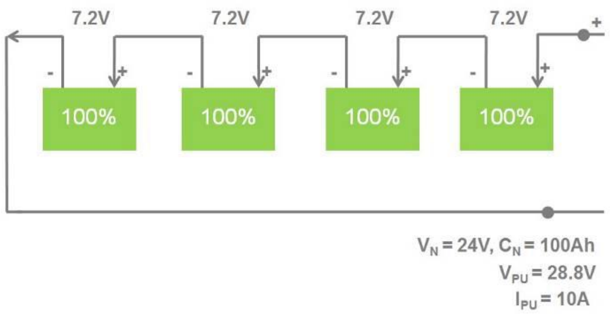

Fig. 1. Charging of series connected battery string with equal internal impedance.

If internal impedance of one battery in string is larger (Fig. 2) that battery will be charged to higher value of voltage, it will be overcharged, and other batteries in string will be undercharged.

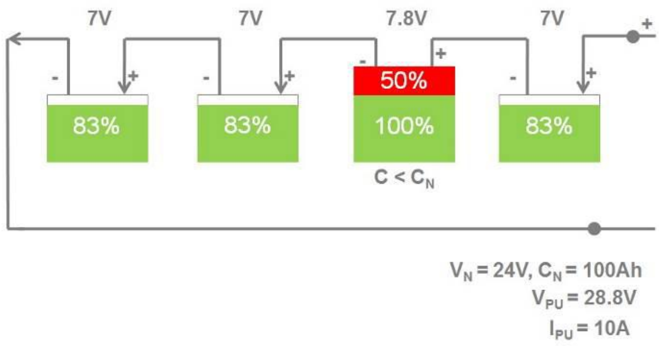

Fig. 2. Charging of series connected battery string with unequal internal impedance.

In Fig. 3, a series connected battery string is shown during discharging process. All batteries in string have same internal impedance, consequently voltage values of discharged batteries are the same.

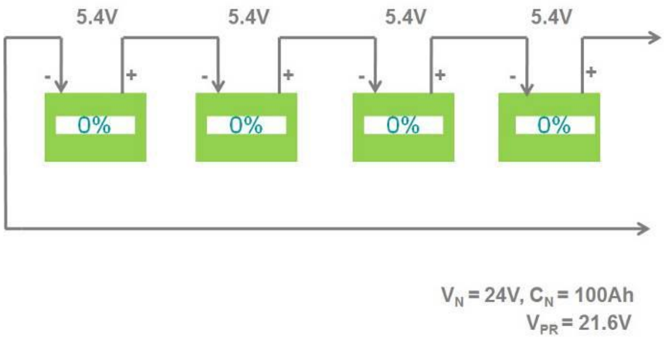

Fig. 3. Discharging of series connected battery string with equal internal impedance.

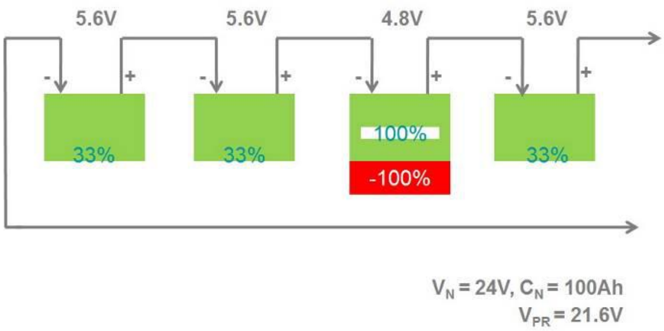

Fig. 4. Discharging of series connected battery string with unequal internal impedance.

If internal impedances of batteries in series connected string are unequal. During discharging process, voltage on bad cells could drop below recommended range (Fig. 4). In that case, worst cell in string determines characteristic of whole battery string.

B. Parallel connected battery string

Parallel battery connection is used to achieve higher current capacity of the battery string. Capacity of parallel connected battery string is equal to the sum of capacity of each individual parallel connected battery module.

Parallel battery connection requires highly similar characteristic of modules. Currents of individual battery modules are equal if their voltages and internal resistance are equal. Otherwise, the distribution of electric charge and discharge between two parallel connected battery strings are not under control, and over time this difference current has a tendency to rapidly increase.

The construction of the wiring must be taken that the resistance installations in both branches are uniform (length of conductors, transition resistances at the contacts, and the resistance of fuses). Passive resistance of the installation must be verified by measurement, and checked as part of the periodic maintenance. Relatively small asymmetry between the battery modules can significantly affect the distribution of charge or discharge current, which impairs the optimal operation of the central battery and leads to accelerated aging. By increasing the difference, electromotive force increases, the incident current in a circuit consisting of a parallel battery strings. This manifests itself as self-discharging or uncontrolled self-balancing, when the branches with lower voltage acts as a load. Despite the fact that the battery string is protected with circuit breaker, this phenomenon increases the risk of permanent destruction of the battery.

C. Series-parallel connected string

This type of battery connection allows maximum design flexibility in order to achieve the desired voltage and current capacity using a standard battery module.

In telecommunication centers, common battery connection is four batteries in series then in parallel with four batteries (4S2P format). Aforementioned way of connection is sense when voltage of one battery is 12V, but if voltage of one battery is 2V then 24S2P configuration used. This type of battery connection allows maximum design flexibility in order to achieve the desired voltage and current capacity using a standard battery module. This is the most complex configuration and includes all the good and bad sides of serial and parallel connections..

III. REMOVING IDENTIFIED DISADVANTAGES

As shown, variation in battery cell impedance results in variation of voltage when charging battery string with equal charging current. One way of removing before mentioned disadvantages of connected string is battery equalization. Equalization is performed usually on individual cells in string or in string in multiple connected strings.

If one battery in string has greater internal impedance then other, this battery will have greater voltage when charging battery string. If we want fully charge each battery cell in string, cell voltage on incorrect battery must be decreased. Voltage on battery cell is decreased until it goes equal to average cell voltage in battery string. Therefore, charging process is finished when voltage on each cell in battery string achieve proper value.

During discharging process, if one battery cell in string has lower voltage than average cell voltage in battery string, it is necessary to correct cell voltage with charge from other batteries in string. Therefore, discharging process is finished when proper value of desired voltage on each cell in battery string is achieved.

On Fig. 5 and Fig. 6 described equalization procedure in series connected string is presented employing bi-directional DC/DC converters. Converters are controlled remotely, by setting equalization direction. In Fig. 5, battery string is charged, and during charging process third cell voltage is decreased to fully charge each battery cell. In Fig. 6, during discharging process, voltage on third battery cell in string is increased, to fully discharge each battery cell in string.

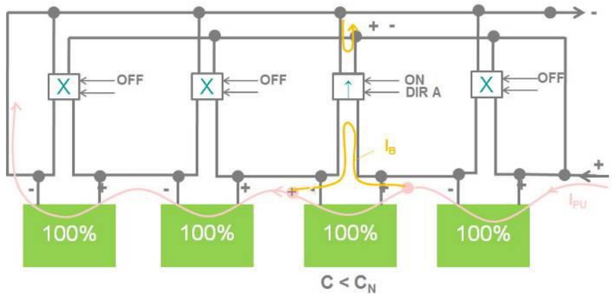

Fig. 5. Charging of battery string with equalization.

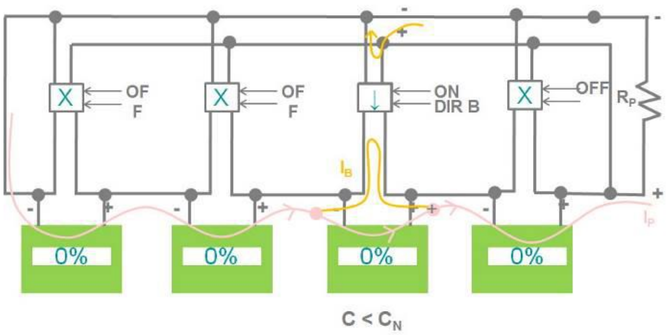

Fig 6. Discharging of battery string with equalization.

IV. BI-DIRECTIONAL DC/DC CONVERTER

For realization battery charge equalization, bi-directional DC/DC converter is developed. Converter is connected between battery electrode as shown on Fig.5 and Fig. 6. Each individual cell in battery string is connected to individual converter. Also voltages and temperatures of each individual cell is measured and processed.

Purpose of bi-directional converter is:

- During battery string discharge process, additionally charge battery with lower voltage then other batteries in string.
- During battery string charge process, additionally discharge battery with greater voltage then other batteries in string.

On Fig. 7 connection block diagram is shown between bi-directional converters and four series battery string. Transfer of energy and its direction in individual converter is controlled with main processing unit.

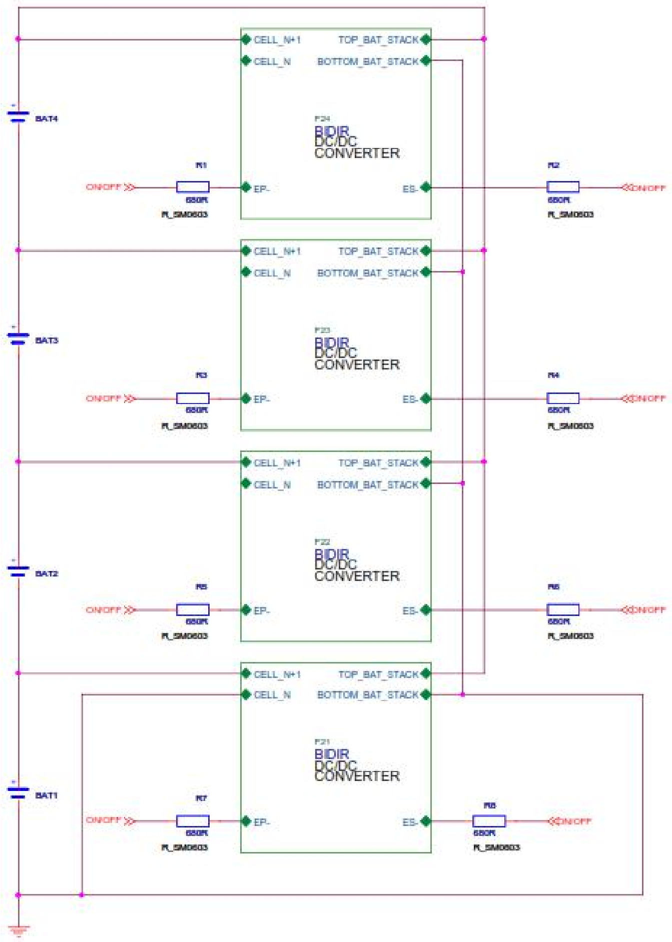

Fig 7. Bi-directional DC/DC converter connection block diagram in series connected string.

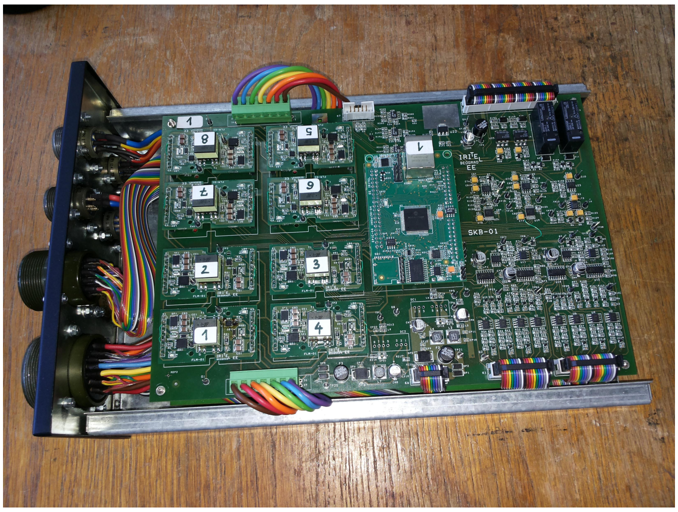

Fig 8. Prototype of system for rechargeable battery control.

As shown on Fig. 8, system for battery control consists of eight bi-directional DC/DC converters, acquisition board and microcontroller unit. Wiring configuration, cell voltages and battery type is programed. Based on set of inital condtions, system is fully automated.

V. Conclusion

System for rechargable batteries control is necessary for users for whom the system reliability is great relevance. Rechargeable batteries are most important part in uninterruptible power supply system especially in telecommunication centers. In the large systems batteries maintenance is a major economic expenditure. Maintenance services often can`t reach that regularly inspecting each battery so the damage due to malfunctioning is large. The charge equalization concept in this paper is based on battery cell voltage having values dependent on battery chemistry, temperature and other related parameters. Advantages of accurate charge equalization are very substantial and include reduced damage to battery cells in the stack, and dramatic increase in battery life.

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