Comparison of Active and Passive Balancing Methods of Li-Ion Battery Management Systems in Vehicles and Communication Devices for Supporting Defense Systems in IKN

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Abstract— To support the TNI-Polri in serving in the new IKN. The imbalance of cells in the battery pack impacts the overall performance of the battery system and can eventually lead to the failure of the entire battery system. Therefore, an efficient Battery Management System (BMS) should incorporate cell balancing features, including battery pack protection and monitoring, to increase the working capacity of the battery and increase its overall efficiency and lifespan. This journal article aims to compare the effectiveness of the Lithium-Ion battery cell balancing method. The comparison includes the efficacy based on the speed of distribution, efficiency, and application, which way is best to apply, which provides for the effectiveness of battery life, and the costs incurred in the field of communication and vehicles to maximize mobility. Data was obtained from exposure and discussion with the KKDN 2022 Defense University resource persons.

Keywords— Battery balancing review, Cell balancing topologies, IKN Kalimantan Timur, TNI-Polri.

I. INTRODUCTION

The Indonesian government and the People's Representative Council have officially announced the movement of the new capital city in East Kalimantan in UU NO. 3 of 2022. According to Rudy Soeprihadi Prawiradinata, Deputy for National Development, the TNI-Polri moved first because the two institutions were to ensure security in the East Kalimantan region. This is also supported by the main task of the TNI based on Law No. 34 of 2004, namely to act as a State tool in the field of defense, a deterrent to every form of a military threat, and an armed threat from outside and to uphold the sovereignty of the State. In addition to being a large area safe from potential earthquakes, East Kalimantan is also considered a middle part of Indonesia.

In supporting the implementation of these tasks, the TNI-Polri must be ready to live in a new area. When carrying out missions in new places, the most crucial thing is mapping and clearing land. In the TNI-Polri environment, mobilization and communication are essential factors determining these tasks' success. The equipment needed for operations is military vehicles, HT, and radio transmitters. Most of the equipment already uses the latest batteries, namely lithium-ion batteries.

However, the lithium battery has a maximum and minimum voltage limit, which, if it exceeds the voltage limit, can cause damage to the battery [1]. One way to overcome this is to install a BMS (Battery Management System). BMS is an electronic device that acts as the brain of the battery, monitors output, and protects the battery from critical damage. In this review article, the existing topologies of the Li-ion battery cell balancing technique, active and passive, will be compared to see the effectiveness based on the speed of distribution, efficiency, and application, which method is the best to implement which includes the significance of battery life and cost—issued in communication and vehicles to maximize mobility to support the TNI-Polri in serving in the new IKN.

II. METHOD

This study uses a qualitative research method with a descriptive approach. The author tries to describe the problems that exist from the study results. The author uses data collection techniques through online interview methods for Domestic Work Lectures (KKDN), non-participant observations and documentation. Data were taken from interviews, journals, books, previous research, scientific articles, literature and news from official websites. Data related to "Battery Management Systems" and "new IKN" were sourced from Scholar Google, Mendeley, and ScienceDirect. Qualitative research and literature review must have good consistency with methodological assumptions [2].

III. RESULT AND DISCUSSION

3.1 Lithium-Ion Battery

Lithium-ion batteries (Li-ion or LIB) When lithium ions are discharged and recharged, they migrate from the negative electrode to the positive electrode. In contrast to non-rechargeable lithium batteries, Li-ion batteries use an intercalated lithium compound as its electrode material. LIB is widely employed in the military, electric car, and aerospace industries, in addition to consumer electrical equipment. Many studies have attempted to improve traditional LIB technologies, focusing on energy density, durability, cost, and intrinsic safety [3].

However, Lithium-based batteries also have the disadvantage of being less tolerant, thus requiring accurate monitoring and protection procedures to ensure that one of the battery cells does not overcharge and ensures that the battery does not overheat, which can reduce battery life [4].

3.2 Li-ION Battery Cell Balancing

The Battery Management System (BMS) is an electronic device that acts as the brain of the battery, monitors output, and protects the battery from critical damage. This includes monitoring temperature, voltage and current, forecasting or preventing failure and collecting data via communication protocols to analyze battery parameters. Battery state of charge (SOC) is the percentage of energy currently stored against the battery's nominal capacity. One of the essential functions of BMS is the cell balancing method [5]

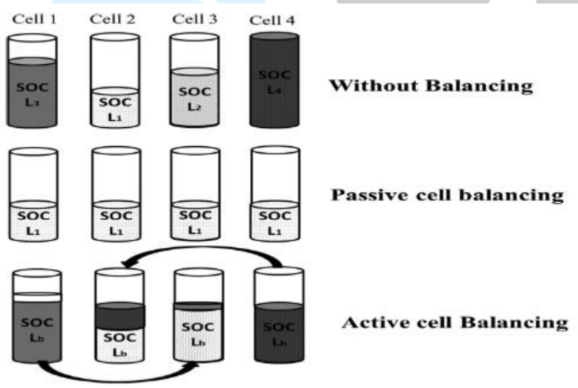

Figure 1: *Cell balancing technique based on state of charge of Li-ion battery* [11]

Cell imbalance is a major critical factor in large battery packs degrading battery performance to meet battery health status (SOH) requirements. [6] The weakest cell (lowest SOH cell) in a set of series-connected cells dominates the overall string strength causing safety issues and thermal runaway when the battery is below the limit. [7] Classification of cell balancing into two methods such as passive cell balancing and active cell balancing, described in Figure 1, based on the SOC of the battery. [8]

For explanation, consider the four cells connected in series in a battery, such as a Cell 1, Cell 2 and Cell 3, and Cell 4. Before equilibration, the SOC levels of cells L1, L2, L3, and L4 were 40%, and 60%, respectively. 80%, and 100%. The passive cell balancing technique equalized the cell SOC with the energy dissipation of the higher SOC cell. It formulated all the cells with a similar SOC equivalent to the lowest level cell SOC, precisely 40% L1 level SOC in Cell 2, as shown in Figure 2.

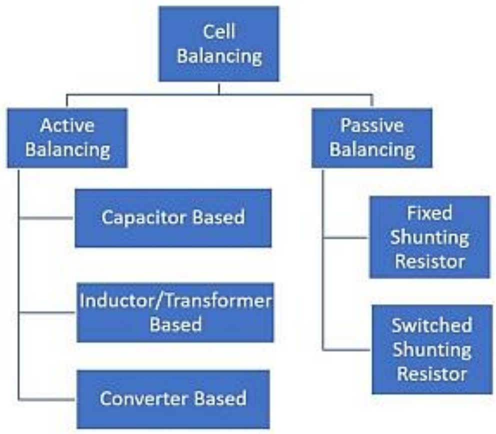

Figure 2*: Cell Balancing Topologies [9]*

3.3 *Passive Cell Balancing*

Using Passive Elements and shunting resistors, the passive cell balancing method removes energy in the form of heat from the higher energy cells in the battery pack to lower their levels to the lower energy balance cells [10]. This cell balancing method has the advantage of using cheaper components and also a relatively more straightforward algorithm. The passive method can be a Fixed Shunt Resistor type or a Switched Shunt Resistor type. Both are briefly described here.

A. Fixed Shunting Resistor

This technique balances each cell voltage by connecting a fixed resistor parallel with each cell connected in series based on the required cell balancing current. The balancing current is dissipated through a resistor that limits the voltage of each cell [11].

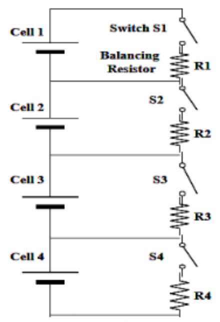

Figure 3: *Fixed Shunting Resistor* [5]

This method is suitable for the balancing circuits of nickel and lead-acid batteries because these batteries are brought to an overcharged state without damage. The circuit is elementary, requiring fewer components and low cost. However, the disadvantage of this technique is that it provides energy lost due to energy lost as heat in all cells during the balancing operation.

B. Switched Shunting Resistor

This technique balances each cell voltage by connecting a resistor in parallel with each cell in series via a controlled on/off semiconductor switch or relay. The resistor value is correctly selected based on the required balancing current in this method. This method requires a controller to control the circuit in two different modes. In continuous mode, the on/off switch is controlled simultaneously. In sensing mode, the voltage of each cell is detected by the voltage sensor, which detects the cell imbalance situation and decides which resistor to shunt [11].

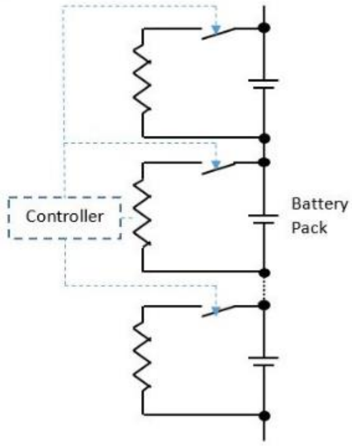

Figure 4: *Switched Shunting Resistor [9]*

This is called the charge shutting method and is generally used for Li-ion battery balancing circuits. This circuit is more reliable than a fixed shunt resistor balancing circuit. Also, this technique provides energy losses due to the higher current flowing through the switches and resistors during the balancing operation

Tabel 1*: Comparison of passive cell balancing methods [11]*

Type	Balancing principle	Merits	Demerits	Applications
Fixed shunt resistors	Cells with higher energy level are dissipated through parallel resistor as heat until charge levels match with cells of lower energy level	Low cost, easy to implement	Permanent energy losses, no controlled operation	Suitable for nickel and lead-acid batteries low power applications
Switched shunt resistors	Cells with higher energy level are dissipated by switch control that decides which resistor should be shunted for energy balance	Simple controlled method based on SOC and SOH, Easy to implement	Energy losses due to high balance current, slow balancing speed, more number of switches, preferable during charging only	Suitable for Li-ion battery Low power applications such as consumer appliances, suitable for electric vehicles when 10 mA/Ah balancing current is used

The two techniques described above can be applied to low power, with a current of less than 10 mA/Ah.

3.4 *Active Cell Balancing*

Using a power electronics interface, the active cell balancing circuit transfers energy from the higher to the lower energy cell through the active element. This method has higher efficiency than passive balancing, but the control algorithm is complicated, resulting in higher costs. Active cell balancing can be Capacitive, Inductive or Converter type.

A. *Capacitor Based Active Balancing Method*

Capacitive cell balancing methods, also referred to as Shuttling Capacitor Balancing methods, utilize capacitors as external energy storage devices for shuttling the energy between the cells [12] to balance their SoC to the same level. Active cell balancing using a Capacitor is shown in Figure 5. They are briefly described here.

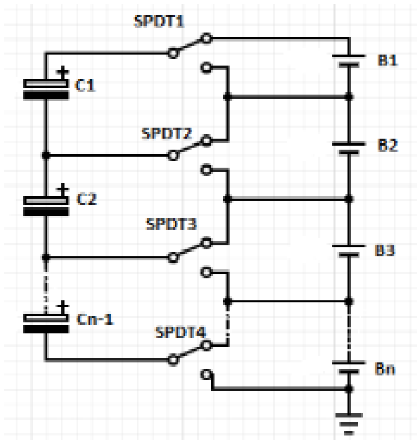

Figure 5. Capacitor Based [13]

This technique is known as the charge transfer method, in which a charge from a higher energy cell is released. That charge must be stored in a capacitor and transferred to a lower energy cell. This technique can be classified based on a single capacitor and multiple capacitors using the equalization method.

This method is also known as the direct cell to cell method and is suitable for high power applications. This is very simple because only one capacitor is used to balance the entire battery pack. However, it has a slow balancing speed and requires several semiconductor switches and intelligent control techniques to control the switches.

- ***Switched Capacitor***

To balance n cells, a balancing topology requires n-1 capacitors and 2n switches. Because it just has two states, its control technique is simple: switches are frequently shifted from upper to lower position and back to higher position with small delay to shuttle through the entire cells consecutively. It has great efficiency and can work in both charging and discharging modes, but its significantly longer equalization time and higher cost are important drawbacks.

- ***Single Switched Capacitor***

Topology is the Switched Capacitor topology derivation and uses only one capacitor, as shown in Figure 7. This topology requires n+5 bidirectional switches to balance n cells, and hence it is employed in the battery system with more than 4 cells, making it more cost efficient than its counterparts. It also has a less sophisticated control method. The energy is shuttled between the cells using a controller that picks the cells with higher and lower SoCs and runs the relevant switches. To boost the balancing speed, more complicated strategies can be applied.

- ***Double Tiered Switched Capacitor***

Derived from the switched capacitor method, this topology of cell balancing utilizes two capacitor tiers to shuttle the energy between the cells. It requires n capacitors and 2n switches to balance n cells. Its advantage is reduced balancing time to the switched capacitor method due to the added second capacitor tier by almost 3/4th time [12]. It can operate in both charging and discharging modes. More tiers result in more paths between batteries, reducing the impedance for shuttling energy over the cells in the pack.

B. *Inductor-based Cell balancing methods*

A cell balancing circuit explained in this part balances battery cells by magnetic elements, such as inductors or transformers, by carrying unequal energy among multiple cells. By conveying unbalanced cell energy from a higher energy cell to a lower energy cell in the battery box via inductors or transformers, the cell balancer levels all cells.

The balancing time of the cell balancing circuitry can reduce by a high cell balancing current. This cell balancing circuit, however, has a high manufacturing cost, and a magnetic transformer loss should be properly considered during the cell balancer's design phase. Every cell in the battery line should include a filtering capacitor because its switching frequency is usually high.

- ***Single/Multi Inductor***

The controller algorithm of this cell equalizing circuit by single or multiple inductors is that it identifies each cell voltage and decides a cell to transfer power. When MOSFETs are switched on and switched off, unbalanced cell energy is passed to an inductor. In this circuit, an inductor carries unbalanced cell energy from a higher energy cell to a lower power cell in the battery line.

- ***Single Transformer***

An active cell balancing circuitry based on a single transformer method that includes a MOSFET, a diode (D), a transformer (T), and N+2 quantity of switches (S1 ~ SN+2) and N quantity of battery cells (B1 ~ BN)11. This cell balancing system with a single transformer has two topologies: the first is a pack-to-cell method, and the second is a cell-to-pack method. This cell balancer has a fast balancing rate with fewer magnetic losses. However, this cell equalizer needs accurate switch control.

- ***Multiple winding transformer***

N cells (B1 BN), diodes (D1 DN), transformers (T1 TN), and a single MOSFET make up an active cell balancing circuitry with multiple transformers. Because this cell matching circuit simply has one switch, the control mechanism is straightforward. Additionally, the balancer has a quick balancing speed. It does, however, necessitate a costly and complicated circuit and should prevent the transformer from being saturated.

C. Active Balancing Berbasis Converter

A converter based cell balancing topology uses a suitable converter to balance unequal cells. These cell balancing circuits have higher energy transfer efficiency but can be bulky and require complex control algorithms due to additional passive components and active switches [14]. Depending on which converter is used for cell balancing, cell balancing topology can be different, including Cúk Converter, Buck-Boost Converter, Flyback Converter, Ramp Converter, Full-Bridge Converter, and Quasi-Resonant converter.

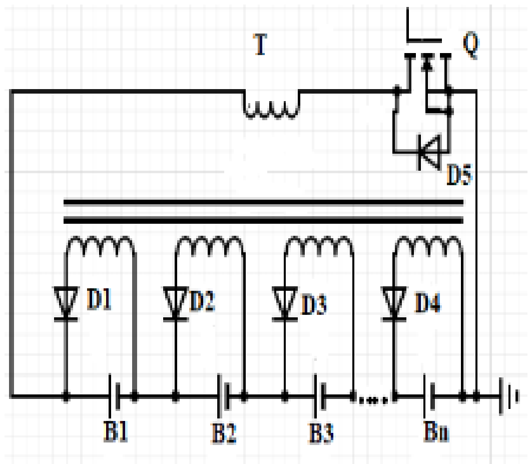

Figure 6: *Active Balancing Berbasis Converter [13]*

Buck-Boost converters are widely used for cell balancing in Battery Management systems. BuckBoost Converter dissipates excess energy from cells with a higher SoC to a different battery system and then transfers the energy back to cells with a lower SoC.

Intelligent controllers and voltage sensing devices are required to operate the topology.

Although this topology is expensive and complex in operation, it can be considered a robust and robust cell are balancing the topology available for BMS with its higher efficiency and modular application.

- ***Cuk Converter***

The Cuk converter is a buck-boost converter that produces zero ripple current. The Cuk converter is a hybrid of the boost and buck converters, using one switching device and a mutual capacitor to link the power or energy.

- ***Buck or/and Boost converter***

A step down (Buck), step-up (Boost) and Buck-Boost energy converters [16] are widely used in cell balancing systems.

These techniques use a variety of balancing topologies, such as a boost converter to transmit surplus energy from a single cell to the entire pack, or a buck-boost converter to send excess energy from the higher cells to the DC link, storage element, and then back to the weak cells.

The voltage sensing and intelligent controller of the cell are required to run the converter. Balancing methods for converters are rather expensive and complex, yet they are appropriate for modular design.

- ***Flyback Converter***

Flyback converters [17] As indicated in Figure 16, are used in isolated structures and can be unidirectional or bidirectional. When the linked switch is on, the energy of the highly charged cell is stored in the transformer, and when it is off, it is transferred to the pack.

The bidirectional flyback converter allows for increased energy transmission flexibility, as it can also transmit energy from the pack to the cells. The magnetic losses and the homogeneity of the multi winding are its disadvantages.

- ***Ramp Converter***

Ramp converter cell balancing topology [18], [19] is shown and shares the same idea as multi-windings transformers.

It only requires one secondary winding for each pair of cells instead of one per cell.

The ramp converter operation can be summarized: most current is used to charge the odd number of lowest voltage cells on the first half cycle.

While on the other half cycle, it supplies the even cells, so that it is called ramp converter.

- ***Full-bridge converter***

Full-bridge PWM energy converters [20] can be considered fully controlled energy converters shown in Fig. 18. They can be used as AC-DC, suitable for the plug-in hybrid electric vehicle (PHEV) or DC-DC converter.

Both need an intelligent control and are superior for modulated battery packs and high power ratings.

The main drawback of the Fullbridge converter is its relatively high cost and complex control.

- ***Quasi-resonant converter***

A DC-DC converter-based cell balancer is the Quasi-Resonant Zero Current Switching (QRZCS) balancer. Except for the addition of the resonant circuit, the QRZCS topology is similar to the buck-boost topology.

Because of the large number of components and the intricate operation of the converter, the QRZCS balancer is also the most complicated equalizer.

***Tabel 2**: Comparison of active cell balancing methods [11]*

Type	Balancing principle	Merits	Demerits	Applications
Single capacitor	Transfer of energy from cell with higher energy level into lower energy cell through only one capacitor	Control with only one capacitor, preferable during both charge and discharge.	More number of switches, intelligent control technique, adequate balancing speed	High power applications such as uninterruptible power sources, energy storage systems, hybrid electric vehicle and electric vehicles
Switched capacitors	Energy equalization between two neighboring cells through switched capacitor	Easy to control and implement, low voltage stress, preferable during both charge and discharge	Long balancing time required for end to end cell equalization	
Double-tiered switched capacitors	Energy equalization between two adjacent cells through first row of capacitor and non-adjacent cells through second row of capacitor	Balancing time can be reduced to more than half compared with the switched capacitor, preferable during charge and discharge condition	Adequate balancing speed, more number of capacitors	
Single inductor	Transfer of energy from cell with higher energy level into lower energy cell through only one inductor	Fast balancing speed than single capacitor, higher efficiency	High system cost, more number of switches, intelligent control technique, filter capacitor is required due to the high switching frequency	
Several inductors	Energy equalization between two adjacent cells through switched inductor	Fast balancing time, high efficiency	High system cost, complex control of end to end cells, filter capacitor is required due to high switching frequency	
Single transformer	Pack to cell equalization and cell to pack equalization through single transformer	Fast balancing speed, low magnetic losses	High system cost, requires perfect electronic switch control, magnetic core must be changed if one or more cells are added	
Single magnetic core transformer	Pack to cell equalization and cell to pack equalization through single core multiple secondary winding transformer	Rapid balancing with minimal losses, no closed-loop control	Very high system cost, complex control, magnetic core must be changed if one or more cells are added	
Multiple magnetic core transformers	Energy balance of each cell through individual multi winding transformers	Fast balancing speed, better modular design, new cells added easily without change of magnetic core	Most expensive, complex circuit, high transformer magnetic losses	

The general comparison between the above active cell balancing topologies is that TNI-Polri can use transformer-based balancing techniques for high power applications such as military electric vehicles with a current of 100 mA/Ah. The drawback is that it is expensive.

***Tabel 3:** Advantage and Disadvantage of Cell Balancing Topologies [15]*

Scheme	Advantage	Disadvantage
1. Fixed Resistor	• Cheap. Simple to implement with a small size.	• Not very effective. Inefficient for its high energy losses.
2. Shunting Resistor	• Cheap, simple to implement and Fast equalization rate. • Charging and discharging but not preferable for discharging. • Suitable for HEV but for EV a 10mA/Ah resistor specified.	• Not very effective; Relatively high energy losses • The requirement for large power dissipating resistors. • Thermal management requirements.
3. Switched Capacitor	• Simple control. Charging and discharging modes. • Low voltage stress, no need for closed loop control.	• Low equalization rate. • High switches number.
4. Single Switched Capacitor	• Simple control. Charging and discharging modes. • One capacitor with minimal switches. EV and HEV app.	• Satisfactory equalization speed. • Intelligent control is necessary to fast the equalization.
5. Double Tiered Switched Capacitor	• Reduce balancing time to quarter than the switched capacitor. • Charging and discharging modes. EV and HEV applications.	• Satisfactory equalization speed. • High switches number.
6. Modularized Switched capacitor	• Low voltage and current stress. • Charging and discharging modes	• Complex control is needed. • Satisfactory equalization speed.
7. single Inductor	• Fast equalization speed.	• Complex control is needed. Switches current stress. • Filtering capacitors are needed for high switching frequency.
8. Multi Inductor	• Fast equalization speed. • Good efficiency	• Less complex control. Needs accurate voltage sensing. • Charging mode only. Switches current stress. • Filtering capacitors are needed for high switching current.

9. Single Windings Transformer	• Fast equalization speed. • Low magnetic losses.	• High complexity control. Expensive implementation. • To add one or more cells the core must be change.
10. Multi Windings Transformer	• Rapidly balancing. No closed-loop controls are required. • Suitable for both EV and HEV applications	• High cost. Complexity control. • The core will be changed if cell or more are added.
11. Multiple Transformers	• Fast equalization speed. Can be modularized • EV and HEV applications. New cells easily added.	• High cost. Complexity control. • Satisfactory efficiency due to magnetic losses.
12. Modularized Switching Transformer	• Fast equalization speed. Suitable for both EV and HEV. • Low voltage and current stress.	• High cost. • Complexity control.
13. Cũk Converter	• Suitable for both EV and HEV applications. • Efficient equalization system.	• Complexity control. Accurate voltage sensing needed. • Satisfactory equalization speed.
14. Buck-Boost Converter	• Good equalization speed. • Easy for modular design.	• High cost • Intelligent control needed.
15. Flyback Converter	• Easy implemented for large number of cells. • EV and HEV application. Suitable modularized system.	• Voltage sensing needed. • Satisfactory equalization speed.
16. Ramp Converter	• Soft switching along with a relatively simple transformer.	• Complex control. Satisfactory equalization speed.
17. Full-Bridge Converter	• Fast equalization speed. • Ideal for transportation applications	• High cost • Intelligent control needed.
18. Quasi-Resonant Converter	• Low switches current stress that increases its efficiency. • Simple implementation.	• High cost • Complex and intelligent implementation needed.

Comparisons between balancing methods are planned in Tables 1, 2, and 3. Generally, the switching shunt resistors are suitable for low power applications with low cost, small size, and effortless control. For simple, active control selecting switching capacitors is the right choice and suitable for EV applications but requires fast equalization time. Switching inductors and transformers are suitable, but there is a need for complex control systems and magnetic losses. Unfortunately, superior energy converters for medium and high power applications with complete control in balancing procedures are high in cost, complex control, and large.

IV CONCLUSION

As one of the components of national defense, the main task of the TNI based on UU No. 34 of 2004 is to act as a tool of the State in the field of defense, a deterrent to every form of military threat and armed threats from outside and to uphold the sovereignty of the State. In carrying out the task in the new IKN to support the role of the TNI by assisting the mobility of the TNI in carrying out its mission, in this article, the significant characteristics of the Li-Ion battery cell balancing technique are analyzed and compared based on the speed of distribution, efficiency, and application, which method is best to apply. which includes the effectiveness of battery life and costs incurred?

Based on this analysis, the passive cell balancing technique is suitable for low power applications as it utilizes low current, low heat dissipation and long balancing time. Here it can be applied to the communication system for the TNI. The active cell balancing technique is suitable for high power applications because it has a low balancing speed and higher efficiency than the passive cell balancing technique. The active cell balancing technique is suitable for vehicles/alutsista to support TNI mobility in carrying out missions. Thus, battery cell balancing is an essential key feature in BMS that improves battery performance, increases cycle life and ensures safe operation during all challenging conditions. Future cell balancing control coverage with intelligent technique.

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