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RESEARCH ARTICLE

Fault Detection for Low Voltage System in Electric Vehicle

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Abstract

With the rapid development of the electric vehicle ecosystem, there are concerns about the electrical safety of electric vehicles. This concern is caused by the problems with electric vehicles, which cannot be used when not used for a long time. This problem is caused by a low voltage rating that is not available when the electric vehicle is in that condition. In this study, an algorithm is proposed to support safety for the availability of low-voltage electrical energy, when electric vehicles are in use or not in use. The results of this research indicate that the created algorithm can provide safety for the availability of low voltage level electrical energy, by adjusting the lead-acid battery charging procedure, monitoring the low voltage level while it not in use, and making existing electric vehicles unable to move as long as problems with the low voltage level charging system cannot be resolved.

Keywords: electric vehicle, safety, low voltage battery, power distribution unit

1. Introduction

Electric vehicles have become one of the transportation modes that are quite popular among various groups at present. This is because the presence of electric vehicles currently offers various attractive features and is one of the efforts to reduce carbon gas emissions that are unfriendly to the environment. From research conducted by [1], it can be known that there are several factors that attract someone to own an electric vehicle. Some of these factors include the vehicle's range, battery charging time, noise level generated, vehicle acceleration, vehicle safety level, and driving reliability. From these factors, it can be understood that the driving safety factor is one of the factors that can attract someone to own an electric vehicle.

There are various types and safety systems embedded in an electric vehicle. The safety systems in an electric vehicle can include battery system safety [2], braking system safety [3], thermal battery system safety [4], and electrical system safety [5]. Among these various types and safety systems of electric vehicles, electrical system safety is the primary aspect that must be present in an electric vehicle.

In the electrical system of an electric vehicle, there are several voltage levels that flow through the vehicle [6]. However, at least two voltage levels are generally present in an electric vehicle. These voltage levels are high voltage (HV) and low voltage (LV). High voltage ranges from 120V to 600V and is sourced from the battery pack in the electric vehicle. On the other hand, low voltage ranges from 12V to 24V and is sourced from a lead-acid battery.

There are differences in the use of electric voltage levels that exist in these electric vehicles. The high voltage level is intended as the main source of electricity for the electric vehicle propulsion system and as the main energy source for several electrical components, such as the Motor Control Unit (MCU), DC-DC converter, on-board charger (OBC), and power distribution unit (PDU) [7]. Meanwhile, at low voltage levels, it is intended as an energy source for the electric vehicle's control electrical systems such as the vehicle control unit and communication systems between electrical components. Since the low-voltage system is necessary to supply electrical energy for the control system in electric vehicles, this research will discuss an algorithm that can maintain the availability of low-voltage electrical energy.

2. Low Voltage System of Electric Vehicles

The low voltage system in electric vehicles is a voltage system used by various electrical components that do not require high power to operate. Some electrical components that do not require high power include electrical control systems and entertainment and safety support systems such as vehicle lighting systems.

Therefore, this low voltage system must be available, as the absence of this level can prevent the electric vehicle from being controlled by humans. Hence, this low-voltage system must always be present to avoid issues that could lead to losses for the driver and the electric vehicle. Figure 1 illustrates various electrical components supplied by the low-voltage system in an electric vehicle.

From Figure 1, it can be observed that the low-voltage system plays a crucial role in an electric vehicle. The low-voltage system accommodates the electrical energy source for various components. If the low-voltage system is not available, all these components cannot be utilized.

The low-voltage system is provided through a process of stepping down the high voltage originating from the 400V battery pack to a range of 27.5V. This voltage range is chosen to accommodate the 24V lead-acid battery being used. Therefore, a higher voltage than the operating voltage of the lead-acid battery is necessary to ensure the availability of low voltage that can be utilized by various electrical components. To facilitate the battery charging process, a DC-DC converter is employed as a means to charge the lead-acid battery. The DC-DC converter reduces the high voltage of 400V from the battery pack to a low voltage of 27.5V. By stepping down the high voltage to this value, the DC-DC converter can consistently charge the lead-acid

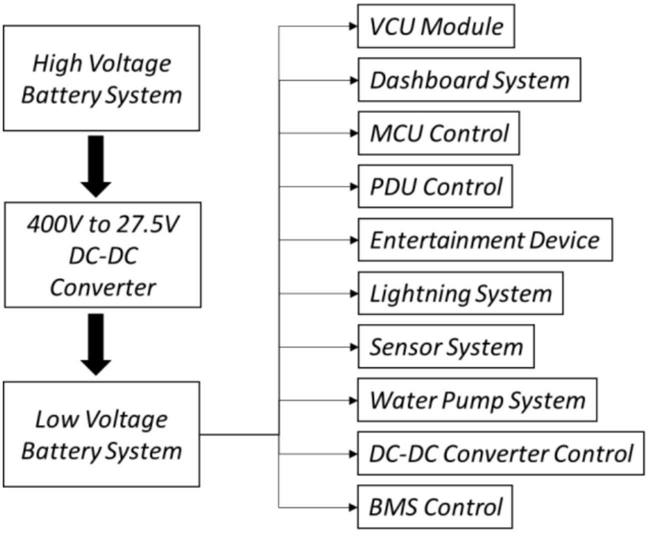

Figure 1. Low Voltage System of Electric Vehicles

battery.

3. Block Diagram of Fault Detection in the Low Voltage System

To create a fault detection system for the low voltage system in electric vehicles, a workflow is required to anticipate system faults. To anticipate low voltage system faults, voltage monitoring is needed for several electrical components that support the availability of the low voltage level. Therefore, several voltage sensors are used, as shown in Figure 2 below.

By placing several sensors on various components that support the availability of the low-voltage system, an algorithm can be developed for detecting faults in the low-voltage system of an electric vehicle. The placement of voltage sensors focuses on the input and output sections of core components such as the DC-DC converter and the lead-acid battery itself. This is done to ensure that the low voltage in the electric vehicle is always charged and monitored at all times.

In addition to placing voltage sensors on different parts of the electrical components, each component in the fault detection system for the low voltage system should also be able to communicate with other components in the electric vehicle. With the presence of communication between components, each component can communicate and execute the low voltage system security algorithms properly, thus creating a safer electric vehicle system.

To ensure the continuity of communication between the components, the communication system in the electric vehicle components must comply with the ISO 11898-CAN security standards [8]. By meeting these security standards, it ensures that the communication process among the components in the electric vehicle operates smoothly.

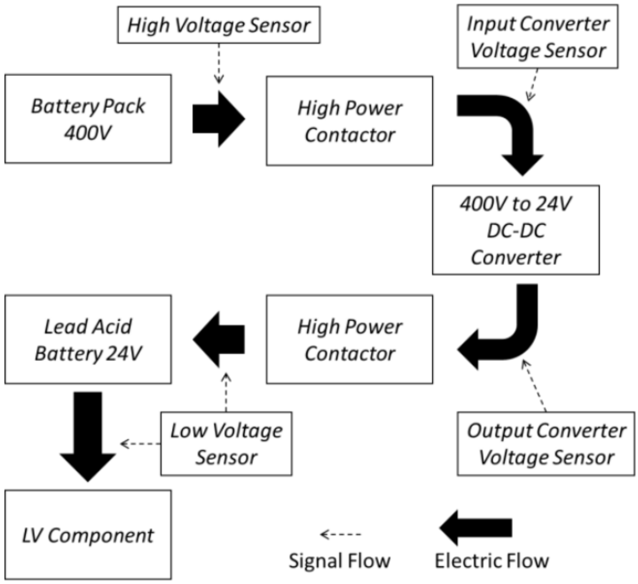

Figure 2. Block Diagram of Low Voltage Fault Detection System

4. The Algorithm for Low Voltage Fault Detection System

In this paper, there are two types of algorithms that can support the low-voltage faults detection system in an electric vehicle. These algorithms are needed by electric vehicles when they are running and when they are not in use for a significant period of time. The algorithms discussed in this paper were obtained through direct testing on an electrical component, namely the Power Distribution Unit (PDU), in an electric vehicle. Implementing these algorithms ensures the availability of the low-voltage system in an electric vehicle. These algorithms are described below.

4.1 Algorithm for LV Fault Detection System When the Vehicle is Running

To detect system faults while the vehicle running, there is an algorithm that supports the fault avoidance process. The first thing to detect to prevent system faults at the low voltage level is to always check and monitor the presence of high voltage sourced from the battery pack. Next, the voltage entering and exiting the DC-DC converter is checked. This voltage source check is crucial to ensure proper charging of the lead-acid battery. After checking the voltage source, the voltage of the lead-acid battery itself is examined. If the lead-acid battery voltage is below the safe operating limit for the electric vehicle, it will be charged first before the vehicle can be used. The flowchart in Figure 3 illustrates the algorithm for low-voltage system fault detection.

4.2 Algorithm for LV Fault Detection System When the Vehicle is Not in Use

When an electric vehicle is not in use for an extended period, the voltage of the low-voltage electrical system may decrease. This occurs because the control system and

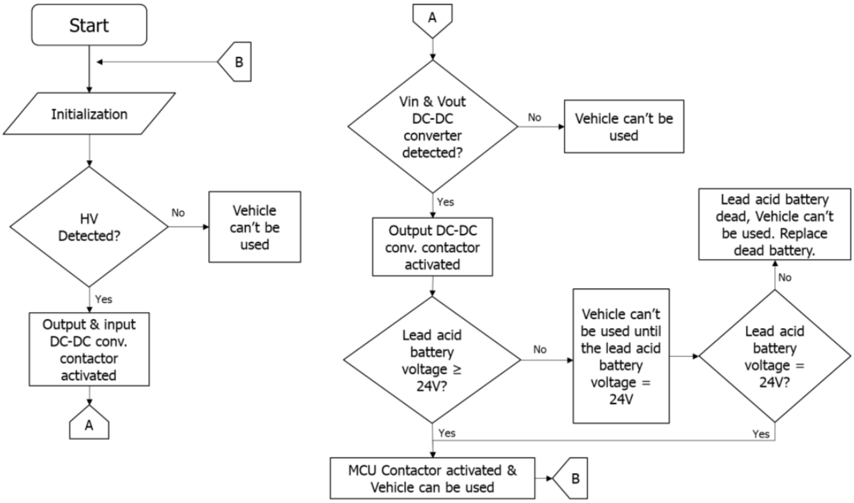

Figure 3. Flowchart Algorithm while the vehicle is running

various additional features, such as vehicle security alarms and keyless entry systems, continue to operate using the low-voltage electrical power source. If the low-voltage electrical system is not recharged, it can result in the electric vehicle being unable to function or start again due to the lack of power in the low-voltage system. Therefore, a different algorithm is needed, separate from the one shown in Figure 3, to anticipate the decrease in the working voltage of the lead-acid battery when the electric vehicle is not in use. This algorithm can be seen in Figure 4 below.

By utilizing the algorithm in Figure 4, the electric vehicle will continuously monitor the battery's state of charge while the vehicle is not in use. In this algorithm, if the battery voltage falls below the predefined threshold, the vehicle will activate a warning alarm corresponding to the availability of voltage from the lead acid battery.

This algorithm can provide notifications to the electric vehicle owner to recharge their low-voltage battery by starting their electric vehicle. This ensures that the electric vehicle can still be used even after a long period of inactivity.

5. Electrical Power Distribution System

To accommodate the performance requirements of the low-voltage fault detection system, an electrical component is needed to control the output flow of electricity from the battery pack. One such component that serves as a controller for the electrical output in the electrical system of an electric vehicle is the Power Distribution Unit (PDU). This component functions as a medium for distributing and dividing high-voltage battery power to various other electrical components such as MCU, DC-DC converter, air conditioner, etc. [7]. The PDU acts as a provider of electrical power distribution and serves as the central control unit for the required power output. The use of the PDU is crucial as all low-voltage fault protection functions are performed

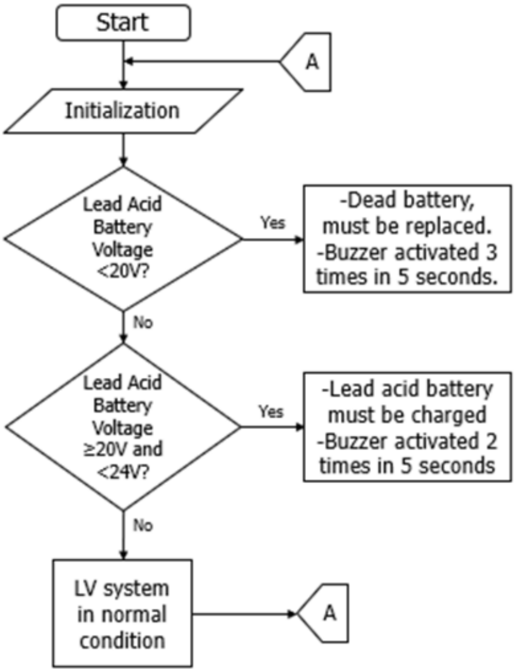

Figure 4. Flowchart algorithm when the vehicle is not in use

within this unit. In addition to being the central control for electrical power output, the PDU also contains various fuses that act as safeguards in the event of electrical surges within the high-power electrical system of the electric vehicle.

Figure 5. PDU For Electric Vehicle

To execute the algorithm of the low-voltage fault detection system within the PDU of an electric vehicle, a controller is required to receive input signals from voltage sensors. Based on the sensor readings, the controller can control the condition of the contactors, which can interrupt or allow the flow of high-voltage electrical currents. Figure 7 illustrates the block diagram of the operational process of the system within the PDU. Therefore, the proposed algorithm in this paper will be implemented in the Power Distribution Unit (PDU) of the electric vehicle.

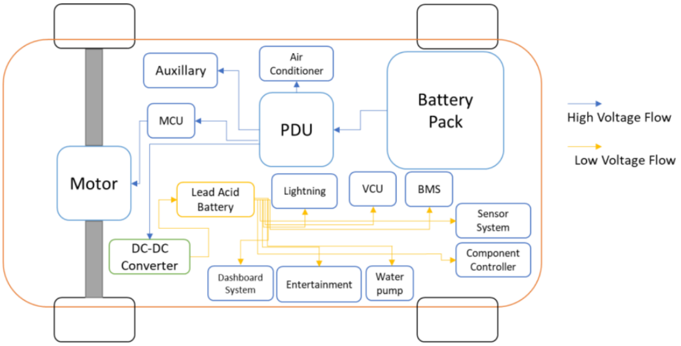

Figure 6. PDU System in Electric Vehicles

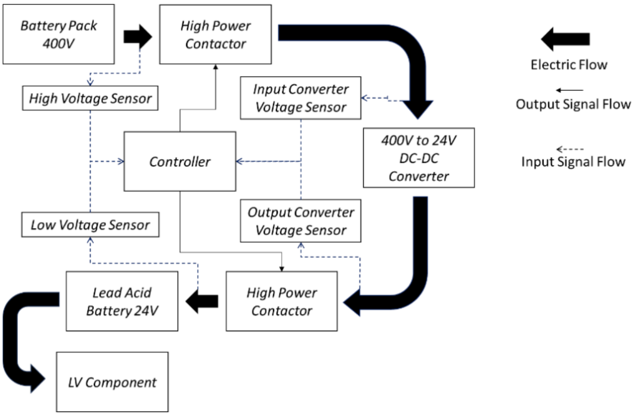

Figure 7. Low Voltage Faults Detection System with PDU

6. Analysis of Electrical Component Conditions

In order to describe the condition of each electrical component in the low voltage fault detection system and ensure system security, several conditioning processes can be established based on logic inputs obtained from sensors. In this paper, four conditions representing the state of the sensors in detecting the presence or absence of voltage within the electrical circuit path in the algorithm were experimentally tested.

Table 1. Voltage Sensor Input Logic

	Input			
Condition	Lead-Acid Battery Sensor	Vout DC-DC Conv. Sensor	Vin DC-DC Conv. Sensor	HV Sensor
1	0	0	0	0
2	0	0	1	1
3	0	1	1	1
4	1	1	1	1

Table 2. Output Condition Based on Input Condition

	Output			
Condition	MCU Contactor	Lead-Acid Battery Contactor	Vin DC-DC Contactor	Vout DC-DC Contactor
1	OFF	OFF	OFF	OFF
2	OFF	OFF	ON	ON
3	OFF	ON	ON	ON
4	ON	ON	ON	ON

Table 1 illustrates the logic inputs from the voltage sensors integrated into the low-voltage failure detection system. These logic inputs are read by the controller within the Power Distribution Unit (PDU) to activate the contactors present in the PDU. From the logic inputs, it can be observed that the sensors provide a logic value of "1" when successfully detecting voltage in the power distribution from the electrical components. Conversely, the sensors provide a logic value of "0" when they fail to detect voltage in the power distribution of these electrical components. Based on these logic inputs, the output is determined, which indicates the active or inactive state of the electrical components.

Since Table 1 and Table 2 are part of the same process in implementing the low-voltage failure detection algorithm, the input sensor data obtained from Table 1 can be used to describe the state of the contactors as presented in Table 2. Hence, Table 2 outlines the conditions under which the contactors will be activated or deactivated based on the input sensor conditions. From Table 2, it can be observed that the Motor Control Unit (MCU) can only be activated if all the sensors successfully detect voltage. This performance limitation of the MCU is intended to enhance vehicle safety, as the vehicle cannot be used if any of the sensors fail to detect voltage in any power distribution path. Additionally, to ensure the charging of the lead-acid battery by the system, the output voltage from the DC-DC converter needs to be monitored. This is done to maintain the battery in a charged state and prevent voltage drops.

The output conditions of the voltage sensor logic can be interpreted as the system's operational state over a period of time. These conditions are illustrated in Figure 8.

Figure 8 depicts the system's operational conditions over a period of time based on the logic input from the sensors in the proposed algorithm. From Figure 8, it can be observed that all contactors are in the "OFF" state when none of the high-voltage sensors provide a logic input value of "1" to the controller within the Power Distribution Unit (PDU). Subsequently, when the HV sensor detects high voltage originating from the 400V battery pack, it activates the input contactor of the DC-DC Converter and checks the condition of the lead-acid battery voltage. To detect the availability of the low-voltage system, the Lead-Acid Battery sensor detects the existing voltage first. If the lead-acid battery voltage remains below the operating voltage of the electric vehicle, the MCU contactor will not supply high voltage for vehicle operation. Therefore, the Output DC-DC Converter contactor becomes active to charge the lead-acid battery until it reaches the specified working voltage of 27.5V. The Output DC-DC Converter contactor remains active during vehicle operation to ensure the availability of the low-voltage system. Furthermore, when

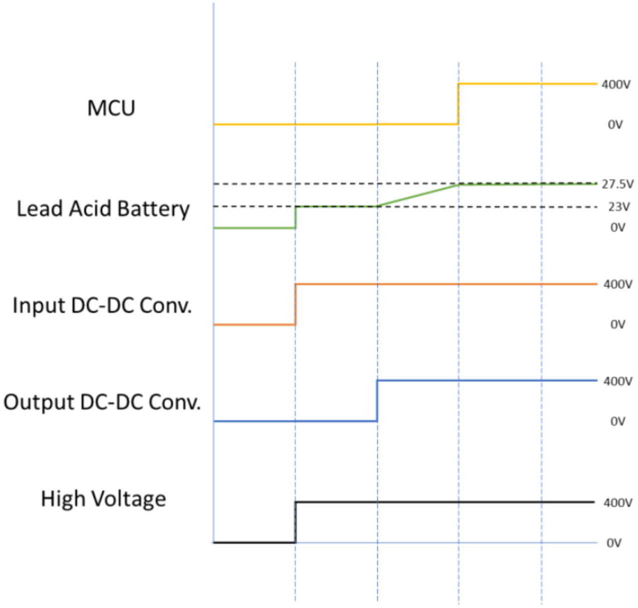

Figure 8. Low Voltage Faults Detection System with PDU

all voltage sensors successfully detect the incoming voltage in the electrical circuitry within the PDU, the MCU contactor can be activated, allowing the flow of the 400V high voltage for vehicle propulsion.

7. Low Voltage System Faults Case in Electric Vehicle

Currently, there is a rapid development of the electric vehicle ecosystem in Indonesia. This can be observed from [9], which provides information on the significant increase in the number of various types of electric vehicles. Moreover, the Indonesian government has implemented policies, such as electric vehicle subsidies, to encourage higher adoption of electric vehicles. This development is further supported by social media influencers who actively promote the use of electric vehicles. However, the progress of the electric vehicle ecosystem is not without challenges. Several users have encountered issues related to the electrical system of their electric vehicles.

Fitra Eri, an automotive influencer, experienced an electrical problem with his Wuling Air EV electric car. After leaving the car unused for two weeks during the Eid holiday, it couldn't be started. Due to the lack of usage, the 12V lead acid battery in the vehicle was not recharged. As a result, the vehicle couldn't be used, and a jump-start process was required to recharge the lead acid battery. Ridwan Hanif R., another automotive influencer, faced a similar issue with his Wuling Air EV electric car.

The same case occurred with a Hyundai Ioniq 5 electric vehicle, which experienced low voltage system faults. The lead acid battery integrated into the vehicle suffered from a voltage drop because it was left unattended for too long by the owner. Due to these low voltage system faults, the electric vehicle couldn't be used.

The inability to recharge the lead acid battery is due to the absence of a low voltage system faults detection algorithm in these vehicles. Consequently, when the lead acid battery's power decreases, the system is unable to directly recharge it, rendering the vehicle unusable. Therefore, the implementation of a low-voltage system faults detection algorithm is crucial in every electric vehicle. By doing so, losses experienced by electric vehicle users can be minimized, and operational efficiency can be enhanced.

8. Conclusion

This paper presents a study on the low voltage failure detection system in electric vehicles. Through the conducted study, a new algorithm has been developed, that involves detecting the electrical voltage in each power distribution pathway of the electrical components. By utilizing this algorithm, it becomes possible to anticipate failures in the low-voltage system caused by the loss or reduction of voltage in the lead-acid battery used to supply various components requiring low voltage for operation. By detecting these voltage variations, the challenges associated with the inability of the low-voltage system to detect existing failures can be addressed. Furthermore, the detection algorithm in this failure detection system can be further expanded to encompass high-voltage systems.

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