

A Study on Automatic Electric Battery Vehicle through Electrical Energy Management System

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Abstract

An electrical energy management system based on service-oriented communication must be designed for an autonomous battery electric vehicle with four-times redundant electrical power supply system. In addition, the electrical energy management system must provide information on the power supply system's internal state. The value of the state of function is presented, which is based on the electrical supply system's self-perception. Using this method, a design for an electrical energy management system is provided that incorporates machine-learning algorithms to meet the expectations for autonomous battery-electric cars. As a result, this article shows innovative techniques for managing electrical energy in autonomous mobility systems.

Keywords: *Electric vehicle, Electrical energy, Service-oriented communication architecture (SOA), Electric Power Supply (EPS)*

INTRODUCTION

Battery electric shuttles with SAE level 4 automation are being developed under the UNICARagil project, which is supported by the German Federal Ministry of Education and Research. These vehicles will have a considerably different approach to the electric power supply (EPS) than typical electric architectural

layouts because of higher requirements in terms of dependability and safety. Furthermore, service-oriented communication architecture (SOA) varies from vehicle design based on functions. Within these limits, a novel electrical energy management (EEM) system strategy is required to maintain power

supply dependability and system performance during failure occurrences.

As a result, the key aspects of the UNICARagil shuttle's EPS system, as well as probable defects in any EPS, are examined in the following section. Furthermore, UNICARagil includes state-of-the-art EEM features as well as the SOA communication strategy.

EPS in conventional Battery Electric Vehicles

In traditional battery electric vehicles (BEVs), the electric drives are powered by a single traction battery, which is commonly a high voltage (HV) battery. Electronic control units (ECU) and other LV consumers are powered by an extra low voltage (LV) power net provided by the HV battery through a DC-DC converter. Figure 1 shows an example of this type of traditional EPS. HV consumers and on-board-chargers are thus other components in the HV power grid. The fundamental distinction between an HV and an LV power network is the requirement for HV components to be protected from direct contact. As a result, both the HV plus pole and the HV minus pole are not linked to the car frame, requiring separation guards.

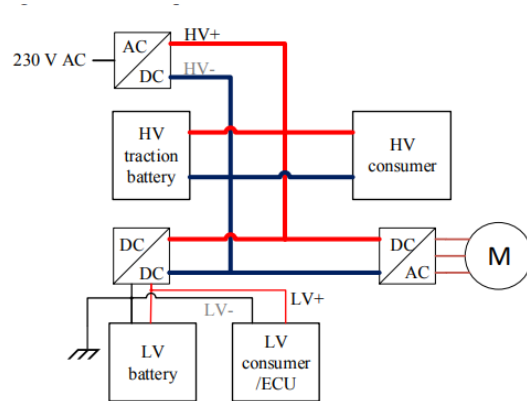


Figure 1: Conventional EPS system with HV traction battery

Faults in EPS System

Various problems in the EPS system can arise during operation, with varying effects on the vehicle's general functionality. These issues include traction battery voltage loss, connection failures, short circuits, and component failure.

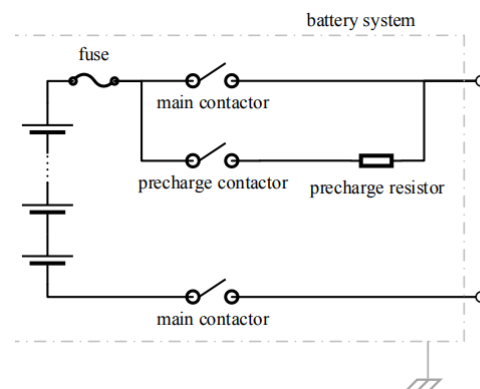


Figure 2: Electric circuit within battery system

The voltage loss of a traction battery, whether HV or LV, can be caused by various factors. As a result, it's critical to comprehend the battery system, which is

depicted in Figure 2. The battery system also includes a primary fuse, contactors, and a battery management system in addition to the battery cells (BMS). The BMS is an ECU that monitors measurement data from current, voltage, and temperature sensors that are also part of the battery system.

In addition, the BMS computes data such as state of charge (SoC) and health status (SoH). As a result, the battery system is a complicated system that relies on many distinct components to function. Open contactors or blown fuses can cause voltage loss. High temperature, over-current, or nearing cut-off voltage might cause contactors to open for safety reasons. Internal or exterior short circuits can occur as a result of a blown a fuse. Open contactors can also be caused by sensor and contactor failures. Sensor readings that are out of range or stuck in range, offsets, slope faults, and oscillations are all common sensor failure types. The BMS ECU is also powered by an external voltage source, such as LV batteries. Contactors will remain open if the BMS's external power source fails.

Poorly fitted plug connections can cause faster corrosion of contacts owing to age, resulting in connection problems. As a

result of the increased contact resistance and voltage loss caused by connection defects, the contact resistance rises. ECUs may shut down as a result of voltage decreases. At 48 V, a loose or intermittent contact causes voltage arcs, posing a threat to nearby components.

Short circuits occur as a result of insulating flaws. The matching inline fuse will blow in a correctly configured power supply, preventing excessive heat buildup within the cable. Every cable connection has fuses placed. However, the current must exceed a particular threshold before the fuse bursts. As a result, any short circuit that occurs below that threshold may not be recognised right away.

High or low resistance might result from a component failure, such as a problem in an ECU or an electric consumer. The current flow will be reduced if the resistance is high. A low resistance that causes a current below the fuse threshold will cause the problem component to heat up. The component may still be able to vary between multiple states of failure towards the electric supply interface, depending on the fault status, which means it might appear as either low or high resistance at different times.

EPS UNICARagil

The UNICARagil EPS system is developed to meet the demands of dependability in autonomous driving mode, preventing harmful situations. The EPS architecture has been shaped by a number of criteria and distinctive design elements:

- The UNICARagil vehicle is propelled by four corner modules, each of which can independently operate and steer each wheel.
- At each vehicle corner, there are four sensor devices that can monitor 270° of the vehicle surroundings.
- Single malfunctions in the electric system must not result in the autonomous driving features being completely shut down.

The fault-tolerant EPS ring architecture depicted in Fig. 3 is the result of these design principles. As a result of the four battery modules in the four component nets, the EPS topology has four times redundancy. The four component nets are

connected by four contactors. All contactors are closed in a fault-free state, indicating that the batteries are linked in parallel. The four component nets can be split in a fault situation for fault isolation. This way, a single malfunction in any portion net will not result in the entire power supply failing. Because of the distributed driving and sensing capabilities, the vehicle will be able to retain safe locomotion functioning even if one portion net fails.

The four battery modules have a 48V voltage level. Each battery has 12 kWh of energy and is fitted with a comprehensive BMS. Air is used to cool the batteries. Due to the fact that certain electric consumers only run on 12 V, there are four 12 V part nets that are all supplied by one 48 V part net independently. Due to the fact that commercially available batteries do not have the SOA interface created for UNICARagil, the BMS is not part of the SOA environment.

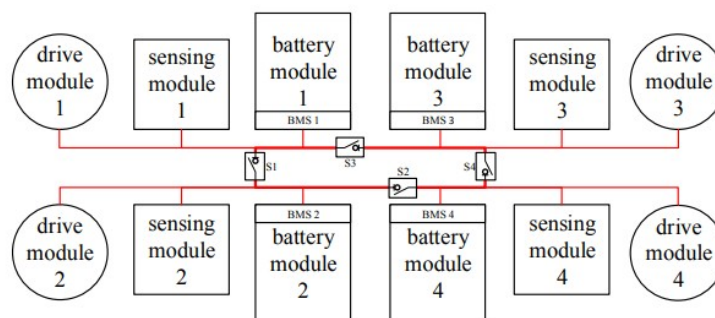


Figure 3: Layout of EPS in UNICARagil vehicle

EEM in BEVs

In traditional BEVs, the EEM is concerned with the proper operation of the traction battery. In this case, proper operation entails keeping the batteries within acceptable operating limits while dealing with ambient factors in tandem with temperature management [5 p. 12]. An EEM, is made up of three parts: energy supply, diagnostic system, and information system. The EEM's primary responsibility in this role is to manage power flow to energetic consumers by classifying and prioritising power flow to various consumers. Proposes a trip-based energy management system that focuses on estimating maximum power demands to ensure that the vehicle arrives at its destination. As a consequence, the findings show that there are a variety of EEM system techniques that go beyond basic functionality by providing optimum operating strategies in some areas.

EEM for Automated BEVs

An EEM is presented for automated BEVs that optimises energy distribution in fault-tolerant power supply systems, predicts energy demands for electric drives based on trajectory planning information, and predicts energy resources. The EEM is predicated on the premise that all DC-DC converters are bidirectional, allowing for entirely regulated energy flow in that study.

Different defects, such as electric faults in power links, power sources, and power loads, are also taken into account. During fault conditions, the EEM must employ techniques to achieve certain safety objectives and maintain defined degrees of operation. The identification and evaluation of the various flaws are either not stated or just suggested in passing [8 p. 117]. As a result, this research does not provide a comprehensive picture of an EEM for autonomous cars, as a diagnostic system may be included in an EEM.

SOA

Unlike the traditional function-based communication design for ECUs in automobiles, which makes it impossible to master any rising complexity provided by future capabilities like autonomous driving features, a service-oriented architecture may meet these issues [9 p. 31]. Different functions are contained in services that any client can access under SOA [10 p. 2]. In addition, several services may be connected together to complete tasks. This method enables for easy access to data from many domains within the vehicle as well as contact with external services.

SOA Concept UNICARagil

Every service in UNICARagil has a specified input and output interface that is

based on a predetermined interface database. Inputs can be both data inputs and service needs, as seen in Fig. 4. As a result, outputs can be used as service assurances. The service itself is made up of calculation source code. During operation, service integration takes place.

Every input and output contains three different kind of data:

- **User data:** data describing physical or logical values
- **Parameter data:** interface specific data for compatibility tests for integration during operation time and communication of non-changeable data.
- **Quality data:** evaluation of quality of user data

Concept of EEM in SOA

Data has already been collected to meet EEM's input and output standards. Power requests and data from trajectory planning

for power demand prediction are expected to be inputs. Output data includes calculated values like state of charge (SoC), state of health (SoH), and whether the batteries are charging or discharging, as well as measurement data such traction battery temperature, voltage, and current. In this instance, SoF denotes a notional value for the battery system's performance capacity based on the internal condition of EPS.

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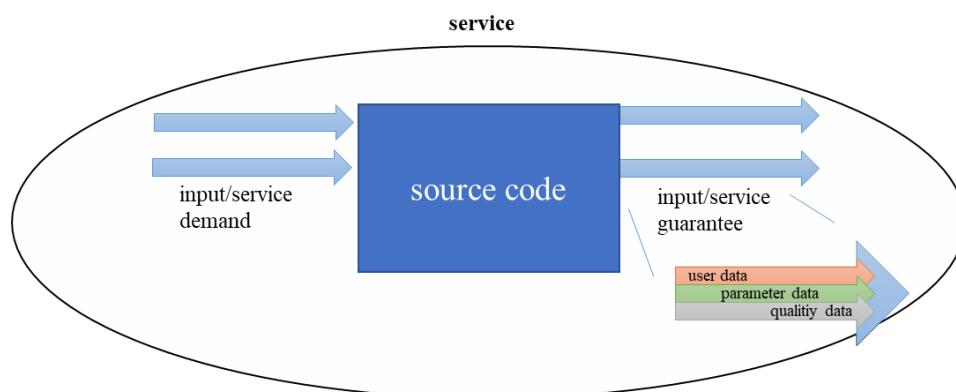


Figure 4: Service interface

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Aim

The safe functioning and management of any system in an autonomous vehicle can only be based on knowledge of the system's internal status, which necessitates particular perception and data fusion abilities. Current EEM approaches do not give these capabilities, nor do they indicate how to share this data with the vehicle's remaining operations. Furthermore, there is no idea for adopting EEM in an automated vehicle as part of a SOA system. As a result, this study will propose a plausible design for an EEM that will diagnose and evaluate the inner state for the UNCARagil project's fault-tolerant EPS. The traction batteries will be the

focus of diagnostic and internal status evaluation in the first stage, since they are both the most complicated systems and the heart of any EPS. The second section discusses various methods for converting diagnosis and internal state evaluation results into output values for the SoA interface.

The rest of the paper is organised as follows. The requirement analysis for the proposed EEM system is covered in Section 2. The concept for building the needed functionality of the EEM system is outlined in section 3, and the prognosis for future steps is provided in section 4.

REQUIREMENTS DEVELOPMENT FOR EEM

The prerequisites for the EEM in UNCARagil will be outlined in the next section. According to the preceding section, the EEM system must be developed in a SOA context and must have self-perception features. As a result, there are both functional and implementation requirements.

Functional Requirements

The awareness of the EPS's internal status is the most important functional prerequisite for EEM. The internal state perception is used to compute the state of

function value and any decision-making process that is designed to allow safety measurements in the power supply system during a fault scenario. As a result, giving a value that represents the internal state to the remaining vehicle domain, as well as the capacity to react to particular fault situations, are additional needs. As a result, these needs may be broken down into two categories: diagnosis and fault plan management.

Diagnosis Functionality

The diagnosis functionality monitors BMS input data for anomalies, evaluates these irregularities for criticality, and matches them to specific defects. As a result, EEM must be provided with classification methods as well as awareness of EPS defects.

Fault Strategy Management

Fault strategy management entails adapting the computation of EEM output values such as SoF and their associated quality data, as well as performing actions such as shutting down single batteries if necessary, based on the knowledge gained from the diagnosis functionality. Treatable and non-treatable defects are the two types of faults. Hardware flaws are almost always untreatable. They can either be tolerated by a loss of functionality or the

entire system can be turned off. Sensor errors, such as offsets or gain problems, may be the only hardware issues that can be treated. The incorrect sensor data can be repaired by post processing if the diagnosis is right.

Implementation of EEM

The inputs and outputs are established in the SOA idea; however the EEM also relies on BMS data that isn't part of SOA. As a result, the EEM acts as a link between the data supplied by the BMS and the SOA vehicle environment, as shown in Fig. 5. Power needs and trajectory planning data are used as inputs. SoC, SoH, SoF, temperature, voltage, and current, as well as the overall condition of operation, are all examples of output data.

Basic implementation requirements for the EEM include BMS data processing, according to Fig. 4 and the preset signals the EEM must give. The four data sets from the four BMS must be combined into a single data set for the output, with just single values for SoC and other parameters. The remaining vehicle domains see the EPS as a single-battery system in this fashion. For various values, however, different techniques to data processing are required. Choosing the lowest, maximum, or average value is the most basic

approach for combining numerous values into a single number. In the following sections, we'll look at some of the numerous ways you may handle BMS data.

Measurement of Voltage

The voltage number shows how much energy is remaining in the battery cells as well as how much load is being applied. When all contactors in the main supply ring are closed, all four traction batteries are linked in parallel, as illustrated in Fig. 5. As a result, it is reasonable to predict that the measured data will be equal at all times. As a result, the average value should be identical to any single number in normal operating mode. When at least two contactors are active in fault mode, however, observed voltage levels may begin to drift apart due to differing power

consumption in distinct main component nets. In this case, the data processing methods adopted may have a significant impact. Choosing the least value from any measurement would be the most cautious approach during a fault event from a safety standpoint.

Measurement at this time

The current readings represent the load on the batteries. In normal operating mode, current readings should be identical at all times due to the parallel connection of all four batteries. With two contactors isolating one portion net in fault mode, current load equality is not assured. As a result, picking the maximum value to represent the highest power demand is the safest but probably not the brightest way.

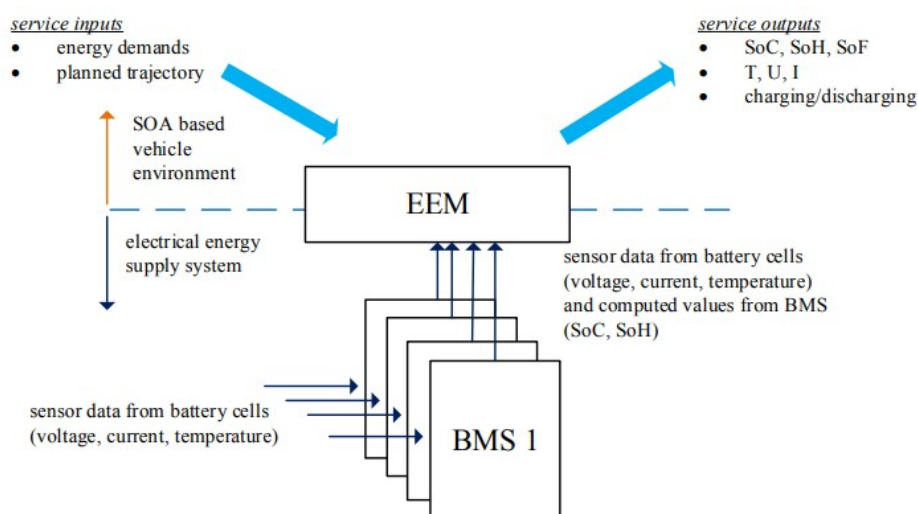


Figure 5: Communication architecture of EEM and BMS.

Measurement of Temperature

The functioning of lithium-ion batteries necessitates a certain temperature range. When the maximum temperature is exceeded, dangerous consequences arise. Additionally, running at high temperatures reduces longevity. To avoid dangerous circumstances, the maximum temperature observed at any given moment should be utilised.

Computation on SoC

The SoC numbers are calculated separately by each of the four BMS and represent how much energy is remaining in the batteries. All four SoC-values should be equal since four identical batteries are linked in parallel. Diverging readings can be caused by merely open primary contactors. Choosing the lowest SoC value, as with the observed voltage readings, may result in the most conservative but not the most accurate value. The average SoC number in fault-free mode does indicate the proper amount of energy in the batteries. The lowest value represents the amount of energy that can be guaranteed at any time in all four batteries in a fault condition, with open contactors in the main supply ring, without causing the shutdown of one part net. As a result, SoC computation should be dependent on the mode of operation.

Computation in SoH

The SoH number represents the actual capacity of the battery in comparison to the nominal capacity. Due to ageing effects, the real capacity will decrease with time. Because the four batteries are positioned in different parts of the car, their temperature effects fluctuate somewhat. Because it is a time-dependent value, the SoH value is not critical for operation safety. As a result, averaging the four batteries' values is sufficient.

CONCEPT

In the next part, a basic design is described that will meet EEM's diagnostic functionality and fault strategy management needs.

Functionality of the Diagnosis

The diagnostic functionality is designed to be at the heart of the EPS system's internal state estimation. As described in earlier sections, the four separate BMS communicate measured and calculated data that characterise the internal condition of each battery system on a continual basis. These statistics are anticipated to be extremely comparable at all times due to the parallel connection of all four batteries. As a result, each measured and calculated irregularity in any battery will result in BMS data that differs from the other BMS.

Following that, the data must be regularly watched and assessed in order to find abnormalities. This endeavour necessitates the use of data processing methods to determine whether or not a given data collection is irregular. If a specific data set could be identified, however, additional steps should be taken to reach a complete diagnosis, as shown in Fig. 6.

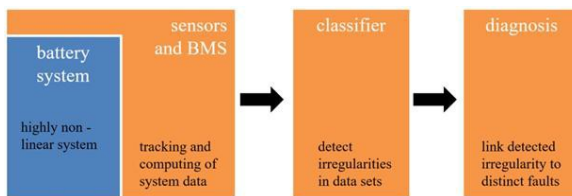


Figure 6: Steps in diagnosis functionality.

Classification

Machine learning (ML) methods will be employed for the classification stage. There are two types of machine learning algorithms: supervised and unsupervised. In order to train the algorithm to predict future outputs, supervised learning methods require known input and output data. Unsupervised learning methods are used to investigate unknown data sets in order to uncover patterns.

There are currently no data sets that might have been captured from a four-time redundant EPS, particularly during a failure situation. As a result, there is no

historical data with which to train any machine-learning system. This data scarcity can be partially addressed by using simulation models to generate data. The cost-effectiveness of simulation-based data creation comes from the fact that hardware defects may be simulated as well. The disadvantage of simulation-based data is that it must be created for a wide range of operation situations as well as numerous failure conditions.

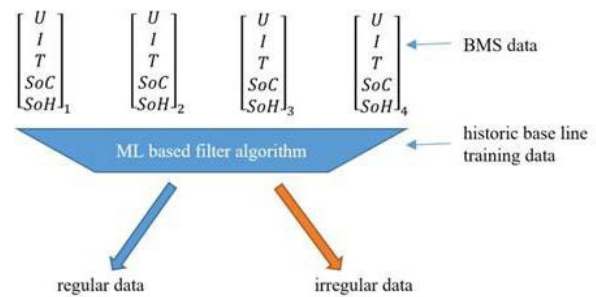


Figure 7: Classification algorithm for filtering BMS data.

The persistent comparability of the four BMS data is, however, a critical component of this EPS.

As a result, real-time data comparisons can somewhat compensate for the unavoidable lack of a complete training data set.

A ML filter algorithm will be built, as illustrated in Fig.7, that has been trained using a simulation-based data set.

This baseline data set will aid the filter algorithm by ensuring that each input data vector is not just compared to other vectors but is also given a general assessment.

This method will improve the filter's resistance to long-term measurement noise. When using a comparison-only method, the input vector with the greatest distance is always sorted as the irregular vector, indicating an unexpected operation circumstance.

In a subsequent phase, it may appear that feeding data inputs that were identified as regular input vectors may be used to update the filter algorithm indefinitely. This might be beneficial for compensating for the battery system's ageing effects over time.

Diagnosis

Irregular data sets are identified as a result of the categorization stage.

These data sets must be matched to separate defects during the diagnostic process.

As a result, similar to the ML filter method, an algorithm must be developed to correlate the singled out data to a specific defect.

This procedure necessitates a broad understanding of certain flaws.

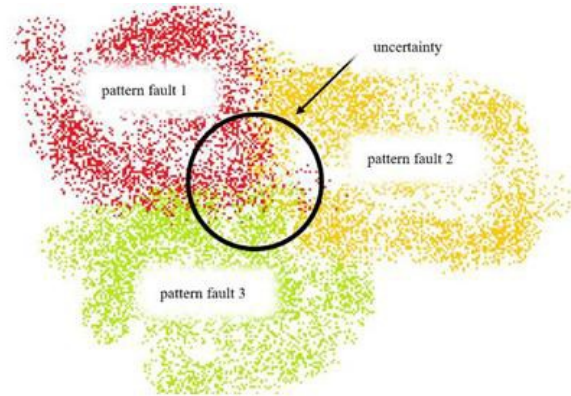


Figure 8: Exemplary illustration of faulty data set patterns and associated faults.

Using simulation data of fault situations is one technique to correlate irregular BMS data sets to specific faults. Pattern recognition algorithms may be used to analyse this data, as seen in Fig. 8. As a result, the limits of various fault patterns may be defined. However, it is clear that the borders between some patterns might be fluid, resulting in confusion. In theory, stochastic approaches that analyse the likelihood of a certain failure in order to improve the uncertainty problem might provide extra help. In practise, this would need a combination of expertise and, at some point, extensive testing of specific hardware components. As a result, the distinction between sensor and hardware problems may be a crucial outcome for the fault strategy management phase in the

first stage. Because hardware results are not always handled in the same manner as sensor or compute failures are, this distinction already gives important information about EPS's internal health.

Management of Fault Strategy

In the event of a fault condition, the strategy application management phase of this process will use the information from the diagnosis stage to apply appropriate strategies. The EEM can react to any issue in one of three ways: it can take hardware-based steps to prevent more risks, resolve the fault circumstances, or adjust the computation of output values.

Hardware based Actions

Actions depending on hardware

Hardware-based actions include fault isolation (by dividing up a fourth of the EPS supply) and battery shutdown (by opening the battery's contactor). Battery shut down may be required to safeguard

the battery from overheating or other operational limitations.

Identifying and Correcting Faults

When properly identified, some defects, such as sensor-related concerns, can be remedied. Under the premise of comparable system behaviour, gain or offset errors in the voltage or current sensors, for example, can be addressed by comparing data sets from other BMS.

Output Values Calculation

The EEM can take indirect measures to lessen the operative pressure on EPS by modifying the computation of output values that the EEM is expected to give at the SOA interface. In this method, the SoF value may be lowered in order to implicate the system's maximum power output. In addition, the diagnosis result must be converted into quality data. In Figure 9, three alternative states of the EPS are depicted, together with the various output values for SoF and quality data.

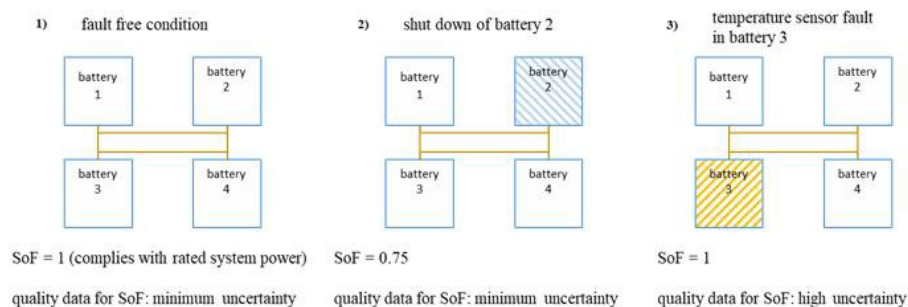


Figure 9: Different states of EPS and affiliated values of SoF and quality vector.

CONCLUSION

As a result, the possibility of converting diagnostic into quality and output data becomes clear. The EPS may be able to supply rated output power with minimal uncertainty in a fault-free condition, resulting in minimal uncertainty in the quality data. The second scenario depicts a single battery being shut down owing to internal issues. As a result, the SoF value will be decreased by 25%, and the certainty of this situation will be established. However, in the third example, a malfunctioning temperature sensor was discovered. As a result, the system's performance is unchanged. Nonetheless, there will be more ambiguity in the quality data. The danger of a mistaken diagnostic of the temperature sensor, whose data is crucial for safe battery operation, is thus reflected in the quality data.

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