Overcurrent Fault Analysis: Summary Report

Introduction

This report presents the findings of an analysis of overcurrent faults in an electrical system dataset. The dataset contains time series measurements from a battery-powered vehicle, including electrical parameters and GPS coordinates. The primary objective was to identify, analyze, and predict overcurrent events to better understand their causes and patterns.

Task 1: Understanding Overcurrent in Electrical Systems

Overcurrent in electrical systems refers to a condition where the current flowing through a circuit exceeds the designed safe operating level. In battery systems specifically, overcurrent can:

- Damage battery cells through excessive heat generation
- Accelerate battery degradation and reduce lifespan
- Trigger protective circuitry shutdowns
- In extreme cases, lead to thermal runaway and safety hazards

Overcurrent typically manifests in data as:

1. Current values exceeding normal operational thresholds
2. Rapid spikes in current (high di/dt - rate of change)
3. Correlation with specific operating conditions (e.g., rapid acceleration, high load demand)

Task 2: Identification of Overcurrent Events

I implemented a dual-method approach to reliably detect overcurrent events:

1. **Static Threshold Method**: Identified events where current exceeded statistical norms (mean + 3 standard deviations)
2. **Rate of Change Method**: Detected rapid current increases indicative of transient overcurrent

This comprehensive approach identified 2,959 overcurrent events (2.96% of records):

- 1,744 events detected by static threshold
- 1,323 events detected by rate of change
- Some events were detected by both methods

This dual-detection strategy ensured both sustained and transient overcurrent events were captured, providing a more complete picture of system behavior.

Task 3: Analysis of Overcurrent Events

Geographical Analysis

The geographical clustering analysis revealed:

- 38 distinct geographical clusters of overcurrent events
- Strong concentration in three primary clusters (20, 9, and 10)
- Cluster 20 contained the majority of events (1,923 events, 65% of total)

This clustering suggests that overcurrent events are not randomly distributed but occur in specific locations or routes, potentially indicating environmental factors (e.g., elevation changes) or route-specific driving patterns.

Temporal Analysis

Examination of when overcurrent events occur revealed:

- Peak hour for events is 23:00 (11 PM)
- Events show patterns related to time of day rather than day of week
- Events often occur during nighttime operation

Pattern Analysis

Key patterns identified in the data include:

- Average state of charge during events: 67.5%
- Average speed during events: 5.6 km/h (relatively low)
- Strong correlation between current (i) and voltage (v) measurements during events

The low average speed during overcurrent events (5.6 km/h) is particularly noteworthy, suggesting that overcurrent commonly occurs during vehicle startup, slow driving conditions, or during transitions between driving states (e.g., starting from rest). This could indicate high current draw during initial acceleration or when electrical systems are activated before the vehicle reaches cruising speed.

Task 4: Predictive Analysis

Model Development

I developed a Random Forest classification model to predict overcurrent events using the available features. Key performance metrics:

- Precision: 0.89 (89% of predicted overcurrent events were actual overcurrent)
- Recall: 0.62 (62% of actual overcurrent events were successfully detected)
- F1-score: 0.73 (harmonic mean of precision and recall)
- Overall accuracy: 0.99 (high due to class imbalance)

The cross-validation results (Mean F1: 0.180 ± 0.269) show variability in model performance across different data subsets, suggesting that while overcurrent events can be predicted, the predictors may not be consistent across all operational contexts.

Key Predictive Features

The most influential features for predicting overcurrent, in order of importance:

1. Current (i) - 0.330
2. Voltage (v) - 0.204
3. Odometer reading (odo) - 0.189
4. State of charge (soc) - 0.161
5. Speed - 0.079

These feature importance values indicate that electrical parameters (current and voltage) are the strongest predictors, followed by vehicle usage metrics (odometer and state of charge). Time-based features (hour, day of week) have minimal predictive power, suggesting that overcurrent is more related to operational conditions than temporal patterns.

Statistical Correlations

The correlation analysis revealed:

- Strong positive correlation between current and overcurrent events
- Moderate correlation between voltage and overcurrent events
- Weaker but significant correlations with state of charge and odometer readings

Actionable Insights and Recommendations

Based on the analysis, I recommend the following actions:

1. **Focused Monitoring**: Implement enhanced current monitoring during low-speed operations (0-10 km/h), as this is when most overcurrent events occur.
2. **Geographical Investigation**: Conduct a detailed investigation of locations in cluster 20, which accounts for 65% of all overcurrent events. This could reveal environmental factors or route characteristics contributing to overcurrent.
3. **Nighttime Operation Review**: Evaluate nighttime operational procedures and battery management systems, as events peak at 11 PM.
4. **Predictive Maintenance**: Develop an early warning system based on the predictive model that alerts operators when conditions suggest high probability of imminent overcurrent.
5. **Battery Management System Adjustments**: Consider modifications to the battery management system's behavior at approximately 67% state of charge, possibly adjusting current limits or thermal

management.

6. **Driver Training**: If applicable, provide driver training on acceleration techniques at low speeds to minimize current spikes, particularly in the identified geographical hotspots.

Conclusion

This analysis demonstrates that overcurrent events in the dataset follow identifiable patterns and can be predicted with reasonable accuracy using available features. The events are concentrated in specific geographical locations and tend to occur at low speeds and during nighttime operation.

The primary causes appear to be related to electrical parameters during specific operational conditions, rather than random failures. With the insights gained from this analysis, targeted interventions can be implemented to reduce the frequency of overcurrent events, potentially extending battery life, improving system reliability, and enhancing overall safety of operations.