

Automotive Power System Optimization through Vehicle Power Consumption Pattern Analysis

Sejoon Lim and Yeongro Yun

Abstract— This paper presents a fuse optimization algorithm for automotive power systems. Automotive wire harness takes up about 40 kg of vehicle weight and the need to reduce wire square is critical both for manufacturing cost reduction and fuel efficiency. First, fuse capacity is determined considering the electric currents flow through the fuse, and then, the wire square is calculated accordingly, so that the fuse can protect the wire.

We present a novel fuse capacity selection algorithm for selecting the right fuse capacity using the fuse fatigue graph and using electric load usage pattern data extracted from automotive CAN signals. The result shows that our algorithm based on the real usage data can reduce the current fuse capacity in vehicles by as much as 31% still preserving the fuse fatigue criteria.

Index Terms—Vehicular Power System, Data Analysis, Fuse Optimization, Big Data

I. INTRODUCTION

THIS paper describes automotive wire harness power system optimization technique through vehicular power consumption pattern analysis. We first propose a novel fuse optimization algorithm based on the fuse fatigue graph and real vehicular load usage data collected by real driving experiments. We then develop a wire square optimization algorithm based on the fuse capacity selected by the fuse optimization algorithm.

Wire harness is a device that provides power and electric signals to various electric and electronic devices inside the vehicle and is a unit that concentrates peripheral parts such as wires and connectors. Automotive wire harnesses account for a large proportion of the function and safety of automobiles, and wire harness weight is increasing due to the increase in electronic equipment in the vehicle. Weight reduction and miniaturization of wire harness are required for manufacturing cost reduction as well as fuel efficiency improvement and optimal vehicle design.

Current wire squares and fuse capacity selection is based on simple methods considering total amounts of electric

currents for all the loads. In this paper we develop algorithms to optimize wire square and fuse capacity through analysis of actual load usage pattern data and correlation with electric current amount. This approach results in much reduced fuse capacity and wire square still guaranteeing the safety of the automotive power system.

A. Related Work

There have been many studies related to the power system and wiring harness of automobiles or robots. For example, there are a study on path planning in the process of installation of automobile wiring harness [1], and modeling and fault detection and diagnosis of mating electric connector of robot [2]. However, there has been no research to optimize the vehicle power system considering the data of the automobile.

In the field of distribution radial feeders, there has been a study to determine the penetration level of distributed generation (DG) by considering the fuse fatigue [3]. Comparing the fault clearing time of fuse and recloser to find out fuse fatigue, the algorithm in the study determines whether the fuse needs to be replaced.

In this paper, we propose how the fuse fatigue graph can be used to determine the cumulative fatigue from various automotive loads usage patterns, and actively use the method to optimize the vehicle power system.

II. PROPOSED SYSTEM OVERVIEW

The purpose of fuse optimization is to efficiently select the fuse capacity considering the influence of the load connected to the bottom of the fuse on the fuse fatigue. Especially, the influence of the load on the fuse is determined by the fuse fatigue graph. The fuse optimization proceeds as shown in Fig. 1.

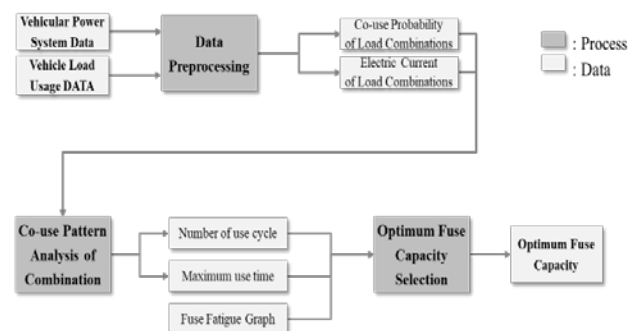


Fig. 1. Fuse optimization algorithm overview

When Vehicular Power System Data and CAN Data are input, the capacity of the fuses in Vehicular Power System Data is optimized as an output.

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The system is largely divided into three processes: the process of preprocessing vehicular power system and CAN data; the process of analyzing the co-use pattern of load combinations; and the process of calculating the optimum fuse capacity.

In the preprocessing step, the input data is processed to extract the probability and electric current data for each load combination. In analyzing co-use pattern of load combination step, given each load combination for a selected fuse, the maximum use time and the number of use cycle are examined. In the optimum fuse capacity selection step, the optimal fuse capacity is selected using the maximum use time, the number of use cycles, and the fuse fatigue graph.

III. DATA

A. Vehicular Power System Data

The Vehicular Power System Data has a tree structure of fuses and loads. In addition, it has a lot of detailed information. In case of fuse, it has capacity and location box information. In case of load, it has information such as design current. The connection structure between the fuse and the load is shown in Fig. 2.

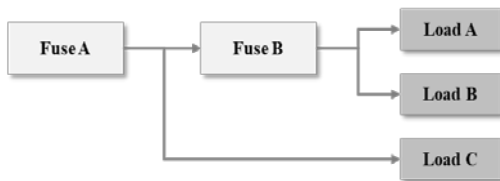


Fig. 2. A tree structure of fuses and loads.

As shown in Fig. 2, the load combination in Fig. 1, consists of all combinations of the bottom loads connected to the fuse. Co-use probability of load combination and total electric current amount of a load combination are used to analyze the co-use pattern.

B. Vehicle Load Usage Data

CAN is a Controller Area Network, which means communication between ECUs (microcontrollers) through data wiring [4].

CAN signal Raw data is the load usage data collected from the vehicle via CAN communication. The collected data consists of one-load usage probabilities, the one-load maximum use time data, the two-load co-use probabilities, the two-load maximum co-use time data, the three-load co-use probabilities, and the three-load maximum co-use time data, respectively. Also, each data set exists on a monthly basis. The total number of measured loads is 70.

C. Preprocessing

We pre-process the input data to obtain the data needed for fuse optimization. As shown in Fig. 1, the input data of preprocessing is Vehicular Power System Data and CAN Data.

First, as shown in Fig. 2, the Vehicular Power System Data is preprocessed to create a tree structure that forms fuses and loads in software. The fuse and load ID, capacity, current,

and other constraints are also applied to the fuse and load object in the software.

Second, the CAN signal Raw data is composed of one load usage probability, two load co-use probabilities and three load co-use probability data per month. Through preprocessing, we integrate one load usage probability, two loads co-use probabilities, and three loads co-use probability data, respectively. In addition, the CAN signal raw data has the maximum use time or co-use time of time data of one, two, and three loads, respectively. These data are integrated as well as the probability data.

The two histograms in Fig. 3 are examples of preprocessed one load maximum use time, and two loads maximum co-use time. The graph in Fig. 3 shows that the one-load maximum use times of half of the loads are less than 10,000 seconds and that the two-load maximum co-use time is less than 50,000 seconds.

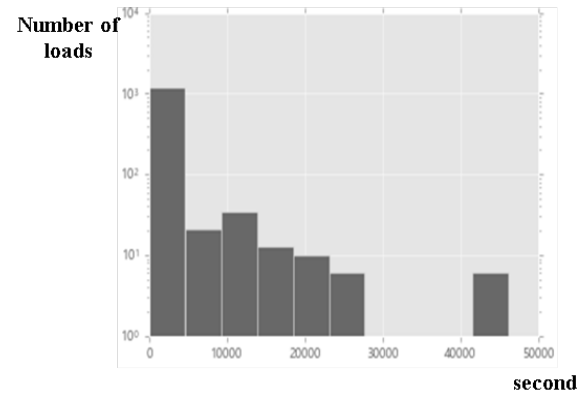
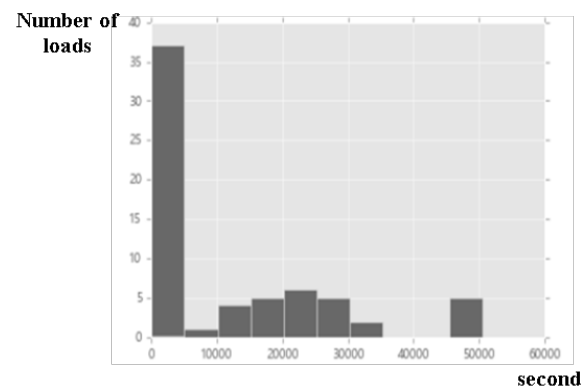


Fig. 3. Histograms of maximum use time for one-load (top) and two-loads (bottom). The Y-axis is log scale.

IV. ALGORITHM

A. Fuse Fatigue Graph

The fuse fatigue graph shows the durability of the fuse in terms of Percent of Rate, fuse use time, and the number of use cycles. Percent of Rate (POR) is defined as the ratio of the amount of current flowing in relation to the fuse capacity.

As shown in Fig. 4, fuse fatigue graph describes the relationship among the fuse use time (X-axis), the number of use cycles (Y-axis), and the Percent of Rate (lines labeled with corresponding percent). The graph basically describes how many cycles (number of use cycles: Y-axis) is needed to affect the durability of the fuse if a specific current respect to

the fuse capacity flows for a specific time period (fuse use time: X-axis).

The fatigue graphs are present for each capacity and type of fuse: One such graph for 40A rated slow-blow fuse is shown in Fig. 4.

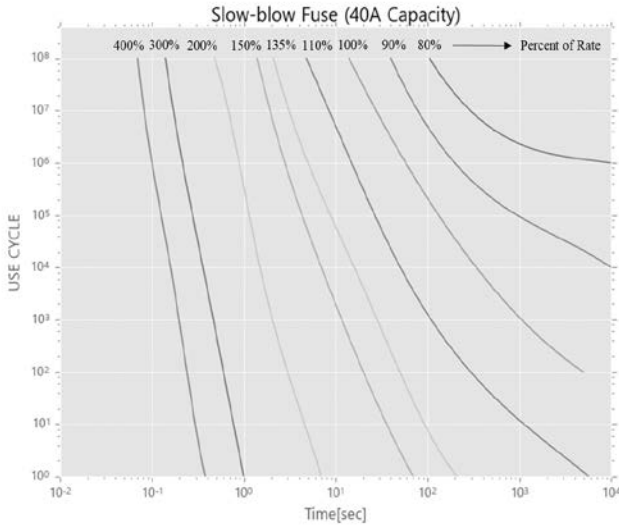


Fig. 4. A fatigue graph of the 40A rated slow-blow fuse. The X and Y axes are in log scale.

For example, the graph with a Percent of Rate of 150% can be used when the 60A current, which is 150% of the fuse rating, flows down through the fuse.

B. Fuse Optimization Algorithm

The fuse optimization is carried out using fuse fatigue graph. The process of selecting the optimum fuse capacity is performed in three processes.

As shown in Fig. 5, Temporary Capacity Selection, Fatigue Graph Satisfaction Test, Cumulative Fatigue Satisfaction Test, and Final Capacity Selection are performed in that order.

The Temporary Capacity Selection process simply selects the capacity of the fuse in increasing order among available fuses to perform the Fatigue Graph and Cumulative Fatigue Satisfaction tests in the subsequent process. We can find the optimal fuse capacity by choosing the temporary capacity from the smallest capacity.

The Fatigue Graph Satisfaction test is to check whether the fuse of the corresponding capacity has durability. The process proceeds by applying the usage patterns of all the combinations of the loads to the graph.

The Percent of Rate for a subset of loads is defined as follows:

$$POR(C_i) = \frac{\text{Total current of all loads in } C_i}{\text{Fuse capacity}},$$

where C_i is i th combination of all in the fuse.

The loads included in the C_i are defined as follows.

$$C_i = \langle \text{load1, load2, ...} \rangle$$

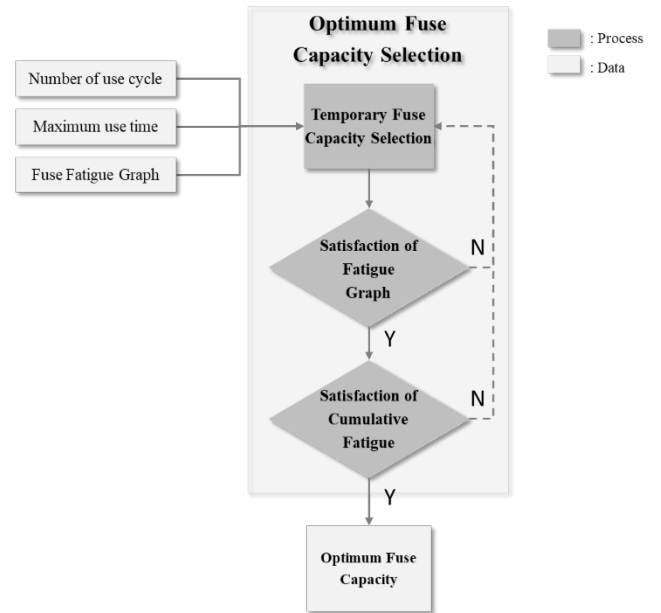


Fig. 5. Flowchart of the fuse optimization algorithm

First, we compare the current of each load combination C_i with the temporarily selected fuse capacity and convert it to Percent of Rate, $POR(C_i)$. We apply it to the fuse fatigue graph using the one maximum time of use (x-point) and the number of times of use (y-point), which is use cycle, of all load combinations. And we check if the point is below the graph of the converted Percent of Rate for each load combination (line 5 in Alg. 1). If any of the points are not below the graph for each Percent of Rate, go back to the temporary capacity selection process and select a larger-capacity fuse (line 6 in Alg. 1).

The Cumulative Fatigue test procedure is a process to check if the fuse can sustain the cumulative effect of each load combination on the fuse. This process also uses the fuse fatigue graph, which calculates the fatigue of each load combination on the fuse through the y-point of the C_i and the y-point of the corresponding percentage of rate graph.

The fatigue for a load combination is defined as

$$F(C_i) = \frac{\text{measured number of cycle}}{\text{number of cycle of } POR(C_i)},$$

where the *measured number of cycle* is the use cycle of C_i and number of cycle of $POR(C_i)$ is the corresponding use cycle of $POR(C_i)$ graph.

The cumulative fatigue is defined as the sum of the fatigues for all the load combinations.

$$CF = \sum_{k=1}^n F(C_k),$$

where n is the number of combinations of all the loads in the fuse.

If the cumulative fatigue is not greater than 1, it is judged that the Cumulative Fatigue test is satisfied and the final capacity is selected (line 10 to 11 in Alg. 1). Otherwise, the algorithm iterates for larger-capacity fuses until both Fatigue

Graph Satisfaction test, Cumulative Fatigue Satisfaction test pass.

The complete algorithm is as shown in Alg. 1.

Input: Available capacities, fatigue graph, load combinations

Output: capacity

```

1  Foreach Capacity in [Available capacities]
2    Initialize  $CF = 0$ 
3    For i in Number of combinations
4       $C_i \leftarrow$  ith combination
5      compute  $POR(C_i)$ 
6      if y-point of  $POR(C_i) <$  y-point of Combination
7        then go back line1
8      else
9        then compute  $F(C_i)$ 
10       then  $CF += F(C_i)$ 
11     End
12   if  $CF \leq 1$ 
13     then return Capacity
14   End

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Alg. 1. Pseudo code of the fuse optimization algorithm.

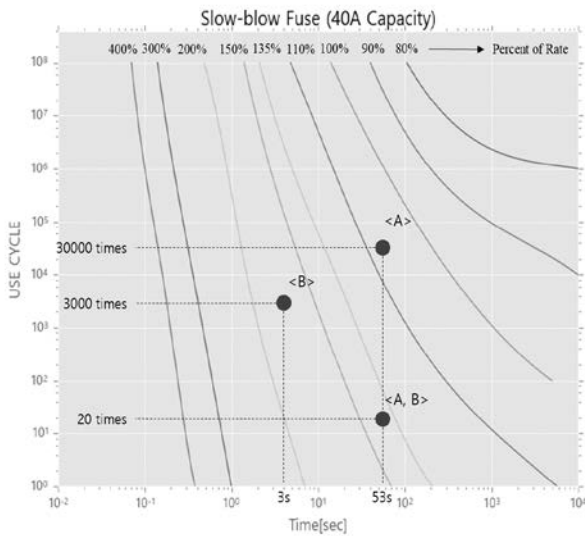


Fig. 6. Example fuse fatigue graph of Fuse B in Fig. 2.

Assume that we are selecting the capacity of Fuse B in Fig. 2 and that the temporary fuse capacity is selected as 40A in the first step. There are two loads at the bottom of Fuse B, and there are three combinations of loads: <Load A, Load B>, <Load A> and <Load B>. The corresponding points for these combinations are shown as dots in Fig. 6. Assuming that Load A has a current of 30A and Load B has a current of 20A, the current for each combination is <Load A, Load B> = 50A, <Load A> = 30A, and <Load B> = 20A. The Percent of Rate of each combination for this fuse is 125%, 100%, and 50%. The graphs to be satisfied for each combination are 135%, 100%, and 80% (assuming there is no data in the graph less than 80%). All three points are below the graph of their Percent of Rate, so the second step, Fatigue Graph Satisfaction test, is passed. In the third step, the fatigue for <Load A, Load B> is 0.4, which is calculated as the ratio of

measured number of cycles of the combination, 20, and the number of cycles of the corresponding 135% Percent of Rate graph, 80. In the same way, the fatigue of <Load A> is 0.03 and the fatigue of <Load B> converges to zero. Therefore, since the cumulative fatigue, 0.43, is smaller than 1, the final stage fuse capacity is selected as 40 A, satisfying the third stage, Cumulative Fatigue Satisfaction test.

V. EXPERIMENTS

The fuse optimization algorithm was performed in a typical personal desktop environment. We used a desktop computer with the Intel Core, i5-4590, 3.30GHz processor, 8.00GB RAM, and Windows 10 operating system. Software development was done in Python language version 3.5. We used the graphical user interface (GUI) library PyQT to display the tree structure of power system and information of various objects. The number of fuses in Vehicular Power System Data is 108, and the number of loads is 257.

VI. RESULTS

The total number of fuses present in the Vehicular Power System Data is 108, and each fuse has its initial capacity. However, only 13 fuses have been optimized, depending on the vehicular power system design constraints and the presence of CAN data at the bottom load.

TABLE I shows the optimization results for 13 fuses. The result shows that the total optimum capacity of 13 fuses has decreased by 31% compared to the total initial capacity.

TABLE I
AGGREGATE FUSE OPTIMIZATION RESULT

Number of fuses	Total initial capacity (A)	Total optimum capacity (A)	Capacity reduction rate (%)
13	180	125	30.56

TABLE II shows details of 13 fuses in TABLE I. The capacity of all fuses has been reduced by 25% to 50%. Especially, for the Fuse 10, the optimal fuse capacity was selected to be 10A, which is less than 15A, the sum of the bottom load current.

TABLE II
INDIVIDUAL FUSE OPTIMIZATION RESULT

Fuse ID	Bottom load count	Sum of bottom load current(A)	Initial Fuse capacity(A)	Optimized Fuse capacity(A)	Capacity reduction rate(%)
Fuse 1	16	3.47	10	7.5	25.00
Fuse 2	2	2.37	10	7.5	25.00
Fuse 3	10	1.26	10	7.5	25.00
Fuse 4	1	1.49	30	15	50.00
Fuse 5	2	6.00	10	7.5	25.00
Fuse 6	1	10.34	20	15	25.00
Fuse 7	1	9.61	20	15	25.00
Fuse 8	3	1.21	10	7.5	25.00
Fuse 9	1	1.82	10	7.5	25.00
Fuse 10	3	15.00	15	10	33.00
Fuse 11	1	2.40	15	10	33.00
Fuse 12	2	2.40	10	7.5	25.00
Fuse 13	3	2.27	10	7.5	25.00

Fig. 7 and 8 show the histogram of the initial fuses capacity and the optimized fuses capacity of the power system. The X-axis represents the fuse capacity and the Y-axis represents the number of fuses.

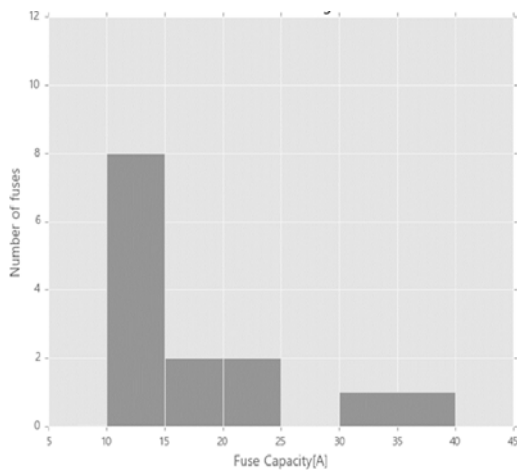


Fig. 7. Histogram of initial fuse capacities

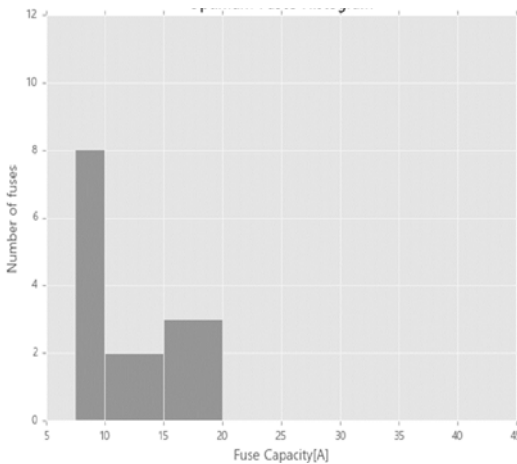


Fig. 8. Histogram of optimum fuse capacities.

Compared to Fig. 7, Fig. 8 shows no fuses with capacity over 20A. After fuse capacity optimization, the fuses with larger capacities were switched to smaller capacity fuses.

The process of optimizing all the fuses in Vehicular Power System Data took 24 seconds. Thus, our algorithm can be practically used for real world applications with large number of fuses and loads.

VII. CONCLUSION

We propose a novel fuse optimization algorithm based on the fuse fatigue graph and load usage data collected by real driving experiments. This data-driven approach using the fuse fatigue graph resulted in reduced fuse capacity by as much as 31%.

The main contribution of the paper includes reducing the fuse capacity and wire square as a result while ensuring the automotive power system safety using the fuse fatigue graph the vehicular CAN data analysis.

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