Smart Power Management System for Ambulance

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Abstract. Ambulance is one the most critical component in healthcare where it must have highest reliability and mobility to ensure minimum travel time of patient to the hospital. In Malaysia, there are significant number of cases where ambulance tend to have breakdown or caught on fire due to electrical current overload which caused by unmanaged electrical usage by medical equipment. To overcome this problem, a smart power management system has been developed by employing Hall-Effect based current sensor replacing conventional fuse. The sensor reading is actively analysed by a microcontroller which will cut off electrical power from over-current equipment. The system also can prioritize some critical equipment to be powered when there are limited current available.

1. Introduction

In this modern era, medical service provider get a lot of technological improvement in order to provide better healthcare service to the society. Despite of this, most of the ambulance technology is still left behind compared to other medical equipment such as MRI, X-Ray, CT Scan, Mammography and Ultrasound. This is due to the lack of dedicated industry for developing comprehensive ambulance platform.

Ambulance normally require combination of automotive and medical industry, which most of the work is carried out by vehicle integrator company that specialized in making special purpose vehicle [1]. However, since it involves with two different engineering disciplines, the integration process is not properly done, inducing several problems that reducing the ambulance reliability and effectiveness [2]. There are much improvement have been made including developing more efficient lighting and siren [3-5]. To reduce the mechanical stress on the vehicle alternator, alternate power source have been develop to support the increasing electric load of the ambulance [6,7]. With the emergence of Industrial Revolution 4.0, there are number of study that uses Internet-of-Things (IOT) to provide interactive control and monitoring of the ambulance [8]. However, there are rare study on providing better power management system, primarily focusing on fuse-less approach and priority-based equipment power channelling.
2. Problems
Each year, additional brand-new equipment being put on-board the ambulance to comply with user requirement. The use of these equipment dramatically increases the power consumption that often higher than those provided by the vehicle. In this study, we made an assumption of possible ambulance equipment list that will have power consumption as below.

| Item         | Description               | Qty | Current (Amp) | Power (Watt) |
|--------------|---------------------------|-----|---------------|--------------|
|              |                           |     | Unit | Total | Unit | Total |               |
| **A** Chassis|                           |     | 1    | 3.00  | 3.00  | 36    | 36            |
| 1 Electrical Fuel Injection | 2 | 3.00 | 6.00 | 36 | 72 | | |
| 2 Headlamps  | 4 | 0.50 | 2.00 | 6 | 24 | | |
| 3 Rear lamp  | 2 | 0.25 | 0.50 | 3 | 6 | | |
| 4 Position lamp, Front | 2 | 0.25 | 0.50 | 3 | 6 | | |
| 5 End-outline marker lamp, rear | 30 | 0.05 | 1.50 | 0.6 | 18 | | |
| 6 Instrument Panel Lighting | 1 | 5.00 | 5.00 | 60 | 60 | | |
| 7 Fan Motor  | 1 | 4.00 | 4.00 | 48 | 48 | | |
| 8 Windscreen Wiper Motor | 1 | 2.00 | 2.00 | 24 | 24 | | |
| **Sub Total**|                           |     |      |       |      |       | 24.5          |
|              |                           |     |      |       |      |       | 294           |
| **B**        |                           |     |      |       |      |       |               |
| Accessories  |                           |     |      |       |      |       |               |
| 1 Siren      | 1 | 8.30 | 8.30 | 100 | 100 | | |
| 2 Scene light (White) | 2 | 0.80 | 1.60 | 9.6 | 19.2 | | |
| 3 Scene light (Red) | 6 | 0.80 | 4.80 | 9.6 | 57.6 | | |
| 4 Scene light (Front) | 2 | 0.40 | 0.80 | 4.8 | 9.6 | | |
| 5 Cabin light | 5 | 1.33 | 6.67 | 16 | 80 | | |
| 6 Light bar  | 1 | 4.00 | 4.00 | 48 | 48 | | |
| 7 Beacon light | 2 | 1.20 | 2.40 | 14.4 | 28.8 | | |
| 8 Spotlight  | 1 | 1.00 | 1.00 | 12 | 12 | | |
| 9 Inverter   | 1 | 1.00 | 80.00 | 1000 | 1000 | | |
| 10 Fan       | 2 | 0.50 | 1.00 | 6 | 12 | | |
| 11 Girn      | 1 | 1.50 | 1.50 | 18 | 18 | | |
| **Medical Equipment** | | | | | | |
| 12 Defibrillator and Monitor | 1 | 9.00 | 9.00 | 108 | 108 | | |
| 13 Ventilator | 1 | 8.30 | 8.30 | 100 | 100 | | |
| 14 Suction Unit | 1 | 2.75 | 2.75 | 33 | 33 | | |
| 15 Syringe Pumps | 2 | 0.83 | 1.67 | 10 | 20 | | |
| **Sub Total**|                           |     |      |       |      |       | 133.8         |
|              |                           |     |      |       |      |       | 1646          |
| **Total (Chassis + Accessories)** | | | | | | 158.3 |
| **Power Available from Alternator 130A** | | | | | | 130 |
| **Power Available after (chassis + Accessories) consumption** | | | | | | -28.3 |
| % Power Available | | | | | | -22% |

As shown in the table above, the total power consumption is about 1940 W, while the supplied power from the vehicle is only 1560 W thus lead to power shortage of about 24%. This situation can lead to severe alternator damage and can bring down the whole vehicle system including the engine which will caused the vehicle to be at full stop. This is the worst condition that can happened to an ambulance.
which can lead to fatality of patient on-board. In some cases, the overcurrent event will lead to slow-burning in the compartment engine, which will spread to the whole vehicle if being left unchecked.

![Figure 1: Ambulance caught on fire due to electrical problem](image)

### 3. System Design

Figure 2 shows the current sensing circuit used to monitor the current consumption in each power output channel in realtime. An ACS758 Hall-Effect current sensor is used to measure the current where it is proportionally converted into 0-5 analogue output corresponding to 0 – 50 A load current. The analogue output is received by a high-speed microcontroller for current analysis. The current value is compared to allowed threshold current value where any value above this threshold will force microcontroller to cut off power source to that channel by powering down the Optocoupler which lead to powering down MOSFET transistor ZXMN6A07F followed by demagnetization of Relay. Optocoupler is being used to prevent high-noise signal generated by high-current channel from interrupting low current microcontroller signal.

![Figure 2: Current sensing mechanism](image)
Figure 3 shows the PCB layout of a Power Management Board, capable of handling up to 15 power output channel. The first 2 relays are able to traverse up to 40A each that normally used to power up a 1000W DC-AC Inverter which used to supply power to a standard 240VAC powered medical equipment. The rest 13 relays are able to traverse up to 30A each. To prevent the low current and sensitive microcontroller from easily get damaged, the signal controller side is separated from high current side as shown in picture. To minimize the usage of microcontroller pin, an MCP3221 ADC is used where current reading from 8 channel can be simultaneously transmitted via only 2 wire using I2C protocol.

Apart from current reading, the system is also employing RGB LED on each channel to indicate availability (Blue), turned-on (Green) and overcurrent (Red) to easily identify each channel status. The total of 45 statuses are triggered by a MCP23018 I/O expander, which also use I2C protocol to reduce number of wire needed. The system also able to receive special trigger such as door switches and manual switch panel trigger. To enhance the connectivity to other system, 3 units of RS-232 serial communication interface are employed which can be use for interconnection to IOT hub, driver switch panel and cabin switch panel.

4. Implementation

Figure 4. System deployment and test on actual ambulance.
The system have been successfully installed on an actual ambulance by replacing conventional power management board. To emulate the input switch, a computer is connected to the system using RS-232 interface where a simplified software is being used to interact with the system.

\[\text{Figure 5. Current consumption monitoring result}\]

The monitoring software is shown in Figure 5 where all current consumption for each channel is been monitored in real-time. In the result shown above, the total current consumption for the vehicle is 128 A, which is nearly reach the maximum value of 130A. To avoid damage to the vehicle AC-DC alternator, the system automatically take preventive action by disabling relay 9 and 10, which corresponding to Lightbar output. In the system priority management, Lightbar is one of the non-critical component while Medical output is the most critical component. In the conventional system, this feature is not available therefore incur high risk to alternator damage.

5. Conclusion

The ambulance smart power management system presented in this study has proven to provide much benefit to the healthcare sector by potentially reducing risk of damage due to electrical current overload. Several upgraded version has been planned including interconnection with GSM/Long Range Wireless communication and adding monitoring capability of vehicle chassis status such as engine condition, fuel level, odometer etc.

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