CENTER FOR INFRASTRUCTURE ENGINEERING STUDIES

High Voltage Disconnect Systems

by

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16. Abstract

The recent establishment of the National University Transportation Center at MST under the "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users," expands the research and education activities to include alternative transportation fuels and other issues that are at the forefront of society and the national agenda. MST in partnership with MTI will establish a rural hydrogen transportation test bed for developing, demonstrating, evaluating, and promoting hydrogen-based technologies in a real-world environment. The State of Missouri is ideally suited to develop and demonstrate the proper operation of hydrogen highways in a rural setting, which represents over 25 percent of the nation's transportation needs and which is not well-represented in the current major national projects. A holistic approach will be taken to address not just the technology but also public perception, permitting, safety standards, and education and training. A key partner already engaged is the NASFM, who regards this project as an "excellent candidate for the model approach to introducing hydrogen to communities." The tasks identified in five areas, viz., Infrastructure Development and Deployment, High-Pressure Composite Cylinders, Inspection and Monitoring, Statistically Validated Codes and Standards, and Safety, constitute a comprehensive research, development and demonstration program to address some of the challenges described in the U.S. Department of Transportation Hydrogen Roadmap 2005.

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High Voltage Disconnect Systems

Scope

Project Area 4: Statistically Validated Codes and Standards

Current components and subsystems of the larger transportation infrastructure operate with a high degree of reliability. As we move forward with integrating new technologies, there is a need to ensure that the technologies are maintained or improved from this current benchmark. However, conducting experiments with a similar degree of exposure is not practical. Therefore, proper experiments and modeling need to be done to prove, with equivalent confidence, that the performance-based and prescriptive consensus codes and standards will maintain this level of safety.

Four critical components in the hydrogen transportation infrastructure - P/TRDs, fueling nozzles, **high voltage disconnect (HVD) systems**, and stationary fuel cells - have been identified for testing as a part of this study. "Design of Experiments" principles will be used in developing experiments to be conducted in simulation and the laboratory to test the functionality of these components and sufficiency of the existing codes and standards. The following are key questions that will be addressed:

- Are the prescriptive tests adequate to reveal deficiencies?
- What modifications, if any, need to be made to the safety codes and standards?

Project Aim: The reliability of a high voltage disconnect system, for hydrogen fuel stations, will be estimated using probabilistic risk assessment, which involves constructing a fault tree for the system and calculating the probability of the end event from the failure probabilities of the basic components. For those components where failure data is missing, experiments will be conducted to determine the failure rate. Where possible, the expected overall failure rate will be compared to actual failure data.

Deliverables: Results will be obtained in this project area to feed back to relevant safety codes and standards of components studied and to create a description of a scenario involving stationary fuel cells for adoption by HELP.

Project Schedule:

Step 1: To look at the existing codes and standards for such systems.
Step 2: Reviewing various practically applicable disconnect systems.

Overview

The project was scheduled in two parts. Firstly, an attempt has been done to review the existing codes and standards. In Section 1.1, they are presented in the hierarchical order as different sets of rules which fall under the categories- regulations, codes and standards. In section 1.2, the different components and subsystems along with the regulating authorities which set the standards for those particular systems were presented.

The various codes and standards that are mandatory, in implementing the high voltage disconnect systems for fuel cell powered vehicle applications, are described in section 1.3. Also, a briefing of the contents of those codes and standards were provided. The requirements which are to be followed essentially for these applications are discussed in section 1.4.

The second part of the project deals with reviewing practical systems for such applications. Three potential candidates are discussed in section 2.1. One is the contact relay and the other two are the current limiting fuses and the inertia switch respectively. All the three components with specifications were presented. Finally, conclusions are drawn and the future work is discussed.

Step 1: Existing Codes and Standards for HVD Systems

1.1 Rules Hierarchy [1]

Following are the various regulations, codes and standards along with the authorities which administer them.

Regulations
–Federal (CFR), state, and local

Codes
–Developed by model code bodies–e.g., NFPA, ICC
–Adopted by governmental bodies and enforced by authorities having jurisdiction (AHJs)–e.g., fire marshals, building inspectors, etc.

Regulations and codes usually apply to the use and placement of products/equipment

Standards
–Developed by standards developing organizations (SDOs)–e.g., UL, SAE, CSA
–Usually pertain to products/equipment

<u>1.2 Vehicle Systems and Refueling Facilities Regulations</u> [1]

The divisions in vehicle systems and fueling facilities along with the regulating authorities for various components and sub systems can be described as follows:

<u>STATIONARY FUEL CELLS:</u>
Controlling Authority: OSHA, State, Local Government Zoning,
Building Permits

Standards Development:
Hydrogen ICEs: CSA, ULH2
Fueled Turbines: CSA, UL, ASME, API
H2-O2 Steam Generators: CSA, ASME, UL, NFPA
Performance Test Procedures: ASME, CSA, NHA-GTI

<u>VEHICLES:</u>
Controlling Authority: NHTSA (Crashworthiness),
EPA (Emissions)
Standards Development:
General FC Vehicle Safety: SAE
Fuel Cell Vehicle Systems: SAE
Fuel Delivery Systems: SAE
Containers: SAE, CSA
Reformers: SAE
Emissions: SAE
Recycling SAE
Service/Repair: SAE

<u>FUEL DELIVERY, STORAGE:</u>
Controlling Authority: RSPA (Over-road Transport, Pipeline Safety)

Standards Development:
Composite Containers: ASME, CSA, CGA, NFPA
Pipelines: ASME, API, CGA, AGA
Equipment: ASME, API, CGA, AGA
Fuel Transfer: NFPA, API

<u>FUELING, SERVICE:</u>
Controlling Authority: State, Local Govt.Zoning, Building Permits

Standards Development:
Storage Tanks: ASME, CSA, CGA, NFPA, API
Piping: ASME, CSA, CGA, NFPA
Dispensers: CSA, UL, NFPA,
On-site H2 Production: CSA, UL, CGA, API

Codes for the Environment: ICC, NFPA

INTERFACE:
Fuel Specs: SAEASTM, API
Wts/Measures: NIST, API, ASME
Fueling: SAE, CSA
Sensors/Detectors: UL, NFPA, SAE, CSA
Connectors: SAE, CSA
Communications: SAEUL, CSA, API, IEEE
Installation Piping: ASME, CSA, CGA, NFPA, ICC
Storage: ASME, CGA, CSA, API, NFPA
Compressors Safety Certification: CSA, UL
Compressor Design, Performance & Safety: API
Sensors/Detectors: UL, CSA, NFPA
Fuel specifications: CGA, SAE, API, ASTM
Weights/Measures: NIST, API, ASME, NCWM
Dispensers: CSA, UL, NFPA, SAE, API
Non-vehicle Dispensing: CGA
Codes for the Built Environment: ASHRAE, ICC, NFPA, CGA
Interconnection: IEEE, UL, NFPA

1.3 Codes and standards [1-3]

The important codes and standards for this system for any of the two applications are studied and are grouped here. Following are a few established codes and standards and a few rules and requirements to be followed in designing or implementing the high voltage disconnects incase of the hydrogen fueling systems.

NFPA 52: Vehicular Fuel Systems Code

NFPA 110: Emergency and Standby Power Systems

ICC IFC Section 2209: Hydrogen Motor-Vehicle Fuel Dispensing and Generation Stations

UL 1741: Standard for Inverters, Converters, and Controllers for Use in Independent Power Systems

–Scope includes both grid connected and grid independent systems, being modified to include fuel cell systems

IEEE P1547: Standard for Interconnecting Distributed Resources with Electric Power Systems

–Series of subdocuments for conformance testing, monitoring and control, application guide, island systems, etc.

SAE J 1742: Connections for High Voltage On-Board Road Vehicle Electrical Wiring Harnesses Test Methods and General Performance Requirements

–This SAE Recommended Practice defines recommended test methods and general performance requirements of single-pole and multi-pole connectors for on-board electrical wiring harnesses of electric or hybrid powered road vehicles operating at voltages between 50 and 600 V AC or DC rms and those circuits using copper wire only. These requirements are not intended for connections internal to electrical/electronic modules or complete subassemblies. This document applies to connectors designed to be disconnected in the case of repair and/or maintenance after mounting in the vehicle. This document excludes one-part connections, i.e., where one part of the connection has direct contact to the pattern of the circuit board. Duty cycles are considered to be application specific and are not specified in this document; however, these effects must be considered during design. The recommended practice for high voltage wiring assembly is contained in SAE J1673. The Recommended Practice for low voltage connector performance is contained in SAE J2223 (Parts 1, 2, 3, and 4).

SAE J 2574: Fuel Cell Vehicle Technology

- This SAE Information Report contains definitions for hydrogen fuel cell powered vehicle terminology. It is intended that this document be a resource for those writing other hydrogen fuel cell vehicle documents, specifically, Standards or Recommended Practices.

SAE J 2578: Recommended Practice for General Fuel Cell Vehicle Safety

- This SAE Recommended Practice identifies and defines the preferred technical guidelines relating to the safe integration of fuel cell system, fuel storage, and electrical systems into the overall Fuel Cell Vehicle. The purpose of this document is to provide introductory mechanical and electrical system safety guidelines that should be considered when designing fuel cell vehicles for use on public roads. This document covers fuel cell vehicles designed for use on public roads.

SAE J 1766: Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing

- Electric and Hybrid Electric Vehicles contain many types of battery systems. Adequate barriers between occupants and battery systems are necessary to provide protection from potentially harmful factors and materials within the battery system that can cause injury to occupants of the vehicle during a crash. This SAE Recommended Practice is applicable to all Electric Vehicle and Hybrid Electric Vehicle battery designs, including those described in SAE J1797. The potentially harmful factors and materials addressed by this document include electrical isolation integrity, electrolyte spillage, and retention of the battery system. The purpose of this document is to define test methods and performance criteria which evaluate battery system spillage, battery retention, and electrical system isolation in Electric and Hybrid Electric Vehicles during specified crash tests.

SAE J 1625: Heavy-Duty Circuit Breakers

- This SAE Recommended Practice defines the test conditions, procedures, and performance requirements for circuit breakers in ratings from 50 to 200 A. The document covers externally mounted automatic reset and manually reset types of circuit breakers for low voltage DC operation (typically 50 V or less).

SAE J 553: Circuit Breakers

- This SAE Standard defines the test conditions, procedures and performance requirements for circuit breakers in ratings up to and including 50A. The document includes externally or internally mounted automatic reset, modified reset, and manually reset types of circuit breakers for 12V and 24V DC operation. Some circuit breakers may have dual voltage ratings (AC and DC), however, this document evaluates DC performance only.

SAE J 2697: DC to AC Inverters for On-Highway Trucks

- This SAE RP is intended to describe the application of single-phase dc to ac inverters, and bidirectional inverter/battery chargers, to supply power to ac loads in heavy duty on-highway trucks. The document identifies appropriate operating performance requirements.

SAE J 1715: Electric Vehicle Terminology

- This SAE Information Report contains definitions for electric vehicle terminology. It is intended that this document be a resource for those writing other electric vehicle documents, specifications, standards, or recommended practices. Hybrid electric vehicle terminology will be covered in future revisions of this document or as a separate document.

SAE AS 7413: Coupling Assemblies, Quick Disconnect, Automatic Shutoff

This specification establishes requirements for automatic shutoff, quick-disconnect coupling assemblies for fuel and oil lines.

SAE J 1811: Power Cable Terminals

This SAE Standard is intended for light and heavy-duty on-highway trucks and their trailers; and off-road machinery applications as described in SAE J1116. The terminals described in this document are primarily used to connect batteries, cranking motors, solenoids, magnetic switches, and master disconnect switches and power cable assemblies.

SAE J 2232: Vehicle System Voltage Initial Recommendations

This SAE Information Report is a summary of the initial recommendations of the SAE committee on Dual/Higher Voltage Vehicle Electrical Systems regarding the application of higher voltages in vehicle systems. This document does not attempt to address the technical merits of specific voltages or electrical system architectures.

1.4 Requirements [4]

Control Devices, Switches, and Cords**:** Control switches for all electrically operated machinery shall be clearly marked to indicate the switch positions that correspond to the electrical circuits being controlled.

Master Cut-off**:** All hydrogen vehicles must incorporate a master electrical disconnect switch that must disable all electrical functions. Switch must disconnect traction motor battery pack section of circuit, and if switch is push-pull design, push must be 'off' function."

This sounds like there are a lot of high-current disconnect switches involved, but there need not be. Often, there is one main 'safety' contactor in the battery pack circuit that is operated from more than one location. Conversely, you may opt for several separate large-current disconnects to fulfill the requirements.

Opening any vehicle front door with the key "switch" in the "on" position should activate an audible alarm. This indicates a potentially "live" power system. A contactor is recommended as an electrical disconnect when the power system is turned "on" through a key "switch".

Step 2: Reviewing various practically applicable disconnect systems

There are two possibilities to implement high voltage disconnects for vehicular applications i.e. hydrogen fueling stations for the mass transit buses. One possible way is to implement the high voltage disconnect at the fuel pump of the fueling station and the other way is to install it in the vehicle.

On installing the high voltage disconnect at the fuel pump of the fueling station, it can be operated manually, before fueling a vehicle, by the operator of the fuel pump or can be operated automatically by placing a position sensor at the pump such that it activates the disconnect whenever a vehicles arrives in the fueling dock of the fuel station.

Otherwise by installing it on board of the hydrogen vehicle, it can be operated manually, before fueling the vehicle, by the driver or can be operated automatically by placing a sensor at the fueling inlet of the vehicle which activates the disconnect.

For any of these applications, an automated switch disconnect system is found to be the practical and feasible solution. Such a system in combination with an over current fuse on board in the vehicle is found to be a very popular choice for this case.

2.1 Applicable Disconnect Systems

CONTACT RELAYS: [5]

Due to their high power handling capability, high voltage relays, and contactors are used in a wide variety of applications. These include:

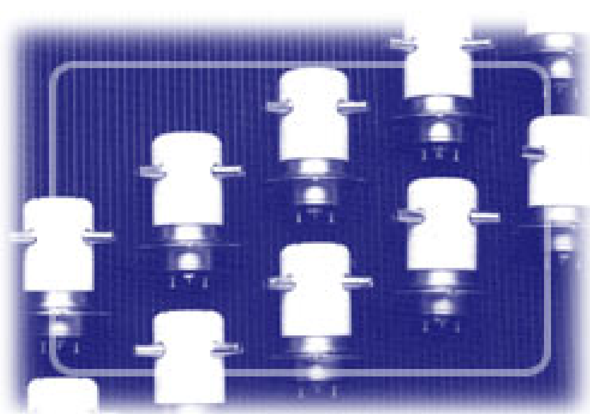
- Electric Vehicles and Rapid Transit
- Undersea Cable Branching Systems

- Silicon Wafer Processing Equipment

Contact relays can be optically isolated, transformer isolated, non-isolated, or aerospace / MIL-Spec. A photo-optically isolated solid-state relay is a contact relay in which there is no direct electrical connection between the input and the output relay. A transformer isolated solid-state relay such as a pulse transformer is used to trigger a triac. A non-isolated relay is not isolated from the electrical connection, it has two or more electrical circuits sharing a common ground. An aerospace or MIL-Spec relay meets appropriate military specifications or is intended for aerospace applications. Applications for relays include general applications, automotive, flasher, and latching. General application solid state relays can be used in any industrial situation where a relay is required. Automotive relays are specifically for use in automobiles. A flasher relay activates indicator lights. A latching relay has the ability to keep the contact status in place even if power is removed from the equipment.

They can handle high inrush current and continuous connection and disconnection of current. Mounting choices for solid state relays include PC board, socket or plug-in style, bracket or flange mount. Important electrical specifications to consider when searching for solid state relays include AC input, DC input, AC output, DC output, input (pick-up) voltage range, input (control signal) current range, maximum switching current, and maximum switching voltage.

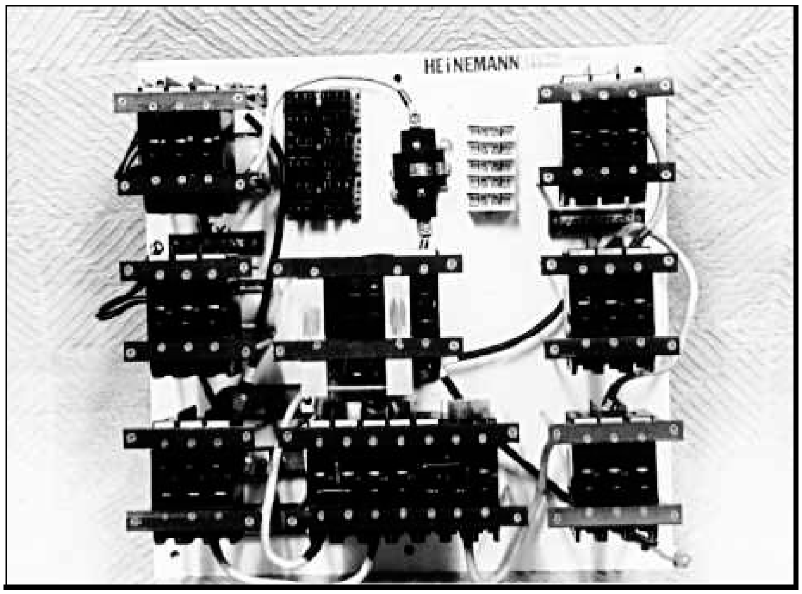
Advanced search parameters to consider when looking for solid state relays include output devices, switch configuration and features. Output device choices include MOSFET, bipolar transistor (BJT), SCR, and Triac. Choices for switch configurations include Form A, Form B, Form C, Form D, Form E, Form K, Form X, Form Y, and Form Z. Common features for solid state relays include built-in heat sink, internal snubber, TTL compatible, visual indicators, reversing, zero switching, instant ON, peak switching, and analog switching. An important environmental parameter to consider is the operating temperature.



Courtesy:relays.tycoelectronics.com/kilovac/hvintro

CURRENT-LIMITING FUSES—STAND-ALONE SYSTEMS: [6]

A current-limiting fuse can be used in each ungrounded conductor from battery to limit the current that a battery bank can supply to short-circuit and to reduce the short-circuit currents to levels that are within the capabilities of downstream equipment.



Courtesy: http://www.re.sandia.gov/en/ti/tu/Copy%20of%20NEC2000.pdf

Electrical fuses shall be of the correct ampere rating and fault capacity rating for the circuit in which they are installed. These fuses are available with UL ratings of 125, 300, and 600 volts dc, currents of 0.1 to 600 amps, and a dc AIR of 20,000amps. They are classified as RK5 or RK1 current-limiting fuses and should be mounted in Class-R rejecting fuse holders or dc-rated, fused disconnects. Class J or T fuses with dc ratings might also be used. For reasons mentioned previously, time-delay fuses should be specified, although some designers are getting good results with Class T fast-acting fuses. One of these fuses and the associated disconnect switch should be used in each bank of batteries with a paralleled amp-hour capacity up to 1,000 amp-hours. Batteries with single cell amp-hour capacities higher than 1,000 amp-hours will require special design considerations, because these batteries may be able to generate short-circuit currents in excess of the 20,000 AIR rating of the current-limiting fuses. When calculating short-circuits currents, the resistances of all connections, terminals, wire, fuse holders, circuit breakers, and switches must be considered. These resistances serve to reduce the magnitude of the available short-circuit currents at any particular point.

Fuse Description	Size	Manufacturer
125-volt dc, RK5 Time delay, current-limiting	0.1-600 amp	Bussmann
125-volt dc, RK5 Time delay, current-limiting	0.1-600 amp	Littelfuse
300-volt dc, RK5 Time delay, current-limiting fuse	0.1-600-amp	Bussmann
300-volt dc, RK5 Time delay, current-limiting fuse	0.1-600 amp	Gould
300-volt dc, RK5 Time delay, current-limiting fuse	0.1-600 amp	Littelfuse
600-volt dc, RK5 Time delay, current-limiting fuse	0.1-600 amp,	Littelfuse
600-volt dc, RK5 Time delay, current-limiting fuse	70-600 amp	Gould

Courtesy: filnor.com/html/products/dbhigh

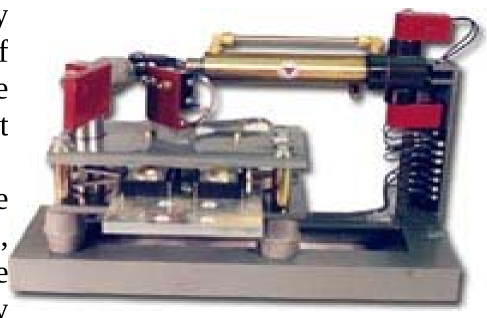
INERTIA SWITCHES: [7]

Inertia switches are designed to disconnect high voltage and fuel in the event of an accident. There are two inertia switches - both front and rear. If either switch opens, it disconnects the high voltage and electrical circuit to the fuel pump.

The power system should be automatically disconnected in the event of a crash; this can be accomplished by connecting an inertia switch to the contactor(s) control circuit. In a vehicle with flooded lead acid batteries, contactors and other components that can create an arc should not be located above or near batteries where they might cause a hydrogen gas explosion.

Courtesy: filnor.com/html/products/dbhigh

The high voltage system is disconnected any time the vehicle ignition key is turned to the off position. The high voltage battery contains a fuse that will open in the event of a high current short circuit.



If the vehicle ignition key is left on, and the high voltage battery temperature exceeds 140 F, thermal sensors will disconnect the high voltage battery. If the key is off, the high voltage is already disconnected. There is an interlock circuit on all high voltage connectors that disables the high voltage anytime they are disconnected.

Conclusion

The various codes and standards for the components and sub systems of a high voltage disconnect system for hydrogen fuel stations were studied. An abstract of the contents of those codes and standards along with the regulating authorities governing them were provided. An attempt has been made to look into the components to implement the disconnect systems. Three practically applicable high voltage disconnects were discussed. Future steps involve the assessment of these components to the applicable codes and standards. Also, the reliability and limitations of these systems will be studied.

References

[1] www.gastechnology.org/hydrogen/mark

[2] www.ul.org

[3] www.sae.org

[4] http://www.sspa.se

[5]http://relays.globalspec.com/LearnMore/Electrical_Electronic_Components/Relays_Timers/Solid_State_Relays

[6] http://www.re.sandia.gov/en/ti/tu/Copy%20of%20NEC2000.pdf

[7] http://www.filnor.com/html/products/dbhigh.html