"SAFETY FIRST"

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INTRODUCTION

Although Electric Vehicles (EVs) have been in existence for more than 100 years, their recent interest and development has occurred faster than the ability to establish industry standards. The purpose of this technical paper is to present the authors' experience in building an EV that can be safely operated and maintained as well as being crashworthy. The authors have extensive experience in building EVs and automotive testing.

A good design results only from careful consideration of the specific EV being built. Each component and each modification to an existing vehicle must be considered relative to its impact on the conversion design and the safety of the overall vehicle. Therefore, any EV project should make use of a qualified engineer for critical decisions.

The specific recommendations are intended to represent a conservative design for the protection of the driver, vehicle occupants, and the general public. There is no intention to supersede or negate any existing codes, standards, or governmental regulations.

CRITERIA

It is important to first identify the criteria for a safe design, these are:

*- The assumption of a "**Single Failure**" There should be no single component that is critical to safe operation. One must assume that any single component may fail and ensure that safety is maintained, even in the event of a crash or rollover. For example, if a circuit is protected by a fuse, consider what would happen in an overcurrent situation, if the fuse failed to "blow". Safety must still be maintained, perhaps by the inclusion of an additional fuse.*

*-The assumption of a single failure leads naturally to "**redundancy**" of safety components. A second fuse should ensure that at least one fuse blows. Redundant contactors, activated by separate power sources, should also be considered to ensure that high voltage power sources can be interrupted, if necessary.*

*-"**Separation**" between high voltage components is also critical for a safe design. Batteries, contactors, or other components that have a significant voltage difference should not be located near each other. For example, in a 120 volt power system, the first and last battery should not be located beside each other. Similarly, the negative side contactor should not be located adjacent to the positive side contactor, if used.*

CONSTRUCTION
It is essential that an EV operate safely to protect the drivers, passengers, and pedestrians. The following design practices are recommended:

<u>Electrical System Recommendations</u>

All control and power circuits should be fused. The fuse should be located near the source of power.

As a minimum, the power system should be protected by at least one fast-acting fuse; however, two fuses should be considered based on the "single failure" criteria.

The wire size should be adequate for the intended load. In addition, the wire should be automotive wire. Wire designated as "THHN" or "TEW" or is marked "oil and gas resistant" is not automotive wire. This wire should not be used because its insulation will crack and contribute to ground faults.

Wiring should be protected against mechanical damage. Wires penetrating metal surfaces, such as the firewall, should use grommets or other protective barriers to protect against chafing of the wire. Other wires in proximity to metal edges or other objects which cause fraying should also be protected.

The power system should not be grounded through the vehicle frame. Although this is acceptable on the 12 volt system, it is unacceptable and unsafe for voltages greater than 24 volts.

Upon actuation by the key "switch", a voltmeter or indicator light should indicate that the power system is connected. Putting the key "switch" in the "off" or "stop" position should disable the power system.

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". Circuit breakers are not designed or recommended for this service.

Flexible wire is recommended in place of solid buss bars for the battery interconnects. Flexible wire doesn't transmit vibration between batteries and provides greater protection from short circuit.

All EVs require an auxiliary battery (12V), even if a DC-DC converter is in use. This ensures operation of the warning flashers, brake lights, headlights, etc. if the DC-DC converter fails.

If the regenerative braking system is actuated on throttle release, the brake lights on the vehicle should be lit.

The wiring system in the vehicle should be protected from the effects of high humidity, salt and water spray.

The accelerator potbox should not be placed in a crush zone of the vehicle. This is to prevent the possibility of causing full power to the motor if the potbox lever is pushed to wide open position.

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.

The controller, motor, and other large components should be located such that they do not penetrate or significantly damage the passenger compartment in the event of a crash or rollover.

<u>Battery System Considerations</u>

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.

In a vehicle with flooded lead acid batteries, the battery box should be vented to ensure that the buildup of hydrogen gas is prevented.

A warning signal should alarm or a fuel gauge should indicate when the battery is at minimum state of charge.

The batteries should be located in enclosed compartments designed to prevent any electrolyte leakage into the passenger compartment during a crash or rollover.

The battery compartment should prevent the batteries from exiting the vehicle or entering the passenger compartment in the event of a crash or rollover event. Welding a restraint system is preferred if the vehicle has a frame. For a unit body vehicle, the requirements are more complex and may involve a combination of welding and bolting to carefully selected attachment points.

The batteries should be restrained inside the battery compartment sufficiently to prevent their leaving the compartment during a crash or rollover event.

Vehicle Handling Recommendations

The vehicle center of gravity should be kept low. Locating the batteries high will adversely affect vehicle handling.

There is considerable flex in a vehicle frame or unit body, so it is essential to allow for differential movement between components.

The Gross Vehicle Weight Rating (GVWR) as identified on the door jam placard should not be exceeded. If this rating is exceeded, one should evaluate the impact on the vehicle including brakes, wheel bearings, axle strength, and fatigue of the unit body. Decreasing the vehicle payload capacity (e.g., passenger, cargo, etc.) will be required in most EV conversions.

The weight distribution of the EV should be considered and remain within the limits set by the manufacturer to ensure proper vehicle handling.

MAINTENANCE

The EV will require periodic maintenance. Therefore, the design should accommodate ease of maintenance as well as safety from electric shock. The following practices are recommended:

It should be possible to disconnect mechanically both electric poles of thebattery pack from the motor and controller. These maintenance disconnects are in addition to the electrical disconnects used for operation. The installation of maintenance disconnects provides positive separation of battery voltage from the motor and controller.

Components should be arranged to allow accessibility for testing and removal.

Segregating the batteries into three or four battery boxes will minimize exposure to high voltages when maintenance is performed on the batteries.

The distance between first and last battery, contactors, etc. should be maximized in order to prevent an accidental short circuit. Dielectric barriers can be used to assist in this separation.

Protective barriers over batteries or protective covers over the battery terminals should be used to protect personnel and reduce the possibility of a short circuit condition.

The battery box should be labeled to alert users of the potential dangers. In addition, if the EV is designed for a specific type of battery, this should be identified.

The direct contact with live parts of an electrical circuit whose voltage is greater than 50 VDC or 30 VAC should be prevented by housings, covers, or other types of protection.

Harnesses carrying cables with voltages greater than 50 VDC or 30 VAC should be easily identifiable by color or a "warning" designation. Individual cables routed separately should also be easily identifiable as power cables.

CONCLUSION

Safety is essential in any vehicle. We accept the explosive risk associated with gasoline vehicles because manufacturers have designed the vehicle to minimize the risk and everyone is aware of the risk. Similarly, everyone should be aware of the risk of electrical shock in an EV.

If you have questions, comments, or have experienced EV safety problems, please contact:

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