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HIGH VOLTAGE vs. LOW VOLTAGE: POTENTIAL IN MILITARY SYSTEMS

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ABSTRACT

Power and energy demands on military vehicles and other large systems have been increasing significantly and modifications to these power systems are being explored on several programs. A key decision in a new power system is determining whether to use "high voltage" or "low voltage" for distribution throughout the vehicle. This decision has far reaching consequences throughout the vehicle and needs to be made after careful consideration. This paper addresses key trade-off criteria for consideration when comparing high voltage and low voltage vehicle architectures and then addresses a few other considerations for this type of decision.

INTRODUCTION

Military power systems have changed significantly over the years. The power and energy demand on vehicles and large systems has increased significantly, and modifications to these power systems are being explored on many platforms.

Previously, batteries were included on vehicles almost exclusively for Starting, Lighting and Ignition (SLI) loads. As vehicles started to include high power radios and other types of high power equipment the vehicle loads increased significantly. With the use of vehicles for silent watch the need for on-board energy storage and advanced generation systems is more critical than ever so that these systems can be powered and used effectively.

One of the key decisions when incorporating energy storage and generation systems on a vehicle is to design it for "high voltage" or "low voltage". These terms can become very tricky as a number of different entities define them differently. For example, IEEE standard 141-1993 (table 3-3) defines low voltage as 120Volts to 600 Volts. IEC 61140 defines extra low voltage as <50Vrms or <120 Volts DC. Other safety standards cite 60V as the dividing line between high voltage and low voltage

Most military vehicles support a 28VDC power bus, but higher voltages such as 300-400VDC and even up to 600VDC are becoming common. For purposes of this paper we will consider augmentations to existing 28VDC power systems to be low voltage solutions and changing a power bus over to operate at voltages above 100VDC to be high voltage.

Because the power system voltage affects everything that is included on the vehicle, the common first step to power system design is the voltage level. In cases of retro-fit of an existing vehicle, moving to a higher voltage may present a different set of challenges than when designing a completely new system.

There is a reason why Low Voltage (28VDC) systems have been prevalent in Military vehicles for a long time. As more complicated "power hungry" systems are incorporated in these systems, however, moving towards high voltage makes sense in some applications. There are pros and cons of each, which will be discussed in this paper.

28VDC systems are common to almost every military vehicle in the fleet. They are typically classified as "low risk" for shock and generally safe for handling and storage (even in extreme conditions such as increased temperature). As more "power hungry" systems become commonplace on military vehicles, the cabling size (diameter and weight) increases significantly (due to the higher current), which not only creates higher losses, but also creates integration problems such as integrating large connectors and dealing with the large bending radii as the cabling is routed through the vehicle.

By increasing the voltage of these large power systems, the end result is smaller cabling, less losses and (for batteries specifically), lower discharge rates for individual cells. This is a tradeoff for higher risk of electric shock, especially during "fault" or non-standard operating conditions. High Voltage corona and need for DC/DC converters (for legacy vehicle retrofits) presents itself in these higher voltage systems that often include integrated starter generators and on-board vehicle power.

This paper will discuss the challenges and options when dealing with the decision to integrate a high voltage vs. low voltage system in a large military application. It will discuss the impacts of each and common mitigation strategies to ensure the total system is successful.

KEY CRITERIA

Deciding on a high voltage or low voltage power architecture should be addressed similarly to any other design consideration with some form of trade study. As the exact needs, weighting and considerations will vary for each vehicle platform, this paper will address key criteria that need to be considered in this type of trade study and considerations for each of these criteria. This paper will not address the relative weight to be given to each criteria or the mechanics of how the trade study is conducted as these will vary widely for different platforms.

Each of these criteria is complicated on its own and even more complicated when repercussions across an entire vehicle are considered. This paper should be considered a starting point for this type of comparison, but a study that takes the whole vehicle into account and addresses the specific concerns of that vehicle should be used for optimizing design decisions.

Criteria discussed in this paper will include: impact to other vehicle systems, cable size and integration, power conversion, commonality, flexibility for future improvements, safety, energy storage, cost and capability.

Impact to other vehicle systems

This criteria is highly dependent upon the specific vehicle under consideration, but it always needs to be remembered that changing a subsystem is going to have trickle down effects throughout the vehicle. As the size, shape, weight and location of the power system changes this will require changes to systems that need to be displaced or repackaged. The important message here is to not look at the electrical power subsystem in isolation.

Cable size and integration

When evaluating integration burden of high and low voltage systems the required cable size will be a large contributor to integration burden. As current requirements in the vehicle increase, the cable required to carry those currents increases as well. Undersized cables will result in additional heat in the vehicle, inefficiency and perhaps a safety concern if the cable size is not rated for a large current than the related fuses.

Since power is proportional to both current and voltage, any increase in voltage results in a decrease in current required for the same power. As the vehicle electrical subsystem voltage is increased the burden of routing cables is decreased.

The volume and weight of the cable is only one part of the concern. When trying to route larger diameter cables the cable bend radius will limit the packaging possibilities. On the cost side the cable cost itself is one concern, but the cost of the related terminals or lugs for the cable is also important.

When evaluating the importance of cable size it is also important to consider the location of the powered devices. If power can be used very close to where it is generated or stored and wire lengths are short then it may be possible to use larger cable without paying a large integration penalty. As the system gets dispersed throughout the vehicle the cable size becomes increasingly important.

As another complicating factor to this criteria, the cable size throughout the vehicle can vary, so cable diameter required can be different for different electrical loads on the vehicle. This may allow for a low voltage system where the large loads are close together and longer cables are going to lower power devices.

In summary, the more power that needs to be distributed throughout the vehicle, the more important cable size is and the more this criterion will favor a high voltage architecture.

Power Conversion

As most current vehicles operate on 28VDC power, most electrical loads on a vehicle also operate at this power. If the electrical subsystem is changed to a high voltage architecture it is likely that one or more DC/DC converters will be required to power legacy electrical loads operating at 28VDC. This extra conversion will result in some loss of electrical efficiency and require additional hardware.

A vehicle using a large number of low voltage loads may make the power conversion needs a hurdle to integration of a high voltage electrical subsystem. One potential response to this would be to include both high and low voltage power distribution on the vehicle. This is addressed later in this paper under the Other Considerations heading.

Commonality

Commonality is a key reason to choose a vehicle voltage at the beginning of a design effort so that electrical loads can be designed for this vehicle voltage. This will reduce the need for power conversion on the vehicle.

Commonality is an important consideration across families of vehicles as well. If vehicles are changed to high voltage electrical power subsystems the selected voltage should be matched to other similar vehicles to maximize commonality between vehicles.

When comparing to legacy systems commonality certainly favors low voltage systems which are already prevalent. As more systems are redesigned this is likely to be less clear.

Commonality should also be considered in regard to the possibility of utilizing dual use components. Dual use components that are rugged enough for military use but also utilized in the commercial market allow for greater economies of scale and can reduce component costs. One example of possible future dual use is the effort CALSTART is putting into integrating 6T form factor batteries (traditionally used for the military) onto commercial trucks.

Flexibility for future improvements

Predicting what vehicles will need in the future is never an easy task. There has been a clear trend in using more and more electrical power on combat vehicles though. As power requirements increase there are more advantages to using a higher vehicle voltage.

Assuming the trend of consuming more on vehicle electrical power continues, it seems likely that a high voltage vehicle architecture is better positioned for future vehicle upgrades.

Safety

A key reason that low voltage systems are used is the perceived safety advantage offered by operating at a lower voltage.

There is certainly a safety advantage to lower voltages, but this advantage decreases as power loads increase. With more power being distributed (and likely stored) on the vehicle the high amperages required by a low voltage system also create a safety concern that needs to be addressed.

High voltage systems can implement several safety features to make them relatively safe on a vehicle and reduce the safety difference between high and low voltage architectures.

Safety features for high voltage systems can include high voltage interlocks that prevent operation of the system when all high voltage connections are not properly connected. This prevents a disconnected connector from being live and presenting a safety risk.

Another key safety feature is isolation detection. A high voltage power subsystem is made substantially safer by being electrically isolated from vehicle ground. This isolation makes the primary safety risk touching both a positive and negative cable rather than just one cable. High voltage systems can implement isolation detection that make sure this condition is maintained and can shut down power distribution when a fault is detected.

Both high and low voltage systems are more likely to include battery management and advanced chemistries as the amount of stored energy is increased. Battery management may include additional safety features such as some level of state of health monitoring to warn of a battery that is losing capacity, monitoring of individual battery cells and monitoring of temperatures within the battery. All of these features increase system safety whether high or low voltage. Similarly advanced batteries may include contactors or similar devices that allow the stored energy to be isolated from the vehicle when the vehicle is not in operation. The removes the hazard of large amounts of electrical power being available throughout the vehicle when not needed.

While safety inherently favors a lower voltage system, careful design can greatly mitigate the safety concerns of high voltage and make this criterion much less important in a vehicle architecture decision. Also, as energy storage is increased the difference between high and low voltage becomes less discernible.

Energy Storage

A key component of the electrical power subsystem is energy storage. Energy storage allows for peak power above what can be generated at any specific instance, it allows for power while the engine is off and it can provide efficiency by allowing for regenerative loads or for storing excess power so that a power generator can be run at a more efficient speed.

Low voltage energy storage can be a traditional lead acid battery if storage needs are low or a more advanced chemistry for higher energy storage needs. Additional energy storage allows for more engine off capability. This silent watch operation can improve vehicle efficiency, as the main engine is not on when only a smaller amount of power is needed.

As silent watch modes become more prevalent even low voltage systems are more likely to require a battery management system that monitors and reports on energy storage. This allows the warfighter to use as much energy from the battery as possible while maintaining confidence that the battery still has enough power to start the engine.

Also, as more energy is stored the weight of the battery becomes more important, again making a more advanced chemistry more likely for vehicles with more energy storage required.

High voltage energy storage is almost exclusively in advanced chemistries. Lead acid batteries have been put in series for voltages above 28VDC, but as the voltage increases the need for additional features typically requires a more actively managed battery.

For a vehicle that is considered a high voltage architecture it is very likely that energy storage will utilize an advanced chemistry and this criteria will have less importance as a deciding factor between high and low voltage.

That said, the importance of energy storage is increasingly important as the amount of stored energy increases regardless of vehicle voltage.

Cost

Certainly cost is an important criterion in any design decision. As with most of these criteria they need to be considered across the entire vehicle.

In general high voltage components are going to cost more than low voltage components and are more likely to require development effort.

Cost will typically favor a low voltage system, but the capability offered by low voltage systems may not allow for desired vehicle upgrades.

Capability

Capability is important when components aren't available at a required voltage. A high voltage vehicle architecture can utilize power conversion to reduce voltage and power low voltage loads if necessary (at an increased integration burden for the extra components), but a low voltage architecture will not typically support a component that has to be powered at a high voltage.

Capability is more of a pass or fail criteria than a sliding scale. The loads that must be powered on a vehicle have to be considered to make sure the power architecture can support those loads.

Related to capability, and discussed in the other considerations section, is when high voltage components may allow for the replacement of a hydraulic system or when a high voltage system is used to provide motive power.

OTHER CONSIDERATIONS

In addition to the criteria described here, each individual vehicle may have other considerations to be weighed unique to that vehicle. Key among these considerations are trade-offs with hydraulic systems, the option of including both high and low voltage power systems in the vehicle or using high voltage for motive power.

Hydraulic systems

Traditionally hydraulic systems have been used on ground vehicles when a large amount of power needs to be delivered to a subsystem. This could be a turret drive, cooling fan, compressor, etc. Power requirements for these systems make use of electrical power unwieldy when delivered at low voltage. Delivering high voltage power will reduce the amperage required and may allow for using electrical power for these types of loads.

At a vehicle level the opportunity to remove a hydraulic system has to be considered when determining vehicle architecture. Key questions are if the high voltage electrical system can provide the same performance through electric drive motors, what the integration trade-offs are in changing over these systems and what the maintenance impact is for changing these legacy systems.

In many respects the use of hydraulics or the use of high voltage electrical power may be interchangeable. At a vehicle level it will likely make sense to choose one of these power systems rather than both, allowing you to remove the equipment required for one of the systems. This could be the hydraulic reservoir, accumulator and pump or the electrical high voltage generator, battery and distribution system.

Including both high and low voltage power

As the number of loads on a vehicle increases more consideration should be given to including both a high voltage and low voltage power system. This will reduce power conversion needs and allows for separation of loads onto two separate distribution systems.

In this case when one electrical power subsystem fails there is still some retained capability from the other subsystem. Although each individual load will only operate at high or low voltage some loads will be operable. So if low voltage is lost it may not be possible to start the vehicle engine, but the turret drives and radios may still work allowing for reconnaissance and a call for backup. In the opposite case some vehicle subsystems may be down but the vehicle may still maintain engine starting capability.

As both high and low voltage systems offer their own advantages and the number of electrical loads on a vehicle continues to grow, it is increasingly likely that future vehicles will include both a traditional 28VDC bus for some loads while utilizing a high power bus for other loads.

Another case of including both high and low voltage power which is common on vehicle systems is to use a low voltage power source to power key controllers and battery management. This allows for a very small low voltage battery for these small loads, while allowing the high voltage system to be turned off and the high voltage energy storage to be disconnected when the vehicle is not in use. While technically this solution involves both high and low voltage systems on the vehicle, for the most part this can be considered a high voltage system, as that is what is used predominantly on the vehicle.

High voltage for motive power

A high voltage architecture may provide enough power delivery to support some level of mobility for vehicles equipped for electric drive. This could be a completely electrically powered vehicle, a hybrid vehicle or anywhere in between.

By providing a new capability high voltage electrical power can be very difficult to compare to low voltage solutions. This makes a full vehicle level trade study and decision process very important for choosing a vehicle voltage.

CONCLUSION

Electrical power is increasingly important on combat vehicles. As power systems are redesigned there are advantages to both high and low voltage systems and a large number of criteria for choosing between them. This makes this decision vitally important for the vehicle architecture.

A careful decision making process should be employed at the beginning of design or redesign efforts to make a carefully considered choice of vehicle voltage level. This decision making process will involve several criteria as outlined above. Many of these criteria impact other vehicle subsystems, making it important to consider the entire vehicle system in this decision making process.

The decision is further complicated by the possible opportunity to remove hydraulics from a vehicle, the chance to provide electric drive capability and the complexity of a real vehicle likely including a combination of both high and low voltage to some extent.