

The Road to Electrification for Specialty Vehicles

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Abstract:

The increasing need for electrical power on vehicles has been apparent for decades, for everything from creature comforts (powerful sound systems), electrification of engine accessories, and other electrical equipment (power tools, IT tools, or “hotel loads”).

For work trucks the need is to power electrical tools such as scene lights, cutting or drilling equipment, or more vocationally specific devices such as pipe welders or insulation testers. This is commonly provided by a generator at the 5-10kW level, or by an inverter at lower power levels. Both of the current solutions have drawbacks. There are auxiliary power systems available to add to the basic vehicle system, but these “add ons” become more and more difficult to implement as vehicles have become more integrated and more standard equipment to meet regulatory requirements has occupied the limited space available on the vehicle. The power demands are really limited because of the availability of electrical power, for example hydraulic systems could also be replaced by electrical power systems for silent operation in a residential environment, if sufficient electrical power were readily available.

Transit buses simply have a high auxiliary electrical power need already, however there is a desire to push available power to higher levels for vehicle electrification, making hybrid buses cleaner and more efficient.

Of course the class 8 over the road trucks have become homes for the drivers and we all know how much power we use in our homes, where can this be found economically and with the flexibility the transportation system needs, and without a high payload or cost penalty?

Last time around the move to 42VDC died because the value just did not justify the development work and production cost, but with gas at \$4 per gallon we have a new impetus for change. The electrical hybrid is eliminating some of the limitations existing in contemporary vehicles and opening new doors for applications of technology in our daily lives through the accessibility of a flexible power management system. This technology will open opportunities in arbitrage, emergency power, power tools, creature comforts, at the same time as enabling carbon footprint reduction.

The Need for Electrification

Electricity is the power source of choice, clean, controllable and relatively safe, all things being equal. Of course everything is not equal so there are numerous other power

sources used throughout the world. Internal combustion engines are the most common, used through direct drive, hydraulics, or a generator, there are other sources such as hydro power, animal power etc. but our world is using more and more electricity and this is reflected in our demands for electrical power to drive accessories on vehicles, of course we want convenience and efficiency of use, but with the cost of fossil fuels the need for energy efficiency is also of importance, and increasingly so.

The electrical accessory demands on vehicles pushed the 42V initiative but that fell on its face because of the additional cost in migrating to the higher voltage. Either everything had to move to 42V or a converter was required to provide the 14 to 42V interface. Although a seemingly simple change, the practicalities killed the desire. Now energy efficiency is driving the push to higher DC voltages on vehicles through the hybrid vehicle market and this will impact the broader vehicle market by changing the economics. One key benefit is the availability of more electrical power is the ability to electrify the engine accessories. Accessories like the water pump and the air conditioning compressor have their hardest job at idle, so at any speed above that they have wasted capacity and efficiency suffers. Electrification gives more control and hence more efficiency under real operating conditions.

I will illustrate the development path for more electrification of vehicles through specialty vehicles, hybrid vehicles and electric vehicles. This path opens up great opportunities in the marketplace, given the scope of these changes and where they are leading. We see computers, cell phones and other portable devices appearing everywhere and the need to recharge these devices is only one small aspect of the need for access to electrical power. There is a contemporary market for this capability but there are significant limitations to current technology, in the near term (five years) there will be a major shift in the cost and availability of electrical power on vehicles driven by the fundamental changes occurring in the vehicle platform.

The Work Truck Market

This application takes the work shop into the field. Typically a class 5, 6, or 7 vehicle, these trucks use electricity to operate power tools at the work site. Tools in this case can mean a huge array of devices, because it is such a diverse application 120VAC or 240VAC power is typically the device interface voltage. The loads can be radios, power tools such as drills or saws, computers, pipe fusion, welding

equipment, scene lights, ventilation fans, basically anything you may use in a work environment. Traditional markets would be field service vehicles for cable, gas, electrical utilities, or almost any service vehicle truck chassis, ambulances are always short of power, all the lights, radios, and electrical medical equipment tax the traditional vehicle electrical system, typically they have two alternators and still struggle for power. A large proportion of ambulances also run inverters, again AC power is ubiquitous, if you want to be sure of compatibility for most devices, run AC power. For the military, there is a long standing requirement for 30kW of auxiliary generation to support field operations, this could be a high value application for a hybrid powertrain.

Over the road or Long Haul Trucks

These vehicles are often “mobile homes”, so there is a need to power “hotel” loads. In the past, idling the truck provided DC power to run accessories directly or through a small inverter, however with the anti idling legislation becoming prevalent alternative solutions must be found. The sleeper cab requirements can be mostly covered by about 2kWhr for an 8hr rest period, which can be reasonably provided by conventional lead acid storage batteries, however air conditioning is an issue requiring much more energy storage for a typical rest period (about 8kWhr). Several solutions are populating the market, such as small auxiliary generators, or large lead acid storage banks, but maintenance, life and weight are significant problems. Idling a truck consumes about one gallon of fuel per hour, so it is relatively easy to calculate the value in a “no idle” solution.

There is also a substantial market for refrigerated trucks (reefers) which presently use an auxiliary engine for refrigeration power, here is a large opportunity for “hybrid scale” accessory power, it will require about 10-20kW to meet this application requirement.

The Transit Bus Market

These vehicles are already seeing a substantial move to hybrid traction systems, as much as 25% of the market will be hybrid this year.

Parasitic loads are the biggest problem in this market and this can lead to lots of other problems. There is not enough energy storage to run loads over the weekend when the bus is not used, and if there is enough charge simply the act of cycling the batteries so deeply reduces life dramatically. Hybrids add storage however apart from the traction the rest of the system is very conventional.

The biggest opportunity is the electrification of accessories to remove belts and further improve the efficiency of the vehicle. Accessory operation can be optimized, air conditioning, engine stop/start, removal of the alternator, there are lots of subsystems which can benefit from integration with the hybrid traction drive. Operational loads are large for these vehicles, as much as 6 or 7 kW, of course at idle this is a problem and this can be even worse for

although increasingly we see more small vehicles as “mobile offices” where the load may be a laptop and a printer. Ambulances are a special case of the work truck, these are typically built on light to medium Coaches, which also run inverters to drive a lot of hotel loads.

Current Technology and Limitations

There are numerous solutions for adding electrical loads to vehicles. For smaller loads, simply tapping into the vehicle 12V system is adequate, although there is always the concern about a dead battery if the loads are operated without the vehicle running. For slightly higher loads an upgraded alternator and more battery storage are common solutions, often with an inverter to provide the ubiquitous power interface. The caution is that as loads increase the impact of the loads becomes significant and the integration of the auxiliary power system becomes critical to vehicle integrity. To alleviate this issue at higher loads sometimes “Dynamic inverters” are used in place of the “Static inverters”. Dynamic inverters only draw power from a dedicated alternator so they do not impact the vehicle electrical system as much but they can be more complex to integrate mechanically, of course a bank of batteries can also be a problem to install and maintain so a static inverter, drawing its power from the battery bank, can be a bigger problem if extended run times are required. Although sometimes the ability of a static inverter to be used while the vehicle is moving can be an advantage, since most dynamic inverters require throttle manipulation.



Figure 1. A 4kW Dynamic inverter system for a work truck

This alternator has a conventional alternator mounting, some are very custom, they are all bigger than a “standard fitment” alternator because of the substantially higher output requirement. This is a forced air cooled unit. Using larger alternators is much more difficult, some are “PTO” driven

because as power levels increase belts become more problematical.

Power Generation

Conventional vehicle alternators, are relatively inefficient but cost effective, and offer very limited power at idle. The cost of alternatives for these specialty vehicle “low volume” applications is relatively high and can be a packaging nightmare given the tightly packed engine compartment that we see on modern vehicles. For buses with high current loads, simply getting enough power to keep normal vehicle loads running is an issue, alternators are large enough to require lifting devices for installation or removal, and the high stress leads to poor life. They may consume 5kW at idle, sometimes more, dual alternator installations are not unusual.

Higher power alternators are a low volume product and still have a low power limit, increasing that power limit results in more complex cooling systems, and greater belt problems, simply getting more power is a problem and belt maintenance is an added cost.

For trucks, finding the space for a larger alternator under a modern hood is very difficult, and impractical a lot of the time. The prevalence of 12V systems in the truck market makes things more difficult as the power levels increase, because of the correspondingly higher currents required when compared with a 24V system.

Increased energy storage may or may not help here because the energy ultimately has to come from either the on board generation or shore power. If it is the onboard generator (alternator) then the increased storage just allows more loads to be operated for longer, leaving the generator with a bigger task in replenishing the store.

A common alternative to an alternator is the portable generator, well known and within our comfort zone, on the other hand they are another engine to maintain, they can be noisy, heavy, and are prone to theft. I’m sure we’ve all seen generators hanging from a crane 50ft in the air when the work site is quiet, just so it is still there after the weekend.

Energy storage

For the Class 8 long haul trucks the need is to allow hotel loads to be operated without idling the truck engine so can we supply that 2kWhr or 8kWhr every night and have a reasonable lifetime for the battery?

Lead acid, is the predominant vehicle battery technology although hybrids are developing NiMh, and Li-ion batteries are coming along. The lead-acid batteries are not meeting current needs adequately, we have limited storage capacity, and a limited cycle life, largely limited by the high mass and volume required to satisfy the requirements of the specialty vehicle applications.

Flooded cranking batteries may achieve 500 cycles with a low depth of discharge, controlling that discharge is a major issue, largely ignored, so poor life and starting problems are the result. AGM batteries can be better under these conditions, but of course they are more expensive, there can be thermal runaway concerns, and they are still large and heavy. For example to achieve the 8kWhr mentioned above

at 50% depth of discharge would require about 1200lbs of batteries which would have a life of about 400 cycles. Heating can be diesel so that is readily available with a high energy density and low cost.

Even if the application has 1200lbs of batteries the 8kWhrs we take out each night has to be put back so to put it back during an 8Hr run will require an extra 100 Amps or more from the alternator, and that will be very difficult to find from a conventional device.



Figure 2. A 1Ton AGM battery for auxiliary loads

The present day option would be to start the engine periodically although that can wake up the driver and interrupted sleep is a safety issue so that is not well received. For a cargo carrying truck either a large battery bank or an auxiliary generator add significantly to the GVW and subtract from the legal payload that can be carried. There are allowances to offset this in order to eliminate truck idling, but obviously this is trading one negative (higher GVW) for another (pollution).

For the work truck starting the engine periodically is a realistic option, however we do have to deal with the cycle life of the storage devices, which are lead acid of course. For example if we have a 200Ahr 12V battery running a 1kW load at 50% depth of discharge we would need to start the vehicle engine after 40mins or so and run it for a couple of hours to recharge the battery bank, so our bank has to be larger to accept the recharge quicker and reduce the number of cycles per day, otherwise the battery wont last six months. Transit buses suffer from the same problems as long haul trucks for different reasons, they don’t have enough energy storage for the parasitic loads, at the same time space on the vehicle is at a premium for “low floor” buses, and GVW can be an issue. The starting problems have transit authorities spending thousands of dollars to retrofit ultracapacitors to alleviate the issues, it is really a band aid albeit a functionally elegant one, adding sufficient storage and control is seen as a more difficult task.

New Desires

Now we have 99.99% reliable utility power and electronic devices are everywhere, we want to use our toys and tools on the road, away from our homes or work places. We want a 1GW power source in the dashboard of our vehicles, unlimited power on demand. Simply put: more power. Our thirst for energy is increasing and the drive for greater operational efficiency means more power tools, computers, etc. Along with that comes a demand for improved reliability, when we have our power tools we learn that we can't live without them, this also means clean power. But this must be achieved at a higher efficiency, while bringing a reduction in maintenance (read reduced moving parts), of which elimination of belts will be a significant contributor, or at least a reduced belt load.

The users are tapping into vehicle systems now with undesirable consequences so that is also providing impetus for change, along with pollution reduction and fuel cost reduction, we have a confluence of motivations.

All of this fits well with the hybrid and electric vehicle development.

Reduction in fuel consumption can come from straight hybrid vehicle benefits, particularly in city driving for delivery trucks and local transportation. Long haul trucks have a "no idle" requirement which is in direct conflict with the needs of the drivers to run the hotel loads, and for transit busses in hot regions there is the pre-use cool down requirement which could be achieved electrically to save engine idling. A standard transit bus air conditioning system needs about 15kW of electrical power. So if you run an electrical air conditioner on a transit bus, how do you cool it under normal operation?

So we want more power available to allow use of more powerful tools and expand the range of applications. We need high specific power from the electromagnetic machine for engine start, rapid re-charge of our storage, and increased available power, and we need better storage with a high specific energy for long run time and a high specific power for a rapid recharge. All this must be achieved of course with a high cycle life.

New technology

Hybrids are making larger electromagnetic machines part of the "off the shelf" solution. More efficient and higher power than contemporary technology, that single component will provide huge opportunities for vehicle enhancements. There have been proposals to make crank mounted alternators to access more power, basically they got nowhere because of the magnitude of the changes, but now we have an application which is developing the capability for reasons other than accessory power, however along with the hybrid capability comes the potential to tap into that high power electrical system and its storage.

A light hybrid vehicle does not have much storage since its function is purely to buffer the energy to accelerate and decelerate the vehicle, and likewise the electromagnetics is there to assist the engine, it is not the primary traction motor.

At the next level there is a bit more storage for "electric launch" and to run accessories while stationary at the lights for example, and sufficient electromagnetics to provide some traction capability. However a plug in hybrid is essentially a short range electric vehicle that also has an internal combustion engine, so it has much more capability for electrification than a milder hybrid.

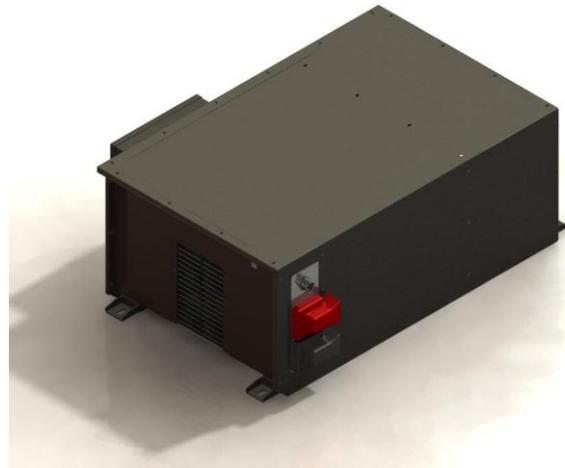


Figure 2. A 7.5kW hybrid vehicle DC-DC converter for a transit bus

Electric power steering is mainstream now there are millions of units in the field, however other electrifiable functions remain to follow in its footsteps. These will lead to further fuel efficiencies as the electrical power sources and storage improve. There is plenty of current technology available for power generation, it is really a packaging and integration exercise, and there is significant new work in batteries that is yielding results. Lithium Ion being the most talked about. The cycle life, energy density and charge acceptance rates for these devices will bring new performance to contemporary systems and improve the cost benefit ratio to acceptable levels for replacement of older solutions (internal combustion driven generators).

Future developments

As the drive for lower fuel oil consumption continues we can see that the drive for hybrid electric vehicles is pushing towards many of the same features that are very desirable or required for the electric vehicle. For example, good batteries, and electric air conditioning, basically the ability to run all of the vehicle accessories directly from electrical power.

At this stage of the game for all electric vehicles, the cost for the all electric accessories is very high, as cost for electric power steering, electric air conditioning, and the large high

performance batteries comes down, the viability of electric transport will become much closer to reality.

The plug in hybrid implies greater energy storage capacity than a regular hybrid simply because to have any impact on fuel consumption a significant portion of the energy consumption must come from the utility sources, these larger batteries also mean an opportunity to use that stored energy for other applications. This stored energy is very attractive to the specialty vehicle market, which by definition is vocationally focused, so we have clean, accessible and flexible energy available to do work. These specialty vehicles are more expensive because of the lower volumes associated with such specialization, the upside of which is a little lower sensitivity to cost and a greater value in some of these features we are discussing. This can be a stepping stone to the high volume low cost consumer market, although the cost of fuel alone may be sufficient drive to push the development of the needed technologies if it is sustained at a high enough level.

Grid interface is obviously a requirement for a plug in hybrid, if that interface is bi-directional then you now have the basis of an AC auxiliary power system.

There has been a lot of interest from the utilities in peak power shaving which helps keep costs down from both a generation and a distribution standpoint. There is also a need for emergency power in disaster areas, and a financial incentive for individual owners for the ability to buy and sell power at the appropriate time.

This can all be achieved within the infrastructure of the hybrid vehicle as most of the development will be in control rather than major power hardware.

Conclusion

The specialty vehicle market has many applications that can benefit significantly from electrification. This fact has a lot of synergy with present trends in overall vehicle electrification which are driven by fuel costs. The rate of progress in the broader market may or may not continue at a rapid pace, but regardless there is sufficient benefit in the specialty vehicle market to ensure continued progress which will help the development in the broader market, and vice versa.