# Power Management – An Integrated Approach

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## 1 Summary

The U.S. Army is activity seeking viable solutions to a growing power challenge within ground vehicles platforms. Power demand can exceed available power, even on the newest production vehicles. Sometimes this excessive power demand is not realized until it is too late and the batteries are depleted or the alternator has been stressed. Compounding this problem, requirements are surfacing for exportable vehicle power and, adding to the complexity, future military concepts show military vehicles exchanging power and interacting with smart grid systems.

For years, TARDEC has recognized this power challenge and, through the SBIR program and other initiatives, has conducted research and development efforts in the area of vehicle system power management and power control.

There are promising solutions. Strategic individual loads that consume a significant amount of power should be considered for point-of-load monitoring and power optimization (which also enables condition based maintenance (CBM)). Vehicle subsystems should be considered for "condition based power optimization". As a complete system, the demand from alternators, the interaction with vehicle batteries, load demand, and interaction with grid systems, should be known and appropriately managed, especially when high priority vehicle missions are at stake. This paper will consider power management as an integrated solution to address the complete system, subsystems, and individual loads. Global Embedded Technologies, Inc. (Global ET) is focused on providing products and solutions in the area of power management, control, and integration to meet the needs of the military and industry.

The authors Mark Stanczak and William Carrothers are from Global ET, an engineering company that is dedicated to providing products and solutions in the area of power management, control, and integration. Founded in 1994, Global ET has been involved with vehicle based power management since 2000 and has been involved with military vehicle power management with TARDEC since 2002 through the SBIR program. Global ET has successfully transitioned to SBIR Phase III opportunities with TARDEC and within the defense industry. Global ET is the #1 Google search result for "power management control integration". Global ET products include the Power Control Unit (PCU) family of products and the Power Management Application (PMA). Global ET is in the process of advancing these products and welcomes opportunities to be involved with power management and power control programs with the military through SBIR Phase III, with the defense industry, and in other commercial applications.

## 2 Power Management

Power Management is a combination of power electronic hardware, sensoring, and software that allows for intelligent use of available vehicle power generation and energy storage. A managed power system adds information and control to address current and future military requirements.

### 2.1 Situational Awareness

Monitoring, processing, and indicating key pieces of information or situations allow for improved usage. Knowing about a problem is the first step in automatically or manually containing or correcting the problem. For example, if a vehicle is running while load demand is excessively high and power is being drawn from the batteries, a power deficit situation exists that should to be addressed. Currently without situational awareness this condition is unknown to the operator. Continuing to run in this state would deplete the batteries when, with the engine running, the batteries would typically be charging. In this situation, the batteries could be discharged and subsequent vehicle starts could be compromised. Additionally, the operating voltage could unexpectedly brownout (low voltage), damaging sensitive and expensive electronic equipment. Awareness of the situation enables the operator to correct the condition by either reducing demand or generating more power by increasing idle speed, would correct the situation.

### 2.2 Load Prioritization, Reduction, Shedding

Load prioritization, reduction, and shedding is the process of intelligently managing available power to ensure highest priority loads are available when electrical power demand is too high or available power has been reduced. A reduction in power could occur in an emergency combat situation, or if an alternator reduces its production because of heat, or if a battery management system indicates that the state of charge is getting critically low. The load shedding process can be automated, semi-automated, or manual “by instruction”. During mission planning, loads are prioritized so that during critical situations quick corrective actions can be taken. With advanced power control, power to some loads can be reduced so that they are still functional in some capacity. For example, in a thermal management system, a decrease in airflow due to power reduction is better than no airflow. The following figures depict a managed power system.

Figure 1, shows a good power system status. The alternator is producing a reasonable amount of power and that power is consumed by the Air Conditioning (AC) System and the communication radio and the batteries are charging.

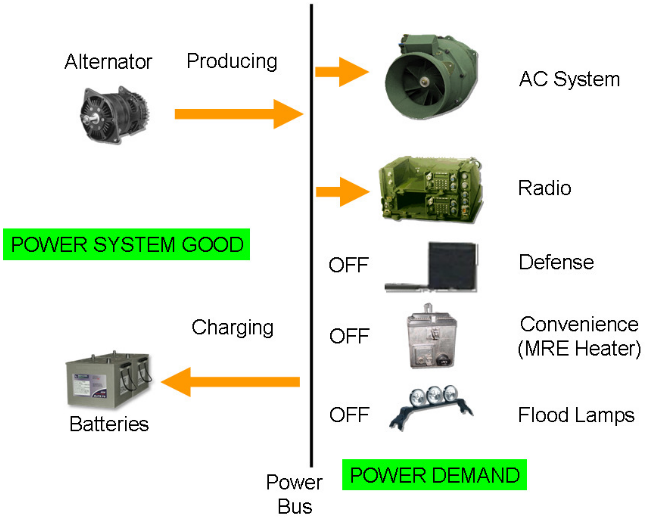

Figure 1 – Power System GOOD

Figure 2, shows a power system that is critically overburdened. The alternator output is extremely high and is still not sufficient to meet the load demand, so the batteries are contributing. Running in this condition too long could stress the alternator to failure, create low voltage brownout conditions, and will eventually drain the batteries.

Figure 2 – Power System CRITICAL

Figure 3, shows an improved power system situation because of power management. The critical communication radio and defense loads have the highest priority and are fully powered. Power to the AC System and the flood lamps were decreased and a convenience load was deactivated. This decreased the output demanded from the alternator to a lower level and the system is no longer demanding power from the batteries.

Figure 3 – Power System Improved Through Power Management

This concept is not limited to reducing power consumption. Intelligent power management allows for routing available power to critical operations. For example, in an emergency dash, alternator demand could be reduced which will increase available horsepower or drive power improving the emergency dash operation.

## 2.3 Load Reconstitution

Load reconstitution is the process of restoring loads that have been reduced or shed. Similar to managed mode transitions (see below), this process ensures that the load demand does not abruptly increase causing an undesirable power system transient.

## 2.4 Signature Management

Survivability considerations include signature management, where parameters such as temperature and sound can be monitored. The resulting improvement in situational awareness alone is of benefit, but in active power management, power sources and loads can be adjusted to reduce detectable signatures. Signature management solutions that incorporate other parameters, such as light, are also possible with a power management system.

## 2.5 Mode Based Load Control & Scheduling

Mode-based load control and load scheduling provides the ability to quickly change from one vehicle mode to another. This semi-automated process ensures that loads that should be off in a given mode are off and it ensures that loads that should be on are automatically turned on. It performs this mode transition in a scheduled / managed way so that the system does not experience a power demand transient that could cause alternator belt slippage and voltage brownout conditions that can damage electronic components. This enables the vehicle power system to be quickly transitioned into its most survivable state. For example, if the vehicle is in a normal transport mode and the crew needs to quickly transition into a combat mode, with one action, certain loads such as headlights would be turned off and critical loads, such as communication radios and defense equipment, would be powered up.

### 2.5.1 Vehicle Starting Mode

Vehicle start is an important mode of operation. In this mode, it was discovered that the air conditioning (AC) system can be active on some military vehicles. Several tests were performed to capture vehicle start with AC on and AC off. With AC off, cranking time was 19% to 37% faster. Given the same number of vehicle start attempts, the vehicle would have an average of 25% less cranking time with this load off, reducing wear to both the starter and the engine. Every second counts, so there is also an inherent survivability factor in being able to start the vehicle faster. In these tests, there was an overall energy savings of 16% to 33% consumed by the starter and 26% to 40% system wide. This reduces the stress on the batteries and if the State of Charge or State of Health is low, this could be the difference between starting and not starting. If less energy is consumed during vehicle start, demand by the batteries after vehicle start is also decreased, improving fuel efficiency. The following graphs depict vehicle start attempts with AC off and AC on. An integrated power and thermal management system would allow for system improvements during vehicle start.

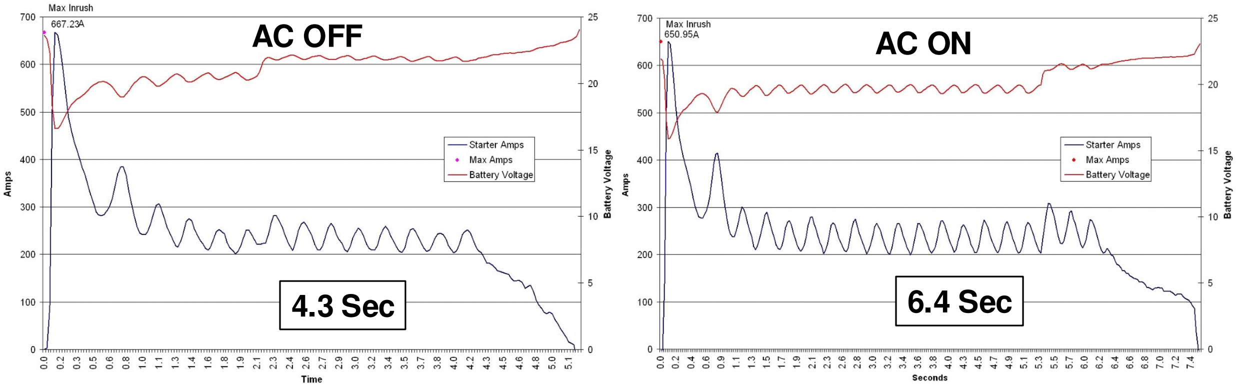

Figure 4 – Vehicle Start Time (AC Off vs. AC On)

## 2.6 Power Optimization

Power optimization provides the ability to optimize power to a particular electrical load and allows for usage of the most cost effective combination of available power generation and energy storage devices (see 2.7 Power Integration). Power optimization includes activities such as ensuring alternator demand is minimized during accelerations or hill climbs or reducing unnecessary loads to improve fuel efficiency.

### 2.6.1 Soft Start

Power Optimization also includes control techniques such as soft start. In the following example, motor current soft start was applied to a vent fan. With power delivered from an ultracapacitor, the fan was 1) turned on without soft start, 2) turned on with soft start with an additional second of run time, and 3) turned on with soft start. After 75 on-off cycles in case 2, 30% more power was available and in case 3, 60% more power was available, showing the power saving benefits of power optimization.

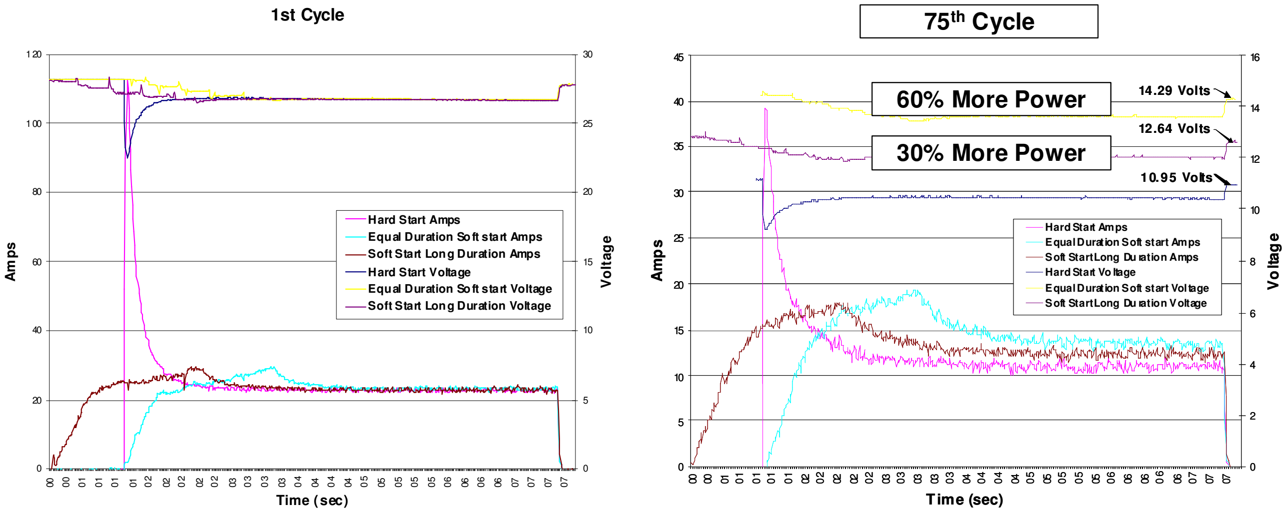

Figure 5 – Power Optimization through Soft Start

## 2.6.2 Condition Based Power Optimization

Power management can be integrated with certain subsystems – the thermal management system for example. In the case of a cooling loop that has a pump and a fan, the pump would be activated only when the load temperature exceeds a certain threshold. The fan would only be activated once the cooling-loop fluid had exceeded a certain temperature. The fan would increase in proportion to the temperature and would hold a certain speed (certain power demand) if the temperature was stabilized at an acceptable level. Without power management, the pump and the fan would be fully activated the entire operation, unnecessarily burdening the power and energy system. As depicted in the following graph, without the active thermal management device, the load temperature would continue to increase beyond an acceptable level. It is also apparent that the active thermal management does not have to consume maximum power to keep the load within an acceptable temperature range. This illustrates an opportunity for power savings.

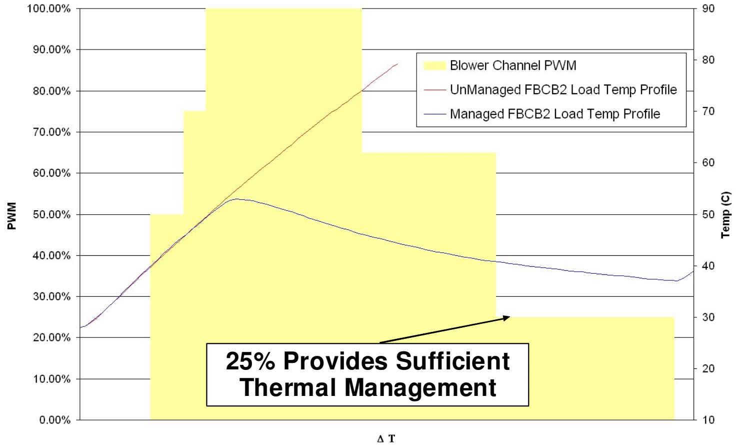

Figure 6 – Power Management Applied to Thermal Management System

### 2.6.3 Charge Control

Power Optimization can also be applied to control battery demand during vehicle start mode. This is especially important during thermal extremes. When batteries are extremely cold, they have a severely limited current output capability. The following graph (left) shows that a 24V battery system during a -40C starting attempt almost immediately drops to an unusable level. An ultracap system (right) is a possible solution for vehicle cold starting because it can deliver power even at extremely low temperatures. As shown below, the first starting attempt from a battery system supplied approximately 90 KJ, while the ultracap system supplied approximately 3 times as much energy, 280 KJ.

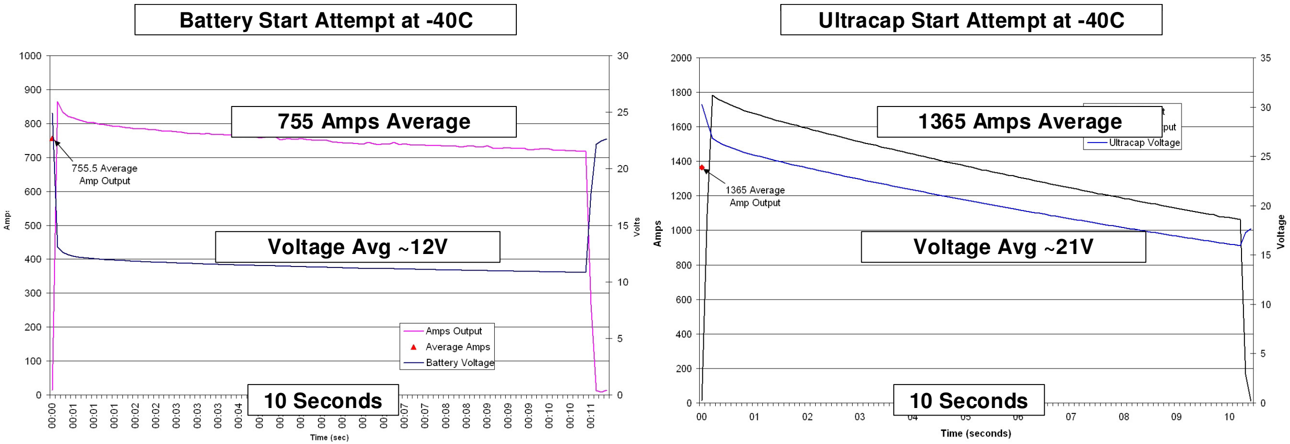

Figure 7 – Battery Starting (1 Attempt) / Ultracap Recharge (After 6th Attempt)

Supplying energy from an ultracap system for the first attempt is not the challenge. The challenge is addressing the practical need for subsequent start attempts. In a hybrid ultracap / battery system, the ultracap system will demand power as aggressively as it supplied power, destroying the batteries on ultracap recharge attempts. With power management, ultracap recharge demand can be controlled. The following graph to the left shows a controlled ultracap recharge. The graph to the right shows that limiting current demand and boosting voltage, can harvest enough energy from a battery system to charge a 1250F ultracapacitor system from 0V to 32V even after 6 vehicle start attempts at -40C.

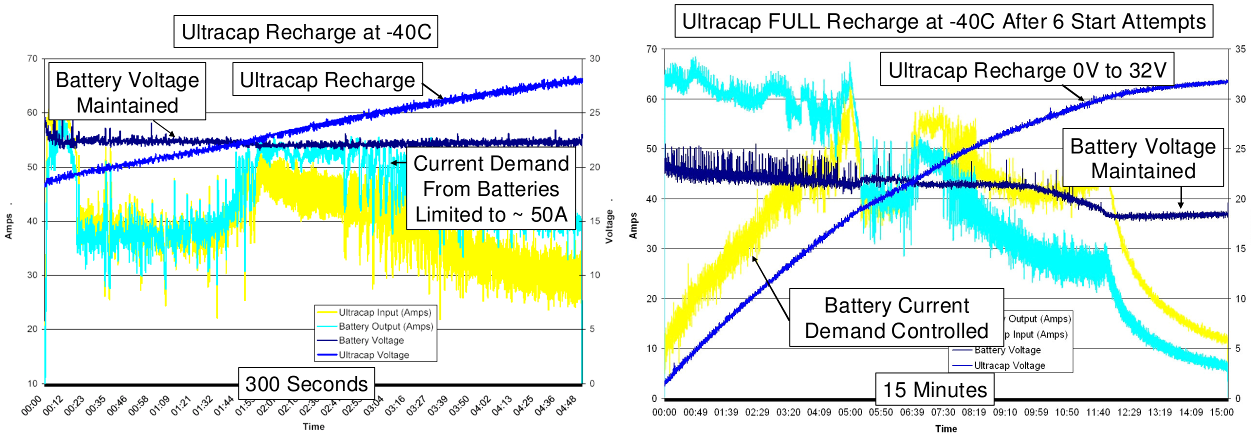

Figure 8 – Ultracap Recharge / Full Ultracap Charge (after 6 Start Attempts)

## 2.7 Power Integration

Power integration provides the ability to precisely control contributions from various disjointed sources to obtain power optimization. The following example illustrates the concept of power integration. Consider a vehicle system performing silent watch multiple DC sources. If all of the sources operate at different voltage levels, the highest voltage will supply power. Power integration provides the ability to merge the power sources in a determined way, for example, obtaining the maximum contribution from the least expensive fuel source (solar power) and precisely supplementing remaining demand from a battery and fuel cell. If the solar power wanes, the battery and fuel cell sources would seamlessly increase in a managed balance. If the battery state of charge decreased past a set threshold, the fuel cells would increase to maintain the supplied power. As described in this example, power integration actively manages power contribution from a combination of disjointed sources.

## 2.8 Maintenance Improvements

As described in the Situational Awareness section, power management can monitor and process key pieces of information. Monitoring load voltage, current, and temperature are essential to power management. Corrective actions can be taken by the power management system to mitigate problems and the information can be used for Condition Based Maintenance (CBM) reducing failures in the field. For example if a fan motor is bound by debris, it would have a higher running current and would run hotter. This detection can also be applied in a prognostic sense. If a load is steadily degrading, a prediction of "time to failure" could be made. Power Management also enables improvements to automated diagnostics. With load control, loads can be activated one at a time in diagnostic mode. The operating parameters would determine the load to be functioning okay or would determine that there was a problem.

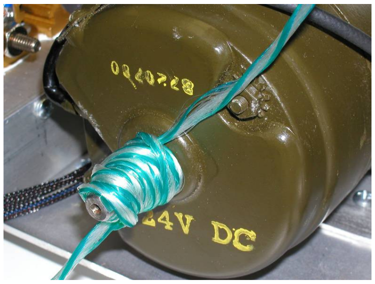

Figure 9 – Bound Motor

With power management, maintenance improvements are not isolated to loads. Battery currents and temperatures can be monitored to ensure batteries are in balance or that batteries or alternators are not overheating. In this example, Figure 10 (left) shows current during a demanding two hour test. Normally, the parallel / series configuration has a symmetrical contribution from the pairs of batteries. In this graph, however, near the end of the test, BT4 overheated and started to wane. In subsequent tests (right), that battery showed very little contribution, indicating that it was damaged by misuse. This battery damage would be avoided with an integrated power and thermal management system.

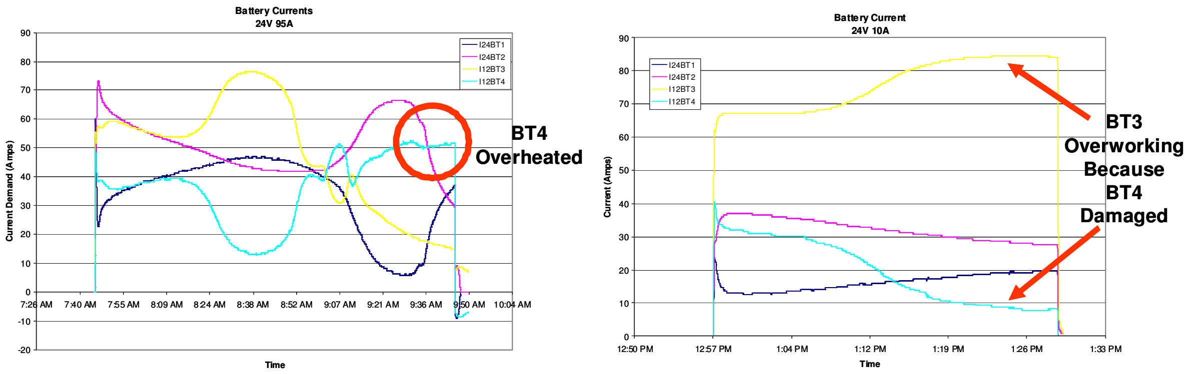

Figure 10 – Battery System Currents

## 2.9 Safety and Robustness

Improvements to safety are critical. With power control, extreme conditions, such as short circuits, can be detected and contained at the point of load without disabling a complete branch line of loads, which increases system safety and robustness. Connector arcing is another potential safety hazard that can be addressed with power control. This is especially true for higher voltage systems and in applications such as vehicle power import / export.

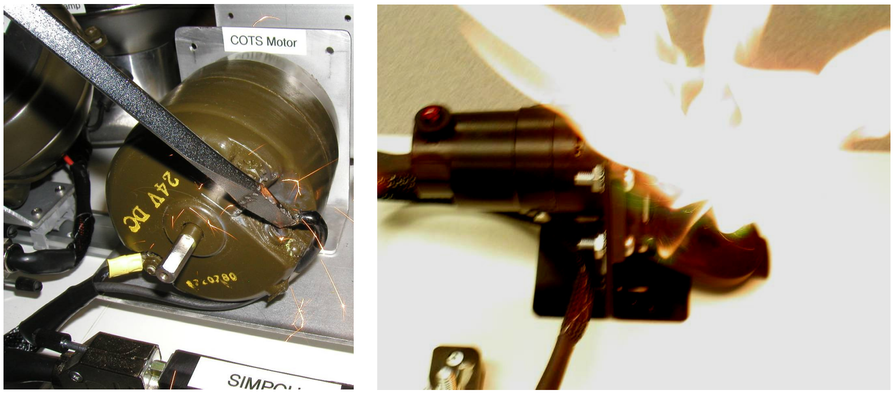

Figure 11 – Shorts / Arcs

## 2.10 Planning, Training, and After Action Reporting

Planning and training is another area of importance for future military operations. Collecting and storing power and thermal information will help mission planning by using real world data. This data can also be integrated into simple training tools that illustrate how usage of unexpected loads can impact the mission and fuel efficiency. After action reports can be automatically generated to improve future mission planning. The following shows an example of an after action report. In the mission, unexpected loads were used, which had an impact on the predicted success of the mission. With power management, a correction was made to make the mission a success.

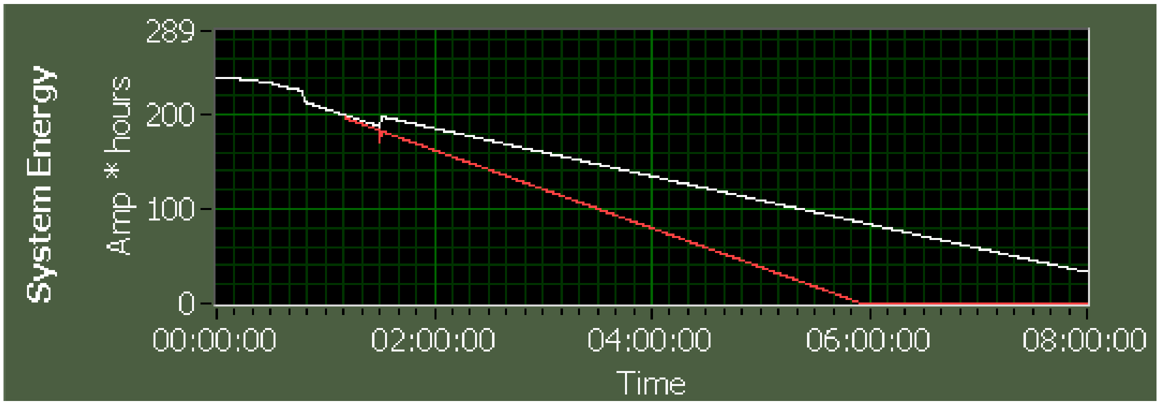

Figure 12 – After Action Report

## 2.11 Interconnectivity and Interoperability

Interconnectivity and interoperability are important for future open architecture vehicle systems. TARDEC has established the Power Management Application Program Interface (PMAPI), which highlights requirements for power management information and functionality. Integrated system-level power management will need to work within a System Of Systems Common Operating Environment (SOSCOE).

## 2.12 Vehicle / Grid Interaction

Vehicles are among the resources that will enable robust power options in tactical environments. Current and future vehicles should be available to provide robust power options to the military. Vehicle generated power should be available for power export to reduce the logistical challenges and costs associated with generators and their trailers, spare parts, tools, and maintenance. Additionally vehicle-based equipment should be operational through power import without having to run the vehicle’s engine. Vehicle based power export and power import will provide robust power options that quickly make equipment operational in the field and provide the redundancy of vehicle to grid / microgrid power systems to ensure successful military operations. For a vehicle, power import / export is typically a secondary priority. Vehicle power interaction must be managed in a way that ensures safety and ensures that the vehicle’s main mission objectives are not compromised. This is accomplished through the vehicle power management system.

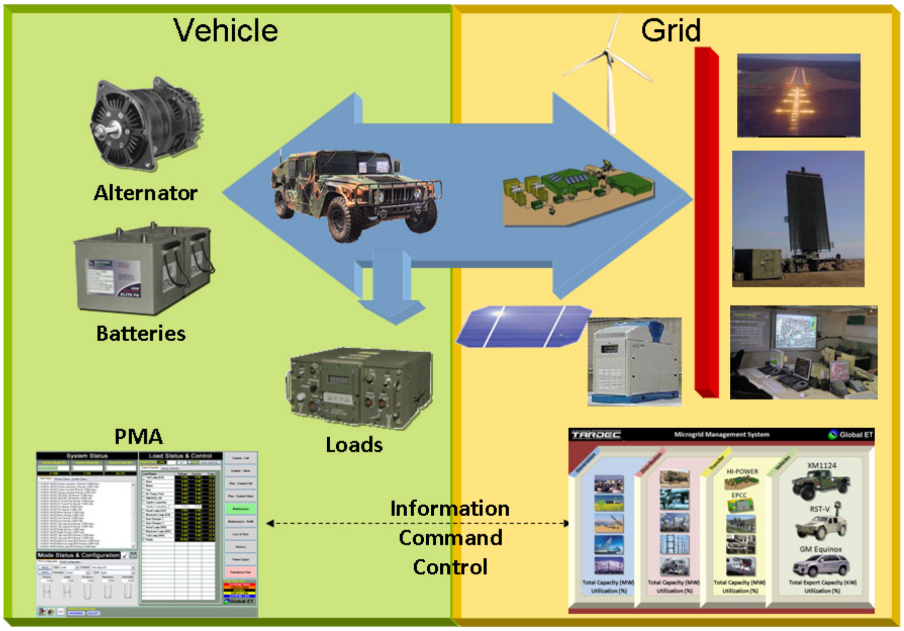

Figure 13 – Smart Vehicle / Smart Grid Interaction

### 2.12.1 Microgrid Management System (MMS)

Similar in concept to vehicle power management application, but applied to a contained grid system, a MMS enables smart grid operation and vehicle / grid interaction. The MMS will display information and statuses, will monitor sources and loads, and will enable manual and automated load and source management. Information will include power, temperatures, subsystem health status (subsystem examples include microgrid battery system, solar panel system, vehicles, etc.). The MMS will also determine the maximum amount of power available from the microgrid, the duration (given the existing demand), the energy delivered, and costs over any time period. The MMS will manage and prioritize based on mode or conditions. For example, with vehicle recharging, priority could be given to a particular vehicle because of its mission or because it has the lowest battery state of charge. This priority will be port independent and will be enabled by communication between the grid and the vehicle. With this communication, an added layer of safety is possible by allowing power transfer only after a successful vehicle / grid negotiation.

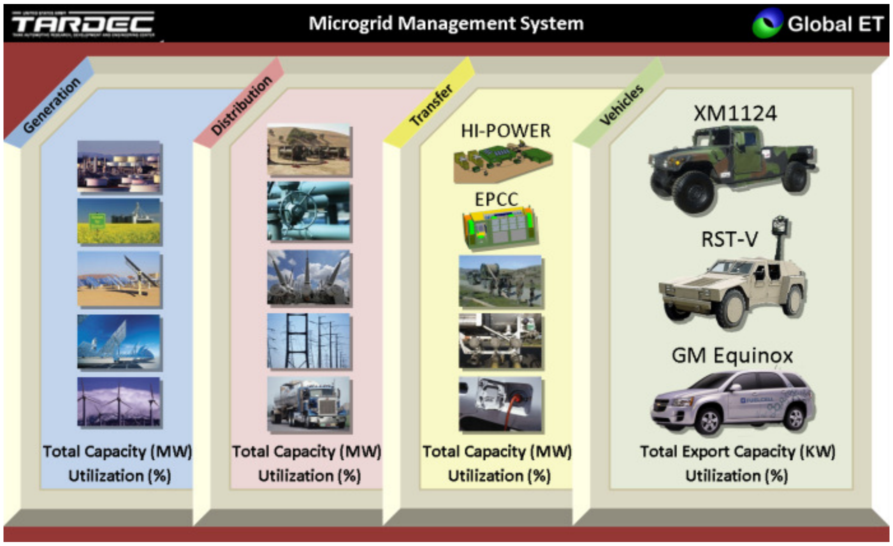

Figure 14 – Microgrid Management System

### 2.12.2 Vehicle / Grid Interaction

Vehicle / grid interaction will be bi-directional in both communication and power flow. When a vehicle is connected for battery recharging or load use, a vehicle ID and vehicle battery SOC will be sent along with a power request from the vehicle to the grid. The grid system will process this information and if it has the capacity or the vehicle request is high priority, power will be granted to the vehicle with a transaction ID. Based on its configuration and priorities, the grid system can reduce or eliminate power flow to the vehicle. If the grid is in need of power, a request can be sent from the grid system to the vehicle and, if the export of power will not impact a higher priority mission, the vehicle can supplement the grid. This vehicle / grid interaction will be recorded at the grid system for future mission planning.

## 3 Conclusion

Power management and control are among the highest priority areas for vehicle modernization efforts and future vehicle systems. As described in this paper, there are far reaching benefits including improvements in capability, survivability, fuel efficiency, maintenance practices, safety, and component wear.