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OPERATIONAL READINESS IMPROVEMENT THROUGH PLATFORM ELECTRIFICATION

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ABSTRACT

New mission requirements will soon overtake the automotive and mission equipment capabilities of electric power systems in tactical and combat vehicles used by the U.S. Army. Incorporating emerging technologies into both existing and new vehicles will allow the vehicles to meet these requirements, facilitate reductions in formation sizes, and make the Army more mobile. When combined, these factors have the potential to improve both the readiness and effectiveness of both vehicles and vehicle formations.

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1. INTRODUCTION

The Modernization Priorities for the United States Army call for the Army to win by "mastering the fundamentals of shoot, move, communicate, and sustain better than any other Army." In the ground vehicle domain, the availability of suitable electric power is a central tenet in four of the six modernization priorities:

Long-Range Precision Fires – Advanced missile launch vehicles will require advanced electric power systems for radars and other sensors, silent watch, and launch capability.

Next Generation Combat Vehicle – Preliminary requirements for the Optionally Manned Fighting Vehicle (OMFV) call for a high voltage electrical system and a substantial power reserve for future growth.

Army Network – The Modernization Priority calls for the Network to be "… sufficiently mobile and expeditionary…". This requires substantial electric power for both network equipment and for the cooling necessary to keep it operating under all environmental conditions.

Air and Missile Defense – The Army is pursuing the use of directed energy weapons for air and missile defense, especially for use against Unmanned Aerial Vehicles (UAVs). Lasers and other directed energy weapons require dramatically more electric power than what has previously been integrated into Army vehicles.

Current combat and tactical vehicle platforms have limited power generation capabilities that affect their ability to perform these new mission roles. Use of the vehicle drivetrain to create electric power will enable these emerging requirements, reduce formation sizes, and make the Army more mobile. Combined, these factors will enable these new requirements while improving both mission readiness and mission effectiveness.

2. POWER GENERATION

2.1. Current State

With few exceptions, both combat and tactical vehicles have MIL-STD-1275 28 Vdc electrical systems. These vehicles use alternators driven by engine belts or transmission Power Take Offs (PTOs) to provide power to both vehicle automotive systems and mission equipment. Current tactical vehicles have alternators as large as 400 A (11.2 kW) while combat vehicles have alternators with capacities up to 1000 A (28.0 kW). A recent study by US Army TARDEC showed certain vehicles have a current (CY 2019) combined automotive and mission equipment power need of over 1500 A (42.0 kW) [1]. Mission equipment power requirements vary widely across vehicle type.

Typical belt-driven alternators are 55% [2] to 75% [6] efficient. Combining this with the 98% efficiency of the typical belt drive results in a system power efficiency of 54% to 74%. Alternators are a mature technology and are generally reliable when properly applied.

Stationary formations use towed and skid mounted Tactical Quiet Generators (TQGs) and Advanced Medium Mobile Power Systems (AMMPS) for AC power generation. AMMPS generators are fielded in capacities ranging from 5 kW to 60 kW and are dramatically more fuel efficient and reliable than the previous generation of TQGs with a published reliability of 750 hours [3]. AMMPS (and TQGs) are very flexible and are capable of providing a wide range of single and multi-phase AC power forms at multiple frequencies.

The Army has recently outfitted the AMMPS with an Advanced Digital Control System (ADCS) to allow multiple AMMPS generators to be used in a microgrid where AMMPS generators cycle on and off and deliver varying amounts of power based on real time sensing of loads. The Army cites a 20-30% fuel savings and 74% reduction in generator operating hours [4] through the use of the ADCS microgrid.

2.2. Drivetrain Based Power

Several companies, to include Leonardo DRS, L-3 Corporation, and Jenoptik USA, produce vehicle power generation systems that receive their mechanical power directly from the vehicle drivetrain; dramatically increasing the amount of mechanical power that can be used to generate electric power. All of these products use Permanent Magnet Machines (PMMs) for power generation and modern switching regulators to convert the multi-phase variable-voltage, variable-frequency generator power to highly-regulated, high-voltage DC busses.

There are two basic approaches for integrating PMMs into vehicle drivetrains:

1. “Sandwiching” the PMM between the engine and the transmission
2. Integrating the PMM directly into the transmission.

Implementing the sandwich approach is simple given the near-universal use of standard SAE flanges for engine-transmission interfaces. It does, however, lengthen the drivetrain by the depth of the PMM. This is a major drawback when working with existing vehicles as most military vehicles are very tightly packaged and there is no room to accommodate a longer engine-transmission assembly.

Leonardo DRS, working with Allison Transmission, has taken a different approach in their development of the TITAN 3200MSG On-Board Vehicle Power (OBVP) system. For this product, Leonardo DRS and Allison Transmission designed a 125 kW PMM that fits directly into the housing of any Allison 3000 series transmission. Use of this Transmission Integral Generator (TIG) approach results in an overall assembly (Figure 1) that has the same 32.36 inch length of the base transmission. This simplifies the integration of this transmission into the Stryker ICV, FMTV, MaxxPro MRAP, M-ATV MRAP, and other vehicles that use Allison 3000 series transmissions. Table 1 shows the prototype integration status of TITAN OBVP into various Army vehicles.

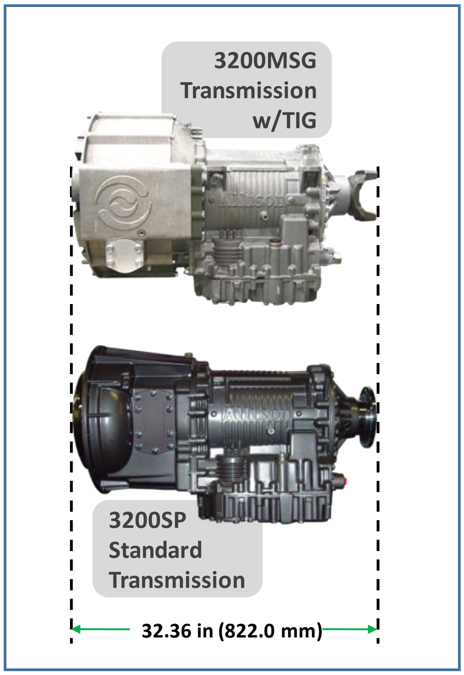

Figure 1: DRS / Allison 3200MSG TITAN Transmission Integral Generator (TIG) OBVP

Table 1: TITAN OBVP Integration Status

Vehicle	Integrator	Purpose
MaxxPro MRAP	Navistar Defense Leonardo DRS	Mobile Command Post Demonstrators
M1126 Stryker	US Army TARDEC, General Dynamics Land Systems	APOP Demonstrator [5]
M1126 Stryker	Leonardo DRS	Mobile Command Post Demonstrator
M1085A1 FMTV (In Process)	Leonardo DRS	CCDC GVSC Microgrid

Figure 2 shows an M1126 Stryker powerpack with the TITAN 3200MSG OBVP being installed in a flat-bottom Stryker.

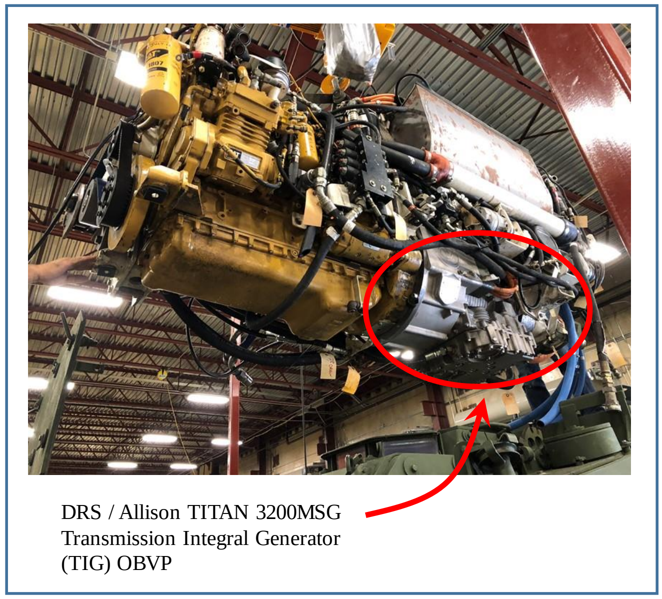

Figure 2: Stryker Powerpack with DRS / Allison 3200 TITAN TIG

In 2016 TARDEC used the TITAN 3200MSG OBVP as the power generation source for their Stryker Vehicle Advanced Propulsion With Onboard Power (APOP) demonstrator. This program used the TITAN 3200MSG OBVP to increase the available onboard power for the Stryker from 16kW (28 Vdc, 570A) to 120kW to support future vehicle capabilities such as directed energy, electromagnetic gun, electromagnetic armor, and electronic warfare. The additional power was also used to run electrified automotive auxiliaries on the vehicle such as the main fan and hydraulic pump more efficiently. Higher efficiency and the ability to temporarily shed electrical loads (by disabling the DC/DC converters and adjusting fan and pump speeds) were used to mitigate the mobility effects of high electrical power loads on the vehicle [5]. In summary, TARDEC testing of the APOP demonstrator showed that electrification can lead to greater efficiency and vehicle automotive performance gains but that the gains diminish as power use on the vehicle continues to grow [5].

TARDEC has also performed dynamometer efficiency testing of the TITAN OBVP system. Their testing verified the 120 kW output capability of the system and showed that system efficiency ranges from 88% to 97% over its' operating range with an average efficiency of 94% [6]. This is dramatically higher than experienced with traditional alternators.

Drivetrain-based power is also an effective power source for micro-grids. In 2016 TARDEC demonstrated a vehicle-based microgrid at the Ft. Devens, MA Base Camp Integration Lab (BCIL). During the Sustainability Logistics Basing (SLB) Science and Technology Objective Demonstration (STO/D), TARDEC demonstrated a vehicle-based microgrid that delivered power more efficiently than the baseline TQG formation [7]. Figure 3 shows a comparison of the fuel consumed by a traditional TQG formation versus a vehicle-based microgrid when both were running the same scripted load exercise.

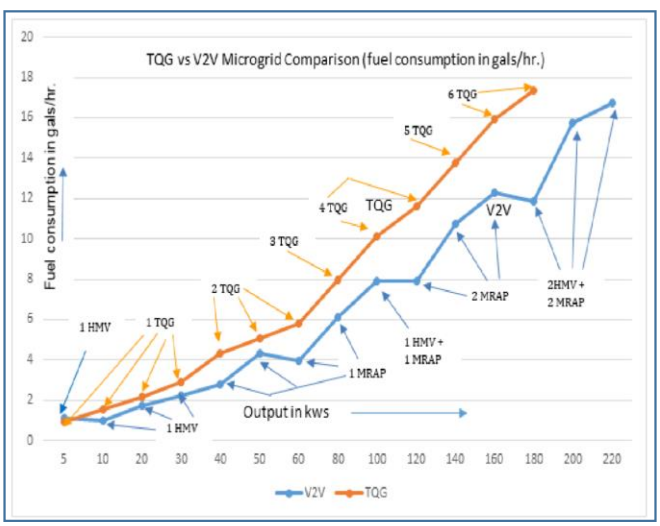

Figure 3: STO/D Total Fuel Consumption, TQGs vs Vehicle-based Microgrid [7]

As stated above, belt-driven alternators are technically mature and reliability shortcomings are largely due to how they are applied. High underhood temperatures and poor underhood airflow are the prime culprits in alternator failures in current vehicle applications. The reliability of towed and skid-mounted generators has improved dramatically in recent years with AMMPS generators now having a published reliability of 750 hours [3].

Allison and DRS have performed a reliability assessment of their TITAN 3200MSG OBVP system with the following results:

- Allison installed a TITAN 3200MSG OBVP into a commercial truck and completed a 15,000 mile (approximately 1632 hour) durability test. There were no OBVP failures during the test. Allison performed a teardown of the transmission at the conclusion of the test and determined that the inclusion of the generator does not detract from the reliability or durability of the transmission.
- Leonardo DRS performed a MIL-HDBK-217 assessment of the TITAN 3200MSG OBVP. Operating at a maximum power output of 125 kW with a coolant temperature of 60 C, the predicted reliability of the TIG generator is 79,700 hours and the predicted reliability of the OBVP system electronics is over 15,000 hours.
- Leonardo DRS supported two 3200MSG TITAN OBVP MaxxPro MRAPs at multiple NIEs. The vehicles generated power for over 10,000 hours in the exercises and associated activities with no system failures.

3. Power System Impact on Army Formations

ATP 3-34.45, Electric Power Generation and Distribution, calls for the initial phases of military operations to use tactical electric power systems that are organic to the units. It further defines tactical electric power as having a distribution of less than 600 Vac, a power level of less than 200 kW, and an expected mission duration of less than six months [8]. Tactical power typically consists of AMMPS generators with capacities of 5 kW to 60 kW. Generators with capacities of up to 15 kW can be transported with HMMWVs while 30 kW and 60 kW generators require FMTV trucks for transport. Figure 4 shows how delivery of power through the use of vehicles with drivetrain based power results in a dramatic savings in material and people when compared to the current approach. As shown in the figure, use of vehicles with a 90 kW power generation capability would result in a reduction of one FMTV, three 60 kW AMMPS generators and M200A1 trailers, and two soldiers. This frees up vehicles and pintles to carry more food or munitions and soldiers to further the fight.

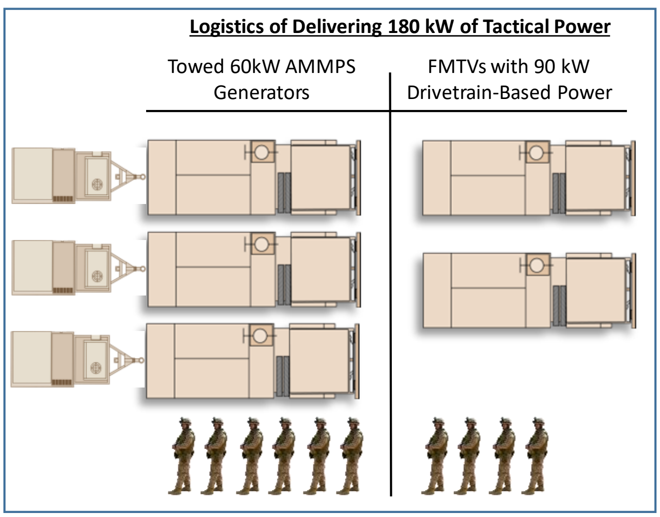

Figure 4: Comparison of Approaches: Delivery of 180 kW of Tactical Power

U.S. Army Training and Doctrine Command (TRADOC) Pamphlet 525-3-1, the U.S. Army in Multi-Domain Operations 2028, published in December 2018 identifies "...how US Army forces, as part of the Joint Force, will militarily compete, penetrate, dis-integrate, and exploit our adversaries in the future." This pamphlet emphasizes that Army forces will need to "execute Multi-Domain Operations with echeloned formations that conduct intelligence, maneuver, and strike activities across all five domains (air, land, maritime, space, and cyberspace) as well as the information environment and the Electro-Magnetic Spectrum."[9].

The concepts described in this document have the following implications for vehicle electric power systems:

- Increased movement and maneuver with less formation time at the halt. All capabilities must be available while on the move
- Increased emphasis on the use of non-kinetic actions will increase the need for vehicle electric power. Non-kinetic actions include (1) denial / disruption of enemy communications, surveillance, tracking, and navigation capabilities, and (2) the introduction of false information into enemy networks by forward-deployed forces operating in areas contested by an adversary [9].

The Army has previously demonstrated Mission Command On The Move, an essential part of these new capabilities, at multiple Network Integration Evaluations (NIEs). During these exercises the Army used Navistar Defense MaxxPro MRAPs equipped with the TITAN 3200MSG OBVP system to create both mobile Tactical Operations Centers (TOCs) and Tactical Command Posts (TACs). These mobile formations were able to "jump" from location to location dramatically quicker than the traditional formation. The MRAPS were also able to export power to other vehicles while operating at the halt [10]. The mobile TOC is shown in Figure 5.

Figure 5: Mobile TOC Powered by 3200MSG TITAN OBVP Systems

4. Impacts on Readiness and Effectiveness

Current Army doctrine is built around the use of vehicle alternators and towed / stationary generators such as AMMPS. Existing vehicles and towed / stationary generators satisfy all DOTMLPF requirements and are long-established Programs of Record. These products meet existing requirements for function, performance and reliability. Repair parts are properly provisioned and soldiers have the appropriate training, tools, and parts to repair items while deployed. They are considered effective in completing current missions.

Can the existing systems meet the emerging requirements? Increased movement and maneuver will lead to requirements for less time at the halt. Analysis of Russian operations in Ukraine have led to the belief that command post formations like TACs and TOCs will need to move every 30 to 60 minutes to survive [11]. Can this be accomplished with a combination of existing vehicle power and towed generators?

As demonstrated at multiple NIEs, drivetrain-based systems facilitate on the move operations and quick transitions from on the move and stationary operations. They also have the promise of higher reliability. The PMMs used for power generation are highly efficient so they do not generate as much waste heat as traditional power generation. The PMMs are also water cooled, making them relatively insensitive to excessive underhood temperatures. The electronics, while complex, have similar architectures to items that are becoming common in the heavy equipment, truck, and automotive industries. This has led to widespread availability of components suitable for the development of reliable electronics assemblies. The predicted (more than 15,000 hrs) and demonstrated (more than 10,000 hrs) reliability of the Leonardo DRS GCBR should be the norm for this type of electronics assembly.

5. Summary

Both the Army and industry have used laboratory and operational testing to demonstrate that drivetrain-based power has the potential to improve the effectiveness of tactical and combat vehicles while improving the overall reliability of power generation and reducing the operational cost of power generation. This technology is mature and ready for adoption in support of emerging requirements.

6. Next Steps

Both Industry and the Army need to do more work to prepare for adoption of drivetrain-based power generation.

Industry:

- Continue to work on reducing the cost of the technology.
- Accelerate the adoption of wide bandgap semiconductors (SiC, GaN) and other technologies that offer the promise of higher efficiency and reduced size and weight.

Army:

- Ensure that new requirements for vehicle and formation power requirements are formulated so that they are technology agnostic and recognize the power needs of the mission equipment, not just the automotive platform.
- Develop doctrine for the use of drivetrain-based power generation. Flowing doctrine into documents like ATP 3-34.45 Electric Power Generation and Distribution would help lead to adoption of the technology.

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