2026 NDIA MICHIGAN CHAPTER
GROUND VEHICLE SYSTEMS ENGINEERING
AND TECHNOLOGY SYMPOSIUM
POWER AND MOBILITY TECHNICAL SESSION
AUGUST 11-13, 2026 - NOVI, MICHIGAN

MODELING THE OPERATIONAL PERFORMANCE IMPACTS OF A VEHICLE INTEGRATED POWER KIT (VIPK) ON A MODERN MEDIUM TACTICAL WHEELED VEHICLE

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ABSTRACT

Michigan Technological University (MTU) was awarded a competitive prototype project to develop a Vehicle Integrated Power Kit (VIPK) for multiple variants of the Family of Medium Tactical Vehicles A2 (FMTV A2). The VIPK provides high voltage power export, expeditionary power for silent watch capability in low load cases, and interoperability with tactical microgrids. To support VIPK development, MTU created a vehicle model to quantify the impacts of VIPK integration, accelerate design decisions, and predict vehicle performance. This model was calibrated using experimental data, and the calibrated model was then used to compare vehicle performance with and without VIPK installed. Power flow diagrams were utilized to understand the energy pathways during vehicle operations. This paper details how the VIPK system affects performance and analyzes its power flow under select operational conditions.

Citation: B. Goodenough, H. Schmidt, J. Naber, P. Dice, D. Subert, K. Meyers, "Modeling the Operational Performance Impacts of a Vehicle Integrated Power Kit (VIPK) on a Modern Medium Tactical Wheeled Vehicle," In *Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium* (GVSETS), NDIA, Novi, MI, Aug. 11-13, 2026.

1. INTRODUCTION

The operational role of medium tactical wheeled vehicles (TWVs) is evolving and expanding as modern ground forces confront a battlefield defined by increased electrical power demands. A Vehicle Integrated Power Kit (VIPK) can transform a vehicle designed for mobility and payload transport to support a wide range of missions and systems that require electrical power, while operating both on the move and at a halt. These mission systems require low to high-voltage, AC (alternating current) and DC (direct current)

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power, while accommodating steady-state and transient loads across mission-dependent duty cycles.

In response to these demands, integrated power architectures are increasingly viewed as a necessary evolution in tactical vehicle design and add-on kits. VIPKs represent one such approach, integrating power electronics and exportable power interfaces into the vehicle platform. VIPKs enable capabilities such as high-voltage high-power export, expeditionary power for silent watch in low-load cases, and interoperability with tactical microgrids. These capabilities position the vehicle as both a mobility platform and a mobile energy asset, capable of supporting diverse battlefield customers across a wide range of austere operational scenarios and environments.

This paper explores a project that introduces a representative VIPK solution designed by Michigan Technological University (MTU) for a modern medium TWV, focusing on the system architecture required to meet evolving requirements of battlefield power. In addition to describing the MTU VIPK solution, this work examines the operational performance impacts on the vehicle resulting from realistic VIPK load scenarios.

To address the need to understand and characterize performance changes from adding a VIPK, a system-level, modeling-based approach was employed to evaluate baseline vehicle performance and vehicle performance with a VIPK integrated. The analysis considered representative electrical loads both during movement and at a halt, and quantified the resulting impacts on operational performance metrics, including acceleration, top speed, maximum grade, and speed on grade. This combined solution-and-assessment approach enables an informed evaluation of how VIPK integration can improve mission capability while managing performance tradeoffs.

2. MOTIVATION

Electrical power has become a central enabler and force multiplier of combat effectiveness on the modern battlefield. There is an increasing demand for onboard and exportable power from vehicles. These power demands are not uniform; different battlefield customers require different power types, magnitudes, and availability, often simultaneously and under constrained operational conditions.

Legacy power generation approaches include engine-driven alternators and auxiliary generators. These solutions impose penalties in fuel consumption, acoustic and thermal signature, logistics burden, and integration complexity, all of which directly affect survivability and operational reach in contested environments. Engine-driven alternators, for example, are also limited in output as they typically provide low voltage at relatively low power below 30 kW. Additionally, at the formation level, reliance on external generators and frequent fuel resupply increases the exposure of logistics assets and constrains maneuver endurance.

VIPK offers a path to address these challenges by consolidating power generation, storage, and distribution into the vehicle platform. VIPK also enables smart generation, in which the kit generates power only when necessary. However, the introduction of such capabilities is not without consequence. Added system mass, added system inertia, and changes in electrical demands can impact acceleration, top speed, gradeability, speed on grade, braking, fuel consumption, and overall vehicle mobility. This paper characterizes some of the effects on the operational performance attributes that tactical vehicles depend on to preserve mobility, survivability, and sustainment.

3. PROJECT DETAILS

This project developed a VIPK solution for the Oshkosh Defense FMTV A2. An M1078A2 variant of the FMTV A2 is seen in **Figure 1**.

Figure 1: Oshkosh Defense FMTV M1078A2 variant at Michigan Technological University (MTU).

The MTU VIPK project aims to design and integrate a power kit for specific variants in the FMTV A2 family of vehicles, including the M1078A2, M1079A2, M1083A2, M1085A2, M1087A2, and M1148A2. MTU is installing the kit on the M1078A2 and M1083A2 variants as VIPK demonstrators for the U.S. Government. In addition to these variants, CAD studies were conducted to ensure compatibility with all listed variants. The critical attributes of this VIPK are given in **Table 1**.

Table 1. Critical attributes for VIPK on FMTV A2.

Critical Attributes
Fast-forming DC microgrid
120 kW stationary / 30 kW on-the-move of 600 VDC
On-board and off-board 600 VDC to MIL-STD-3071 [1]
208 VAC, 5-wire, 3-phase with 60 kW power
28 VDC with 18 kW of power

MTU leveraged its considerable experience in vehicle systems and prototypes for this effort. Comprehensive, high-fidelity models have been developed in the past for military vehicles [2] and for off-road equipment [3].

4. PROPULSION SYSTEM ARCHITECTURE

The MTU VIPK solution is implemented as a kit that draws mechanical power from the existing internal combustion engine to generate electrical power, eliminating the need for vehicle driveline modifications. MTU's VIPK design maximizes the use of high-technology-readiness-level commercial-off-the-shelf components while remaining focused on ease of kit integration. A high-voltage (HV) generator was added to the propulsion system, off the front power take-off of the stock internal combustion engine, to enable HV power generation. The engine serves as the sole source of power for both mobility and energy generation. A one-way clutch is located between the engine and generator, so the generator can spin components on the front end of the engine without spinning the engine. A high-level propulsion system diagram is seen in **Figure 2**.

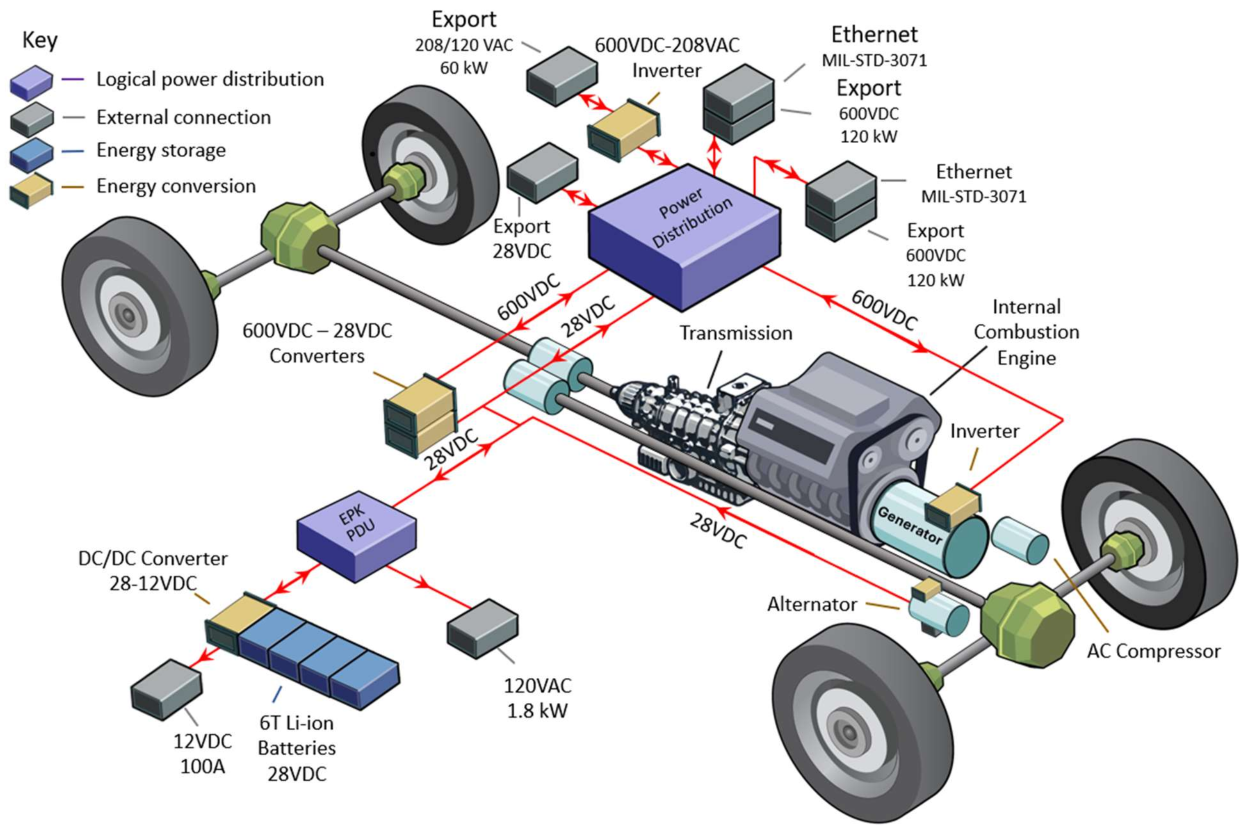

Figure 2: MTU VIPK architecture, showing primary components. Expeditionary Power Kit (EPK) enables engine-off operation and silent watch. Engine, transmission, drivelines, axles, wheels, and AC compressor are retained from base vehicle. All other components shown are added or changed for the MTU VIPK.

Figure 2 shows the primary components involved in the MTU VIPK system and their respective power and voltage levels. These components were needed to accommodate the requirements, as given in **Table 1**. The MTU VIPK also has a dedicated cooling loop for HV components, with its own radiator.

The 600VDC-28VDC Converters, also known as DCDC converters, are used primarily to support 600VDC loads and may also be used to support 28VDC loads in certain scenarios.

5. MODELING OF VEHICLE INTEGRATED POWER KIT

The MTU VIPK system adds loads to the stock vehicle's internal combustion engine. As such, a model of the system's performance was essential to inform and accelerate design decisions, reduce development costs and risks, predict vehicle performance, and optimize the energy management strategy. The performance thresholds of the baseline FMTV A2s needed to remain with the VIPK installed. As such, MTU leveraged its considerable modeling and simulation experience to develop 1D models of the baseline FMTV A2 and the FMTV A2 with MTU VIPK.

This paper focuses on the M1083A2 variant of the FMTV A2 at gross vehicle weight (GVW) with the armor kit installed. GVW is defined as the sum of the vehicle weight and the maximum payload weight. The GVW is assumed to remain the same after installing the MTU VIPK; the MTU VIPK system reduces payload capacity by the difference in weight of components added and removed.

This GVW is assumed to remain the same because the MTU VIPK did not make structural changes that would allow for a higher total weight capacity. Hence, the payload capacity needed to be reduced by the weight of the MTU VIPK system.

5.1. Modeling the Baseline FMTV A2

Siemens Simcenter Amesim was used to develop the baseline model of the FMTV A2 [4]. The vehicle architecture, as modeled in the Amesim environment, is shown in **Figure 3**.

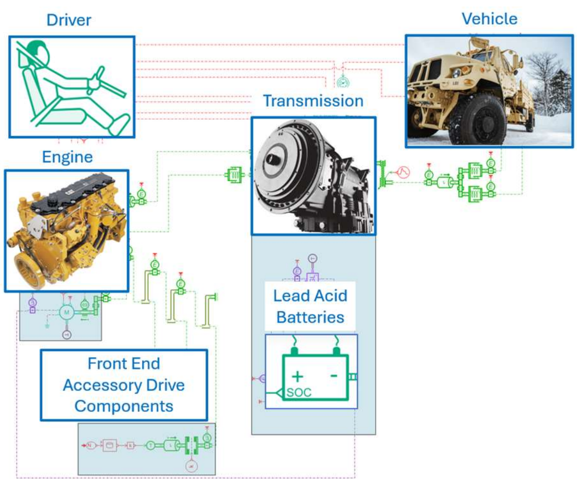

Figure 3: The baseline FMTV A2 vehicle model in Siemens Simcenter Amesim without the integrated MTU VIPK system. See **Figure 5** for the model with MTU VIPK.

Using knowledge from past vehicle projects [2, 3], MTU modeled the vehicle architecture and performed simulations to analyze results to assess the design, control, and impact as part of the vehicle development program. The parameters used in this model were derived from data on the FMTV A2s and obtained from the vehicles' technical specifications.

5.2. Calibrating the Baseline Model with Experimental Data

With the vehicle model built in Amesim and the simulations completed successfully, the model needed to be calibrated using experimental data.

Rolling resistance coefficients for each vehicle variant were identified using coastdown testing on the same nominally flat road segment. Tests were conducted in both directions to minimize the effects of wind and residual road grade. The results were averaged to produce a mean speed versus time coastdown curve, which was used to validate equivalent coastdown simulations. The coastdown coefficients were tuned to closely match the experimental coastdown curve, as shown in **Figure 4**.

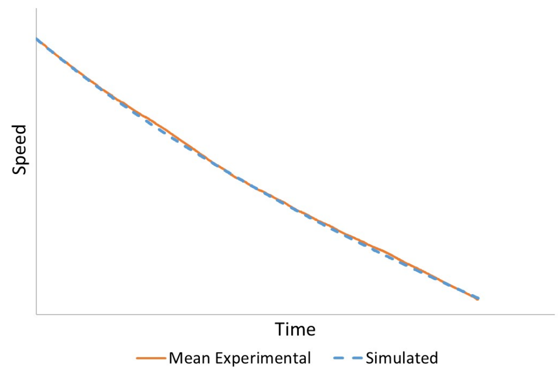

Figure 4: Coastdown test for FMTV M1083A2 variant, comparing experimental to simulated results.

Additional experimental data sets were required to fully characterize the baseline vehicle, including fan torque loads. For components that could not be measured directly and lacked manufacturer specifications, assumptions were introduced and calibrated to ensure agreement between model predictions and experimental results. For example, experimental acceleration tests were used to establish peak performance, and transmission parameters in Amesim were tuned so that simulated acceleration matched measured vehicle response, as given in **Table 2**.

Table 2. Acceleration and top speed comparison between experimental and simulated FMTV M1083A2 variant at GVW.

	Experimental: Baseline FMTV M1083A2 without MTU VIPK	**Simulated:** Baseline FMTV M1083A2 without MTU VIPK
Accel: 0 to 5 mph	Baseline	-1.0 s
Accel: 0 to 30 mph	Baseline	-0.2 s
Accel: 0 to 50 mph	Baseline	+3.7 s
Top Speed	Baseline[1]	+4 mph

[1] Experimental top speed results were constrained by available track length and may not represent absolute top speed.

Acceleration results were well aligned, except that the difference between the experimental and modeled time to accelerate to 5 mph was higher than anticipated. This difference is due to the estimated torque converter parameters, as data on these torque converters was not publicly available. The available time for model development limited the achievable model fidelity. MTU's resulting model is appropriate for the level of analysis pursued here, where performance impacts are studied from adding the MTU VIPK system.

5.3. Modeling the FMTV A2 with MTU VIPK

After the tuning and calibration was performed to obtain simulated results that aligned with the experimental results, the MTU VIPK system was integrated into the modeling environment to assess its impact on the mobility performance of the FMTV A2. **Figure 5** displays the Amesim model of the FMTV M1083A2 variant with the MTU VIPK system, located in the green outlined boxes toward the bottom of the figure.

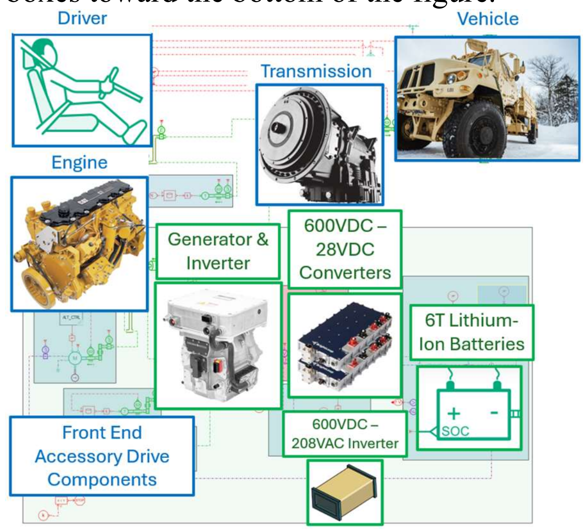

Figure 5: FMTV A2 model in Siemens Simcenter Amesim. The major MTU VIPK additions are outlined in green.

The MTU VIPK system was added to the modeling environment to mimic the actual architecture implementation as seen in Section 4. PROPULSION SYSTEM ARCHITECTURE. Added components were parameterized based on performance specifications provided by component manufacturers for items such as generators, DCDC converters, batteries, etc. Like the baseline vehicle model, assumptions were made when component data were unavailable.

Since a critical attribute of VIPK is to provide 120 kW at 600 VDC, this condition was modeled with the engine and generator supplying this power under stationary conditions. Several other power export conditions with varying voltages also needed to be met. The next section analyzes simulation performance data to assess MTU VIPK's compliance with propulsion and power generation demands.

5.4. Performance Results

The sections below present simulated performance results with the MTU VIPK installed, along with baseline results for comparison.

The performance simulations in this section are executed under the following conditions:

- Cooling fan is engaged
- Air conditioning (AC) is on and providing max cooling
- Alternator is providing 1 kW of electrical power
- Air brake compressor is unloaded
- The GVW is the same with and without the MTU VIPK, as the MTU VIPK system is assumed to reduce payload capacity by the difference in weight of components added and removed
- Worst-case thermal scenario for the FMTV A2, with a 49°C (120°F) ambient temperature requiring maximum cooling.

5.4.1 Impact of the MTU VIPK on Propulsion System Performance

Table 3 shows the comparison between the model with MTU VIPK and without load, and with the MTU VIPK with both 30 kW HV export and 19.2 kW DCDC support. The results are given as percentages relative to the baseline model without MTU VIPK.

Table 3. Simulated performance comparison for FMTV M1083A2 variant at GVW. All percentage values are relative to the baseline model without MTU VIPK.

	Simulated: FMTV M1083A2 with MTU VIPK 0 kW HV Export	**Simulated:** FMTV M1083A2 with MTU VIPK 30 kW HV Export with 19.2 kW DCDC Support[1]
Accel: 0 to 5 mph[2]	+11%	+33%
Accel: 0 to 30 mph	+1%	+13%
Accel: 0 to 50 mph	+1%	+13%
Top Speed	+0%	+0%
Max Grade	+0%	-10%[3]
Speed on Grade (2%)	+0%	-14%
Speed on Grade (3%)	+0%	-7%

[1] DCDC converters provide maximum support during these events that are assumed to be short-term events.
[2] For accelerations, positive change values mean the acceleration takes longer by the given percentage.
[3] The maximum grade percentage represents a relative 10% reduction in maximum gradient capability, not an absolute reduction of 10% grade.

The results in **Table 3** show 1% to 11% decreases in acceleration performance with the MTU VIPK installed, due to increased system rotational inertia. The simulated results for the 30 kW export condition with 19.2 kW DCDC support show a notable decrease in performance, as engine power must be dedicated to HV export rather than to propelling the vehicle. The DCDC converters are used to deliver their maximum power output in these short-term cases, with energy drawn from the 6 kWh of 28 VDC lithium-ion battery storage.

Also note the largest percentage change in acceleration from 0 to 5 mph, due to increased rotational inertia in the system, and because the baseline time to reach 5 mph is short, even minor absolute increases produce relatively large percentage changes. The simulated acceleration response is strongly influenced by the assumed torque converter characteristics, which were recognized as a limitation of the model, as seen in the calibration comparison from **Table 2** in the 0 to 5 mph acceleration instance.

5.4.2 Export Performance of MTU VIPK

The following sections elaborate on the power flow of the MTU VIPK during various operations. These are among the most significant operations the MTU VIPK performs, and they required further modeling to understand the flow of energy and how performance characteristics changed as a result. Additional operating conditions were modeled to evaluate performance and power flow, but are omitted here for brevity.

5.4.2.1. 600 VDC 120 kW Power Export While Stationary

A critical function of the MTU VIPK is to provide 120 kW of 600 VDC power to support applications including field hospitals, missile defense, command posts, vehicle charging, and directed energy weapons. This stationary power export of 120 kW represents a high-power scenario in which the engine supplies power to a microgrid via the Tactical Microgrid Standard Power Distribution Unit (TMSPDU). This MIL-STD-3071-compliant export power is a crucial aspect of this MTU VIPK system, hence a strong focus on ensuring this power delivery is fully understood. It is critical to ensure the engine can provide the necessary power after accounting for component losses and power consumption from all required systems. Those conditions were simulated under a worst-case operating condition that assumed a 49°C ambient temperature. **Figure 6** shows the crucial components involved in 600 VDC 120 kW export condition and **Figure 7** shows the associated power flow diagram.

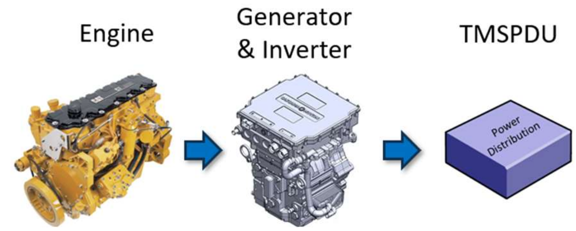

Figure 6: Components involved in 600 VDC 120 kW stationary power export condition.

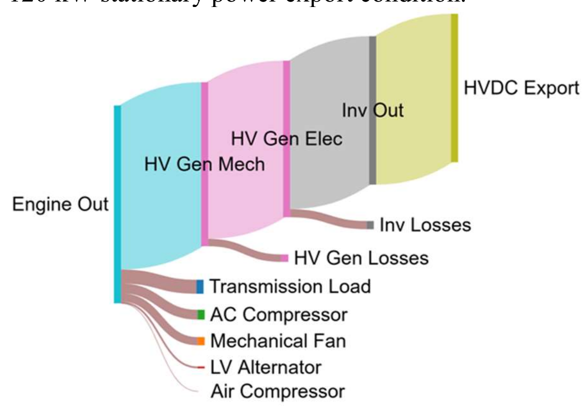

Figure 7: Power flow of 600 VDC 120 kW stationary power export condition.

Figure 7 demonstrates how the engine's power is primarily directed to support the 600 VDC 120 kW export, while also supporting loads including the transmission load, air-conditioning compressor, mechanical cooling fan, and alternator. Note that the transmission load is represented in these losses, since the engine will be spinning the torque converter while in neutral. These transmission losses were calibrated in the model using experimental results comparing reported engine torque to engine speed across multiple steady-state speeds.

5.4.2.2. 600 VDC 30 kW Electrical Load at Max Forward Speed

Another significant vehicle operation was the vehicle's performance while exporting 30 kW of 600 VDC power at maximum vehicle speed. As opposed to the condition in the last column of **Table 3**, this looks at all 30 kW export power coming from the generator, without DCDC support. **Figure 8** shows the significant components involved in this operation with **Figure 9** showing the power flow.

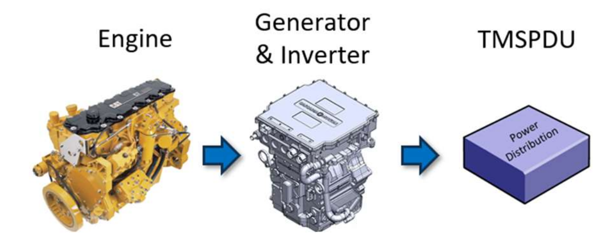

Figure 8: Components involved in 600 VDC 30 kW power export while at maximum vehicle speed.

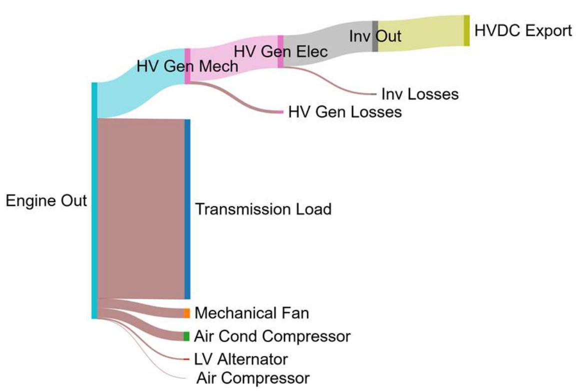

Figure 9: Power flow of 600 VDC 30 kW power export while at max vehicle speed.

In this scenario, the transmission load is the highest percentage of engine power because the tractive effort required to drive the vehicle at maximum speed is at its peak. After this, the generator accounts for the largest portion of the engine's load.

The critical vehicle performance conditions elaborated in this section detail the power flow of the MTU VIPK system. This power flow and performance modeling enabled the research team to understand the impact of the MTU VIPK system on vehicle performance across multiple significant operating conditions.

6. CONCLUSIONS

The added capabilities of a VIPK make a TWV not only a mobility platform, but a mobile energy asset. Electrical power generation can be performed both while stationary and on the move, with smart power generation enabling the MTU VIPK to scale energy output to match situational demand. With these benefits, integrated power systems like VIPK still alter the vehicle's mass, power flow, thermal loading, and control strategy. In this paper, the system's performance was modeled to understand how performance changes with VIPK integration and to examine power flows throughout the system under varying operating conditions.

The baseline performance of the FMTV A2 without MTU VIPK was compared to the performance of the FMTV A2 with MTU VIPK, as seen in **Table 3**, where the system's increased rotational inertia led to a 1% slower acceleration time from 0 to 30 mph. When generating 30 kW for HV export with 19.2 kW of DCDC support, the acceleration time from 0 to 30 mph increases by 13% due to the additional load on the engine that reduces power to the wheels.

The MTU VIPK did not affect speed, grade, or speed on grade results, since these are near-steady-state tests where inertial effects are minimal. When MTU VIPK was exporting 30 kW with 19.2 kW of DCDC support, the max grade and speed on grade results decreased, as expected, due to reduced power to the wheels.

Additionally, this paper explored the power flow during 600 VDC 120 kW stationary power export and 600 VDC 30 kW export at maximum vehicle speed. These power flow diagrams help to understand the significant components of power consumption during these representative conditions, where losses and other loads add considerable demand to the engine. This is especially pertinent to the 49°C (120°F) ambient assumption, under which the air-conditioning compressor and the engine fan are assumed to remain operational indefinitely.

This performance modeling effort enabled the MTU team to optimize the impacts to operational performance in the design phase, accelerate design decisions, reduce development costs and risks, predict vehicle performance, and optimize the energy management strategy.

Future work:

- This vehicle model continues to support control system development. Simulated power consumption enables testing and tuning of the energy management strategy prior to vehicle build. Modeled results from prior projects at MTU were used to inform energy management strategies [5].
- This model also enables complex modeling of certain critical subsystems. While not elaborated on in this paper, higher-fidelity modeling has been pursued for other vehicle subsystems, enabling the research team to focus on crucial aspects of vehicle performance prior to vehicle build.

Figure 10: Michigan Technological University's team for VIPK, in front of the FMTV M1078A2.

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9. ACKNOWLEDGMENT

This work was funded by the Defense Innovation Unit (DIU) under contract W15QKN2599005. The authors recognize the support of the following agencies, without whom this work would not have been possible:

- Portfolio Acquisition Executive (PAE) Agile Sustainment and Ammunition (AS&A)
- Capability Program Executive (CPE) Combat Sustainment (CS)
- Project Manager (PM) Transportation Systems (TS)
- Product Director (PdD) Multi-Mission Protected Vehicle Systems (MPVS)
- Office of Secretary of War Defense Innovation Unit (DIU)
- Office of Secretary of War Operational Energy-Innovation (OE-I)
- Ground Vehicle System Center (GVSC)
- Combat Capabilities Development Command

10. ACRONYMS

AC	Alternating current
DC	Direct current
DCDC	DCDC converter, also known as 600 VDC – 28 VDC converter
FMTV	Family of Medium Tactical Vehicles
GVW	Gross vehicle weight
HV	High voltage
LV	Low voltage
MTU	Michigan Technological University
MTU VIPK	Michigan Technological University Vehicle Integrated Power Kit
TMSPDU	Tactical Microgrid Standard Power Distribution Unit
TWV	Tactical wheeled vehicle
VAC	Volts of alternating current
VDC	Volts of direct current
VIPK	Vehicle Integrated Power Kit