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TACTICAL VEHICLE TO GRID (V2G) AND VEHICLE TO VEHICLE (V2V) DEMONSTRATION

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ABSTRACT
The roll-up roll-away Tactical Vehicle-to-Grid / Vehicle-to-Vehicle (V2G/V2V) system provides a plug-and-play, very fast forming, smart, aggregated, and efficient power system for an emerging (including austere) contingency base. The V2G/V2V system gives the Soldier a capability they currently lack: The ability to generate up to 240kW of 120/208 VAC 3-phase power anywhere, anytime using Transmission-Integrated Generators (TIGs) to produce 600VDC for use by vehicle hotel loads (electrification), transfer of power from V2V, and export power off-vehicle in a Forward Operating Base (FOB) environment, V2G. The system is designed to provide grid services (peak shaving, Volt/VAR control, power regulation, and current source mode) beneficial to emerging and mature grids (CONUS or OCONUS). Data collected during the FY 14 Tactical Enabled Contingency Basing Demonstration (TECD 4a) of a single vehicle with V2G capability showed that variable speed engine power management can provide up to 50 percent fuel reduction. This multivehicle based power system utilizes variable engine speeds for efficient power generation. The demonstration project includes the sub-system development, communications systems development, system integration, testing, and demonstration. The system supports host-grid connectivity to reduce deployed fuel consumption for power generation by 20 percent. The system capability will be first demonstrated at TARDEC and then with the Warfighter at Fort Devens, Sustainability Logistics Basing (SLB) Science and Technology Objective Demonstration (STO/D), in FY16.

INTRODUCTION
The goal of the V2G/V2V effort is to demonstrate the capability to assemble a vehicle based power supply for austere contingency bases. The demonstration achieves this by providing 240 kW of 120/208 VAC power in less than 20 minutes while achieving an estimated 20% fuel savings over conventional methods. This project implements operational energy improvements on the move and when at a base by aggregating multiple vehicles into the grid. Currently there are multiple operational energy gaps identified by the Department of Defense (DoD). Vehicles that are not on a mission can use the onboard vehicle power systems to reduce the fuel consumption for generating power at the contingency bases - currently more than 50% of the Army fuel consumption supports power generation. Data shows that intelligent power distribution and management systems that aggregate power generation sources and manage prioritized loads reduce fuel consumption by >20%. Data shows that vehicles are not on missions 95% of the time; the demonstration will show that the vehicle's capability can be utilized use when not on missions. Vehicles with V2G capability can intelligently and securely contribute to the FOB's power grid and reduce fuel demand through use of the stored energy on the vehicles.

TECHNOLOGY ENABLED CONTINGENCY BASING DEMONSTRATION (TEC-D/4A)

A single-vehicle version of the system called the On-Board Vehicle Power with Tactical Vehicle-to-Grid Module, or OBVP/TV2GM, was demonstrated at Ft. Devens during Phase 1 - Demo 1 of the Technology Enabled Contingency Basing Demonstration (TEC-D/4a) in October 2014. The objective of this demonstration was to realize a 20+% reduction in fuel consumption when compared to the baseline of two MEP-805B Tactical Quiet Generators (TQGs).

The OBVP/TV2GM, consists of a high-power transmission-integrated generator system integrated onto an M1152 HMMWV, a TV2GM, and four remote smart switch boxes, which powered high- and low-priority loads. By prioritizing loads, the system was to demonstrate the ability to manage a load total in excess of its generating capacity. High-priority loads would consist of lighting, Communication, Force-Protection, and other situational-awareness systems. Low-priority loads consisted of four HVAC units (one for each shelter) which were time-sliced on a rotational basis. The demonstration took place in two Camps – North (Test) and South (Control). The OBVP/TVGM and one 30kW MEP-805B TQG powered 4 tents in the North, while two 30kW MEP-805Bs powered 4 tents in the South. Data from the demonstration event revealed comparable fuel consumption rates to a 30kW MEP-805b TQG when operated in high-power (30kW) mode, and that, when operated in low-power mode (less than 10kW), the system's ability to run engine speed at tactical idle (1100rpm), demonstrated an almost 2-to-1 reduction in fuel consumption when compared to the baseline, with the OBVP/TVGM system producing approximately 11.8kWh/Gal, while the TQGs produced anywhere from 5.8- to 6.6kWh/Gal (Reference Table 1).

Table 1: OBVP/TV2GM Power and Fuel Data

		North Camp - OBVP + TVGM						South Camp - 2 x MEP-805Bs				
Date		Runtime (decimal hours)	Energy (kWh)	Fuel (gal)	Gallons per hour (GPH)	kWh/g		Runtime (decimal hours)	Energy (kWh)	Fuel (gal)*	Gallons per hour (GPH)	kWh/g
9-Oct		6.52	32.09	13.4	2.06	2.39		6.42	70.98	30.4	4.74	2.33
10-Oct		3.75	23.8	9.2	2.45	2.59		3.79	60.42	18.8	4.96	3.21
14-Oct		5.18	8.9	10	1.93	0.89		5.19	30.98	19.6	3.78	1.58
15-Oct		6.05	15.02	6.2	1.02	2.42		6.05	40.09	23.6	3.90	1.70
16-Oct		6.48	12.15	**6.3**	**0.97**	**1.93**		6.50	12.15	**12.6**	**1.94**	**0.96**
17-Oct		5.38	19.719	6.5	1.21	3.03		5.39	49.02	22.0	4.08	2.23

The basic premise was to demonstrate fuel saved by powering four tents in the North Camp with only one power source running compared to the baseline South Camp, which had two power sources running all the time. As the numbers show, OBVP fuel consumption on 9, 10, & 11 Oct was not considerably different from the combined fuel consumed by the TQGs in the Control Camp. Considering that the HMMWV engine is not designed nor optimized for steady-state operation like the engines in the MEP-805Bs, the capability increase validates the comparison. **On 15 Oct, the OBVP/TVGM was switched to Low-power mode (with reduced engine speed) and the fuel savings was considerable, 6.2 gallons for the OBVP vs. 11.8 gallons per MEP-805B.** The TVGM demonstrated its ability to integrate other power sources by running a single 30kW MEP-805B TQG instead of the HMMWV. So with one TQG in the North compared to two in the South, the fuel savings was also significant.

The OBVP/TV2GM tandem is designed to rapidly provide electrical power to a camp or structures while more permanent power generation systems are absent or being installed. The OBVP provides 30kW of vehicle-generated power and the TV2GM intelligently manages the distribution of power from the OBVP and a variety of sources. For this demonstration the OBVP was paired with a MEP-805b 30 kW TQG.

Right-Front View Rear View Cab Interior

Figure 1: OBVP/TV2GM

Soldiers from the 542nd Quartermaster's Force Provider Company, were trained on these power management technologies and provided valuable feedback through a focus group session.

FY16 System Overview

The system uses vehicle 3000 Transmission-Integrated Generators (3TIGs) to produce 600VDC power for use by vehicle hotel-loads (electrification) and off-board loads (tents/shelters, communications centers, or other electrical loads). This effort involves four tactical vehicles; two HMMWVS equipped with 30kW of On-Board Vehicle Power (OBVP) and two MRAPS equipped with a 120kW 3000 Transmission-Integrated Generators (3TIGs) with V2G and V2V capability, four 60kW AC to DC power converters with 600 VDC bus distribution systems and four 22.8 kWh Energy Storage Systems (ESU). Each vehicle is equipped with a Vehicle Communication Module (VCM), which provides the communication capability to transfer up to 100kW of power via the SAE J1772 Combo Connector between vehicles (V2V) and/or for export power off-vehicle (V2G).

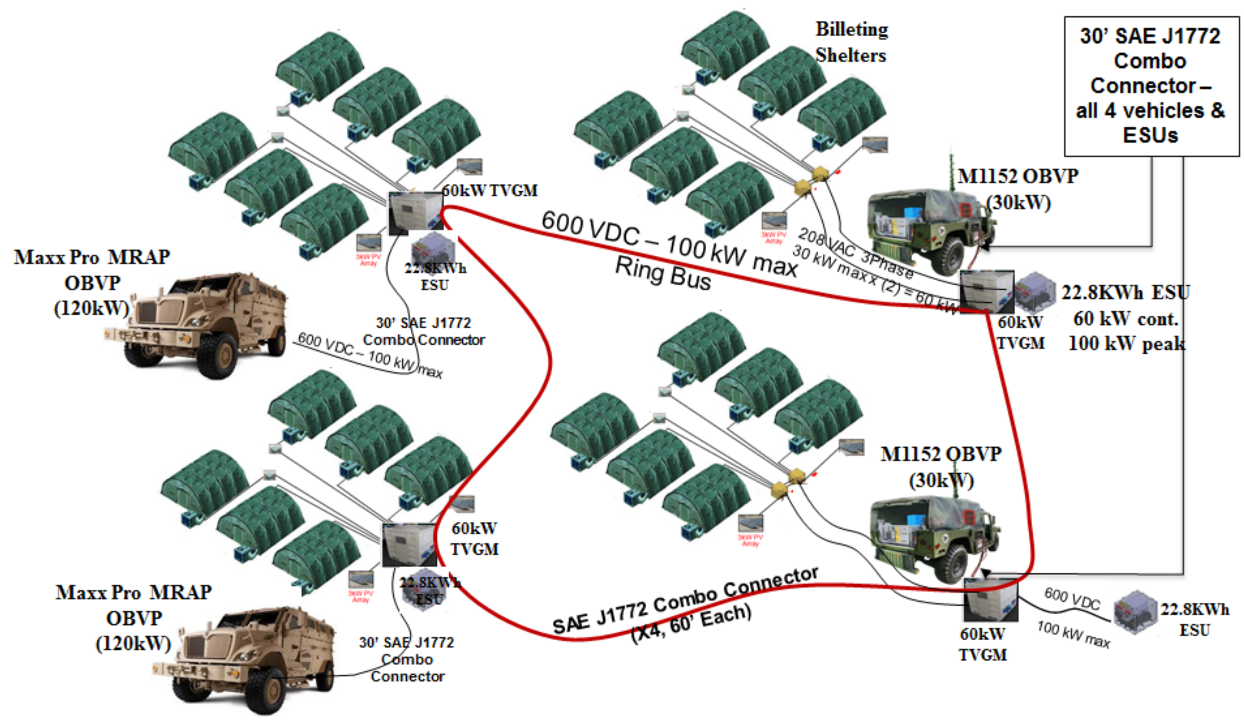

Figure 2: System Diagram

Integrated Program Team (IPT) Stakeholders

Intelligent Power & Energy Research Corporation (**IPERC**): Responsible for delivering the Vehicle Communication Module (VCM), which will be integrated in the vehicles, ESUs and TVGMS (Reference Figure 3). The VCM requirement leverages TARDEC's investment in hardware, software, and bi-directional communication and power standards development used to demonstrate bi-directional, cyber-secure vehicle to grid power management, as a part of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS)) Joint Capability Technology Demonstration (JCTD). The VCM integrates several different SPIDERS demonstrated functions into one compact package. The main functions are data signal conversion, V2V communication networking and bi-directional power flow, and establishing a master/slave hierarchy among all vehicles and grid assets. The SPIDERS JCTD Interface Control Document (ICD) for Electric Vehicle Supply Equipment (EVSE) to Electric Vehicles will be augmented to include V2V communication networking and power flow between vehicles. This communication capability will allow for approximately 100kW of smart power to be used for: vehicle starting, powering vehicle functions such as communications, radar, electrified armor, electric weapons systems, and vehicle mobility (in the event that the stranded vehicle has an electric drive). This new package will provide a single communication package that will accept data signals, determine its position in the communication network, and send data to other communication modules that will assist in determining total power available and where to direct power flow.

DRS Test & Energy Management, Inc.: Responsible with upgrading two OBVP-equipped M1152 HMMWVs and two MAXX Pro MRAPs. DRS will upgrade the High-Voltage Direct-Current (HVDC) buses on the two M1152 HMMWVs, from 400VDC to 600VDC, bringing both vehicles into compliance with MIL-PRF-GCS600A. The 600 VDC architecture enables vehicles to participate in grid services when not deployed – saving the Army on energy costs, provides power assurity, maintains vehicle energy storage systems and aligns with SAE standards. The 600 VDC bus (or voltages near 600 VDC) is the emerging standard for the Army. DC is much easier to use than AC because it does not require synchronization or phase-sequencing like AC does when connecting multiple power sources to a given load. TARDEC is pushing for a common 600 VDC BUS, which will enable V2V capabilities similar to the NATO 24 VDC slave connection but provide for high-power (100 kW) to power vehicle systems (communication, radar, force-protection) future ground-platform hybridization, and vehicle electrification of engine parasitic loads. As the Army is moving away from spot-power generation, the Roll-up, Roll-away V2G/V2V system moves the Soldier in that direction. DRS will also, integrate a Society Automotive Engineer (SAE)-J1772 Combo, with bi-directional DC power capability, an integrate the VCM and add variable engine speed to both M1152 HMMWVs to enable the system to vary the engine speed proportionally to power demand for stationary operation.

Navitas: Responsible to deliver four Energy Storage Units (ESU), each equipped with a 22.8kWh A123 lithium-ion (Li-Ion) Core Battery Pack, high voltage 60kW continuous (120kW peak) DC-DC converter, VCM and cooling unit.

DCS: Responsible for supplying four 60kW Tactical Vehicle Grid Modules (TVGMs), each with an integrated VCM, bi-directional capability and the ability to demonstrate system parallel-ability. Each TVGM will be able to communicate with one V2G capable vehicle, one ESU and two TVGMs via the SAE-J1772 Combo Connector (Reference Figure 3). The TVGMs will accept 600VDC from the vehicles and convert the 600VDC to supply FOBs with the required Three-Phase (3Ø) 120/208VAC power.

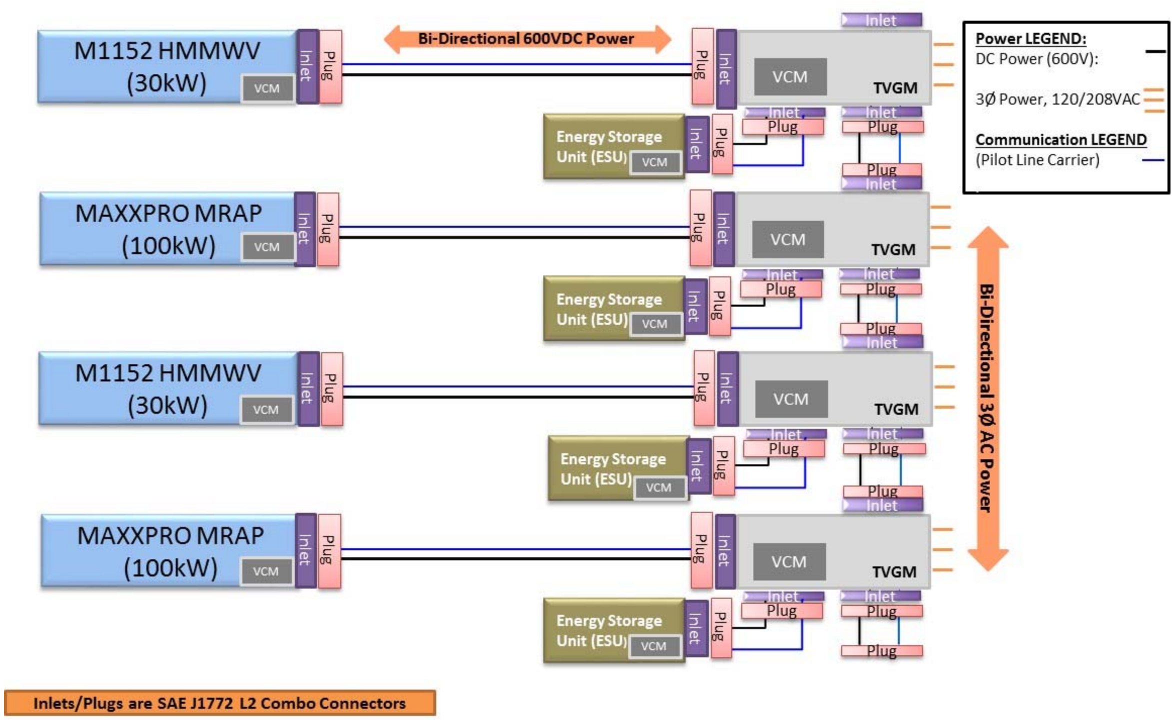

Figure 3: Demonstration Set-up

TACTICAL QUIET GENERATORS (TQGS) VS. V2G/V2V SYSTEM

The system gives Soldiers the capability to supply up to 240kW of vehicle-sourced power in mission-flexible configurations to FOBs within 20 minutes of arrival (Reference Figure 4). Present doctrine builds in a three day delay for arrival of TQGs. Soldiers will now travel with their power sources rather than wait for them. The system we are providing is plug-and-play. Connect the wires and push the start button. Everything in our system establishes communication, self identifies, self-adjudicates, authenticates, and then operates. TQGs require more work to connect and operate.

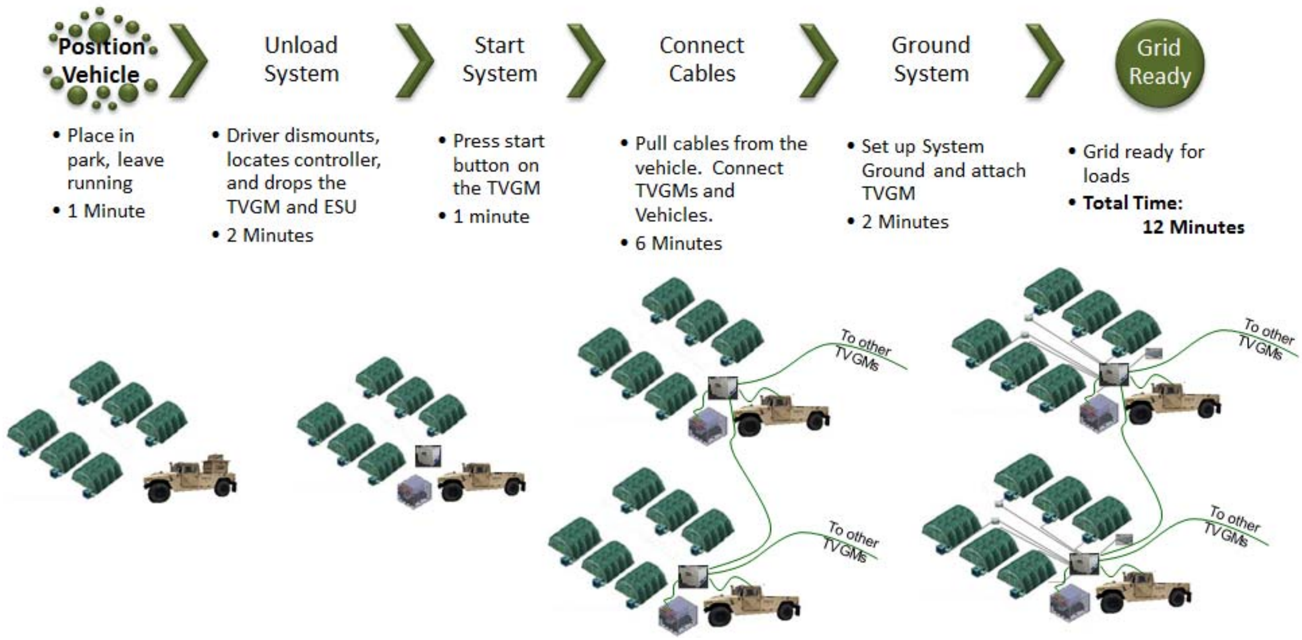

Figure 4: System Set-up Time

Regarding Cost: In volume, the cost should be extremely competitive with a TQG. Vehicles will already be generating the DC source, adding DC export is about $1000. Commercial power conversion costs approximately $75/kW. With all the TVGM switches and militarization a likely cost per kilo-watt is $300/kW. Using this cost per kilo-watt a 60 kW to converter would cost $18,000 which is on par with a commercial Generac Guardian 60 kW generator.

Regarding cost of operation: TQGs run at a constant 1800rpm, regardless of load, generating a 3Ø AC voltage (either 120/208V or 240/416V). OBVP and 3TIG-based generators operate at variable engine speeds, slowing down under light loads to improve efficiency. Our system also leverages energy storage much like a hybrid vehicle does to improve system efficiency. Between the variable-speed operation and energy storage a 20+% reduction in fuel consumption will be realized. The Fort Devens TECD 4a FY14 testing of the HMMWV/OBVP w/TM3 converter showed that slower engine speeds provide a two to one reduction in fuel under lightly loaded conditions versus TQGs.

MODELING AND SIMULATION (M&S)

The electric power system is an enabling infrastructure that supports the continuous operation related to different mission critical facilities, both at the component level and the system level. There is a need to build an extensive library of V2G/V2V components in the simulation environment. This includes the development of adequate models for simulation of a variety of distributed generators and short term storage, including the corresponding control and power electronic interface. Without M&S, a piece of a complex system, when integrated, may not perform as anticipated, which will require rework to portions of the systems. A generic model is preferable to enable the integration of control strategies. Dynamic loads are modeled as well as constant electrical loads. The MATLAB/Simulink models each components of the system and is able to describe their steady-state and dynamic behaviors. The transient responses are analyzed as well.

The modeling and simulation portion of this work involves a modeled system of the V2G/V2V using the SimPowerSystems toolbox in the MATLAB/Simulink environment. The model of four main physical components will be developed and will include: generators (power sources), DERs (energy storage units), loads (power draws), contactors (control switches for the power circuit for generators and loads), and vehicles, which can dynamically act as either power sources or power loads, depending on their states and the state of the microgrid. The model will be utilized to understand the system performance and control based on three layered architecture control loops –current, impedance and voltage. The V2G/V2V model will be utilized to understand the system performance and control. The model will use a Direct Current (DC) three level Hierarchical control loops approach - current, impedance and voltage, similar to the DC microgrid [1]. The primary loop uses an impedance feedback loop to control the power percentage for each electrical source so that each source carries its share of the electrical load. The secondary control handles differences in voltage to the microgrid. The tertiary control, controls power from the microgrid to the electrical distribution system. In addition, the model will be used to develop and design energy efficient vehicle coordination control system. This simulation will track two main parameters to characterize the resultant behavior over the simulated time period: fuel consumption and number of failures.

The main objective is to model and simulate the system and to evaluate, and analyze the energy efficiency and fuel consumption for various scenarios. The results will be compared to a system performance supported by Tactically Quiet Generators (TQG). This system model will be verified and validated with V2G/V2V loading scenarios. Since this is a new FY15 effort, the results will be known at the end of FY 15.

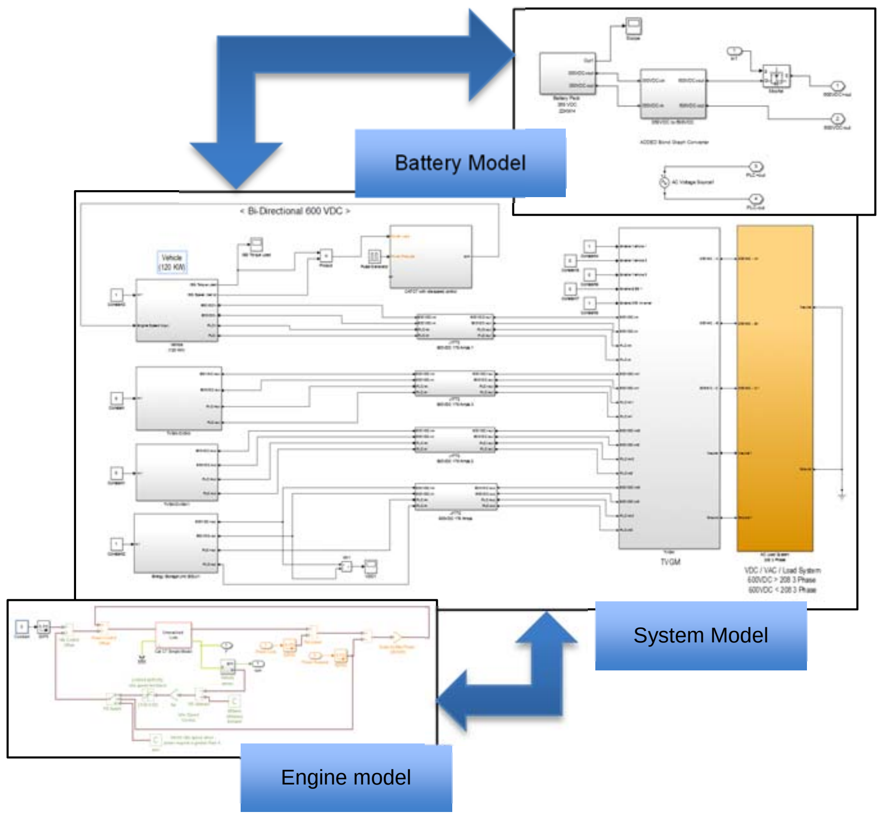

Figure 5: Generic diagram of the V2G/V2V system model including battery and engine model

SUMMARY

The objective is to develop Roll-up/Roll-away vehicle based microgrid system with cyber secure bi-directional power/communications management and grid services. The FY16 V2G/V2V will demonstrate

- On-board power generation from an ISG used for export power
- Vehicle export power used to support emerging microgrid
- Very fast aggregation of multiple vehicle assets for power supply, 240 kW AC power supply < 20 minutes
- Base Power Fuel Reduction: 20% fuel usage reduction utilizing energy storage
- Vehicle to Vehicle power to support high power systems
- Microgrid to Vehicle power to support high power systems
- Ad-hoc microgrid forming/operation in a dynamic environment
- Vehicle based grid services used to reduce the number of generator assets required to support nominal load
- Ability for Army vehicle assets to provide value a greater percentage of the time when deployed or stateside

REFERENCES

[1] J. Guerrero, J. Vasquez, J. Matas, L. de Vicuna, and M. Castilla, “Hierarchical Control of Droop-Controlled AC and DC Microgrids – A General Approach Toward Standardization”, *IEEE Transactions on Industrial Electronics*, 58(1), 2011.