2015 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER & MOBILITY (P&M) TECHNICAL SESSION
AUGUST 4-6, 2015 - NOVI, MICHIGAN

STUDY OF THE STRYKER VEHICLE WITH APOP (ADVANCED PROPULSION WITH ON-BOARD POWER) USING MODELING AND SIMULATION TOOLS

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ABSTRACT

Military ground vehicles need greater electrical power generation to address continually increasing power demands due to various loads, e.g. advanced communications equipment, jamming equipment, electronic armor, and electronic weapons system. More electrical power is also required for electrification of auxiliary systems (steering, cooling fans, HVAC, and pumps) to improve system efficiency - currently driven mechanically. Electrical equipment can be powered from the 600 volt DC bus power supply or from the conventional 28 volt DC bus depending on size, cost, weight, cooling, performance, and cooling impact. Appropriate power electronics converters (dc to dc, ac to dc, dc to ac) are used to manipulate the DC source to drive equipment on the Stryker APOP electrical system. These devices are highly efficient and should lead to the reduction of parasitic losses. With the above in perspective, the US Army RDECOM-TARDEC, GVPM (Ground Vehicle Power and Mobility) has been pursuing the APOP (Advanced Propulsion with On-Board Power) project which is being implemented in the Stryker vehicle. This paper describes the effort related to modeling and simulation (M&S) in order to study the effect of having the higher power generator and the engine, together with the newly introduced electrical loads in the APOP vehicle and how the overall vehicle behavior is impacted.

INTRODUCTION

In order to study the effect of having the higher power generator and the engine in the APOP Stryker vehicle, together with the newly introduced electrical loads, TARDEC GVPM and the Analytics Departments are currently engaged in modeling and simulation (M&S) of the Stryker vehicle with APOP. The effort starts with information of the drive cycle or terrain on which the vehicle is driven, the engine and vehicle mechanical system model, leading to computation of mobility or traction power involved. Any remaining power in the engine, based on the engine operating point derived from the engine map, can then be utilized for additional electrical power generation needed for vehicle electrification by running the ISG (Integrated Starter Generator). The electrical side of the APOP vehicle is also modeled to study the system behavior. This will initially include simplified models of the ISG, battery, various power electronics converters, and loads. All these subsystems will be under an overall supervisory control, which will issue appropriate commands to various subsystems as needed. This supervisory control system will also be modeled and interfaced with the rest of the M&S environment.

The M&S effort will allow us to study the overall system behavior under different drive cycles and different electrical load conditions. In later phases it will also allow identifying any potential issues related to control, stability, and any other unforeseen issues which could be then be addressed in the physical vehicle. M&S will also allow adjust various control parameters and try different control options to run the vehicle most efficiently, thus enhancing fuel economy. This article describes the M&S effort indicated above.

Further extension of the above effort in the future can initially involve replacing one or more of the modeled system by actual hardware, automated generating of controller software codes by using software tools, and using these codes to control the actual system hardware in a HIL (hardware in the loop) environment. This will allow quick modification of software involved in controlling the system, thus reducing development time. It is expected that the above effort in the future can also be extended to other line of military vehicles besides Stryker, with the objective of higher fuel economy and better performance in all lines of vehicle platforms.

APOP STRYKER VEHICLE ARCHITECTURE

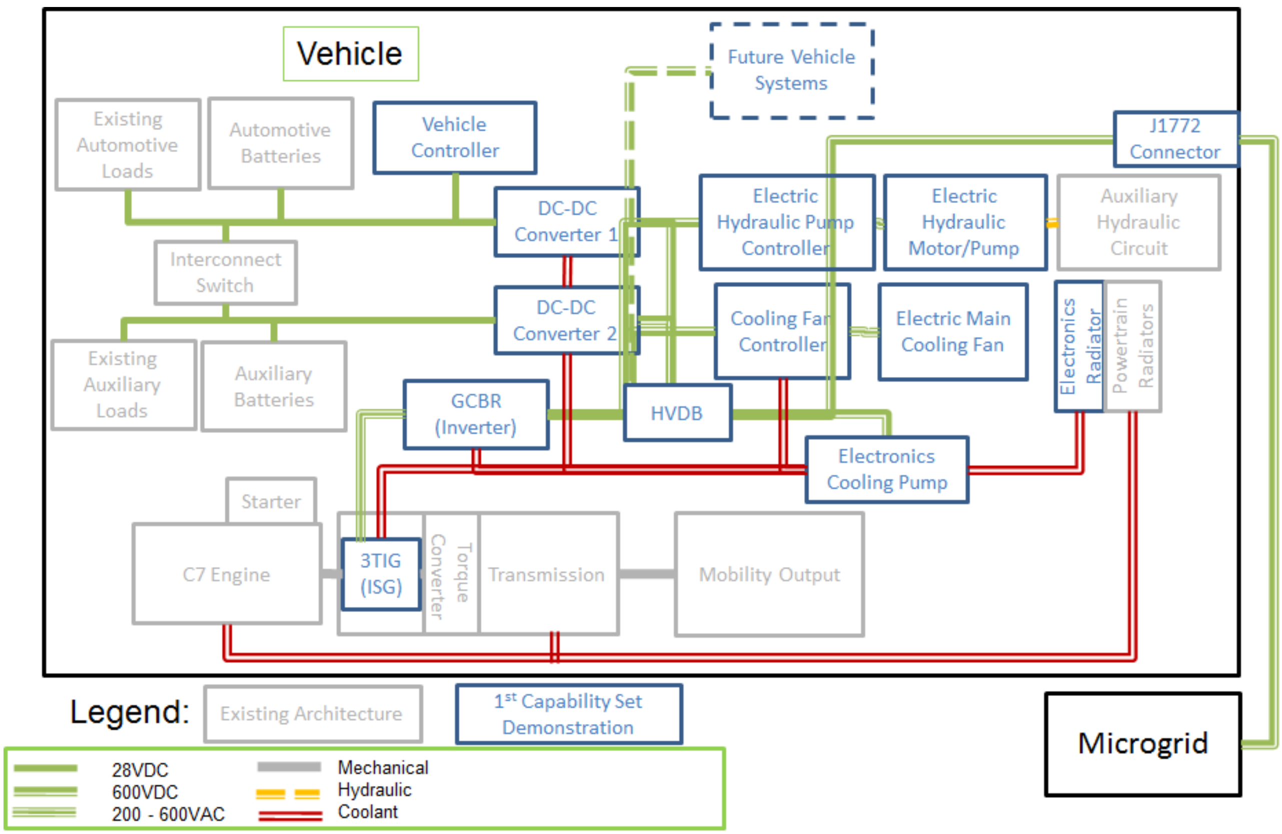

Figure 1. Stryker APOP Vehicle System Level Architecture.

Figure 1 shows the overall architecture of the Stryker vehicle. As can be noticed, this diagram indicates significant amount of added electrification compared to the legacy vehicle. Introduction of high voltage, replacement of the main engine radiator fan with a high voltage electrically driven fan motor, and finally the introduction of high voltage integrated starter generator, along with a number of dc to dc converters, and all associated controllers, make this vehicle different from its legacy counterpart. In addition to the above, the engine used in the vehicle is a Caterpillar CAT C-7, which can potentially meet the needs of the traction and also added electrification.

As noted earlier, introduction of electrical components to replace the mechanical components, leads to higher efficiency, which is the main motivation of electrification.

Specifications of Few Important Components

The vital components of the APOP vehicle is the high power engine, ISG, dc to dc converters, battery, and high power fan motor, along with any future potential high power loads. The technical specifications of the existing items are given below:

Caterpillar CAT-7 engine: 350 hp.
ISG – 600 volt, 120 kw.
Fan motor – (permanent magnet motor), 36 kw
dc to dc converter – 2 identical converters, rated 10 kw in up convert mode, and 8 kw in down convert mode
Batteries – 4 identical Hawker sealed lead acid batteries, each 12 volt, 120 amp-hrs. 2 of these are connected in series to get 24 volts, and 2 such sets are connected in parallel.

MODELING AND SIMULATION

One of the important aspects that GVPM is currently engaged in, relates to M&S of the architecture indicated in Figure 1. The intent of the work is to initially study steady state and macroscopic behavior of the APOP vehicle under various operating conditions. This includes simulating the vehicle operation in different drive cycles or course in the Aberdeen Proving Ground (APG), and also under different electrical load conditions.

Figure 2 shows the M&S architectural flow diagram for the vehicle system controller. This implies managing the overall system from the time when the vehicle operator starts the engine, followed by initiation of the operation of dc to dc converter, ISG, monitoring the accelerator position, monitoring the engine map, monitoring the ISG map, controlling (i.e. turn on/off) various loads, both high and low voltage items. The overall organization of the algorithm is based on Figure 2. In Figure 2, the area bounded with red dotted are related to mobility (traction, engine, transmission etc.). Remaining portion relates to overall vehicle control and management.

The engine map was created by using test data for Caterpillar CAT-7 engine in TARDEC-GVPM labs. Engine map basically implies relationship between throttle or acceleration state and engine power at different engine speeds. Similarly the ISG map was based on tests done in labs and it is a relationship between the ISG efficiency and power at different ISG speeds.

The M&S proceeds as follows: based on the throttle or accelerator condition, and knowing the engine speed, a corresponding engine power is found out from the engine map. This is followed by a computation of the total electrical loads which are "on" at a particular time. Total electrical load includes both high and low voltage loads. Some of the low voltage loads may sometimes be energized only by the battery, which is not the normal situation. In general the high voltage from ISG will be used for: (a) delivering the high voltage loads, (b) delivering the low voltage loads by down converting the high voltage through a dc to dc converter. (c) low voltage load can include charging of the low voltage batteries as well.

Once the total electrical load on the ISG is known, the ISG map is used to compute the corresponding efficiency, which then gives the corresponding engine power needed to drive the ISG. This engine power is then translated into a corresponding accelerator or throttle position, based on the engine map, which is then passed to the engine and mobility system model.

Challenges involved in the control system

In the APOP vehicle one important issue is to make sure that the mobility (or mechanical traction) demand is not compromised under any circumstances. This situation may arise when a heavy electrical load is turned on, while the engine is using most of its power for traction and there is no surplus power to meet all electrical demands. In this case the only remaining option is to shed some electrical loads based on priority. This item related to load shedding has not yet been incorporated in the M&S system described in this paper, mainly due to the fact that various loads and their priorities have not yet been determined and the authors are working towards that.

Additional issues which need to be addressed in the future involve dynamic power management of the overall system including the engine, ISG, and the loads (including the battery). This power management should also include strategies which will take into account the SOC (State of Charge), best operating point at which the ISG will be run, best operating point at which the engine should run (implying that appropriate state of the transmission or gear shift should be used), and use the battery only when it is considered necessary. Such needs could include short time delivering of the high voltage loads by up converting the battery power as well, if deemed necessary. At this time some of these have not been addressed in the M&S algorithm. After the first version of the simulation is tested under different operating conditions, additional features will be added in the future.

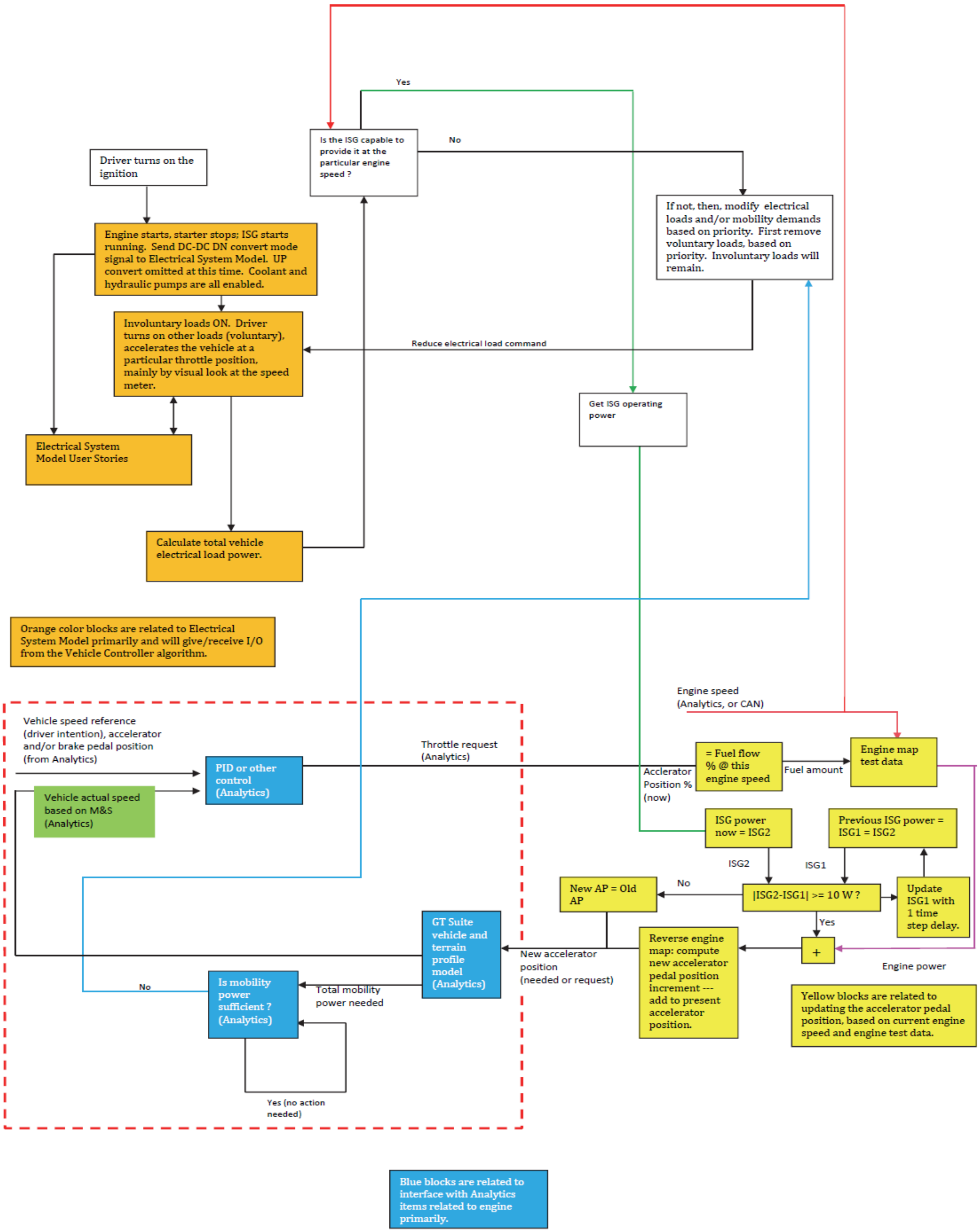

Figure 2. APOP Stryker Vehicle M&S Architecture.

Implementation of the M&S

The system architectures shown in Figure 1 and 2 were implemented by using multiple tools. The engine and vehicular mobility related subsystems were modeled by using the GT-Suite, which also included thermal model for the system. Electrical subsystem was modeled by using Matlab-Simulink software, and some parts of the electrical system were simulated using Simpower toolbox within Simulink. Figures 3(a) and (b) show the top level of the Matlab-Simulink M&S system diagram and the subsystem level vehicle controller architecture for the APOP system.

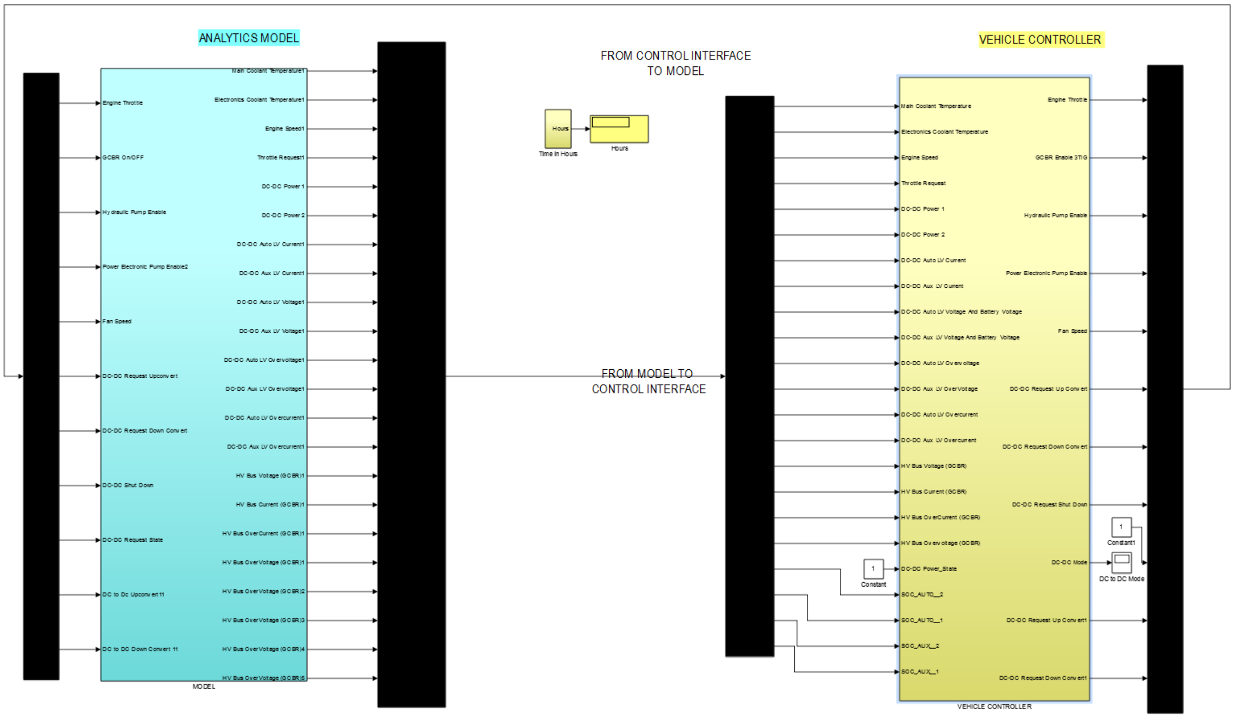

Figure 3(a). Top Level APOP Vehicle M&S Simulation Architecture in Matlab-Simulink

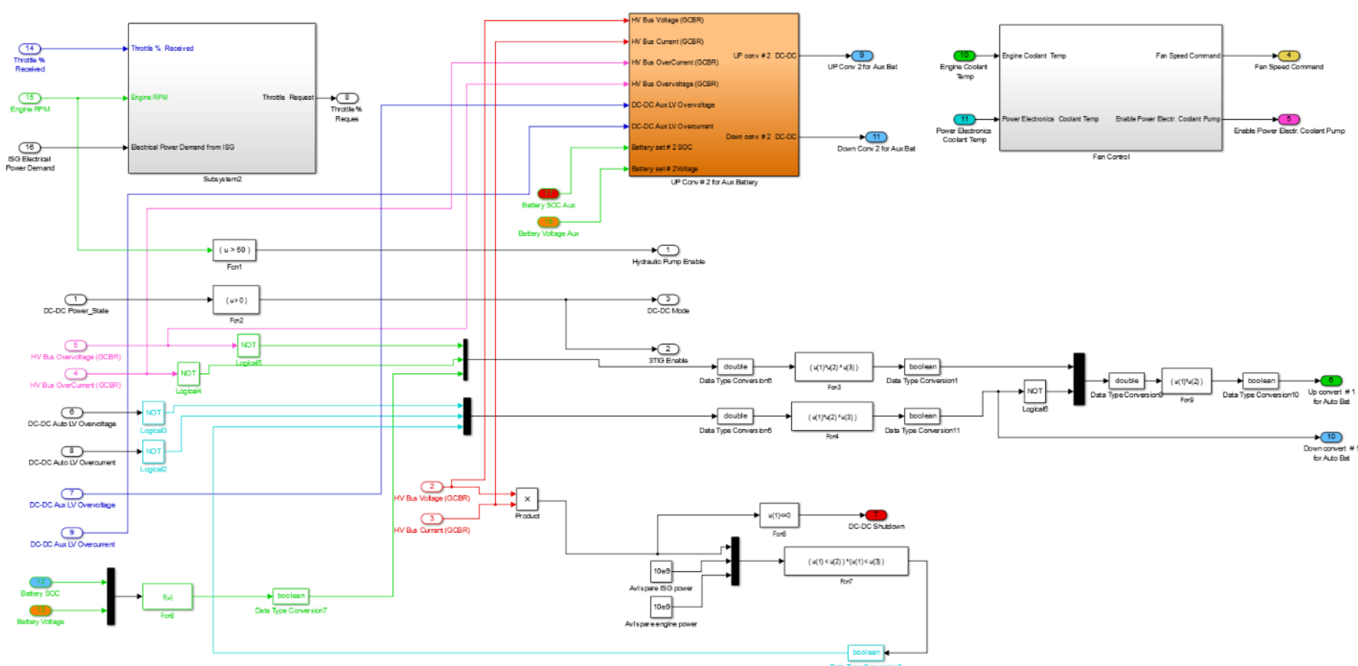

Figure 3(b). Subsystem Level APOP Vehicle Controller Architecture in Matlab-Simulink

Initial Results

Figures 4(a) and (b) show a couple of simulation runs from the vehicle system controller. Here the throttle input (percentage) "received" (second graph in Figure 4(a) implies what was actually ongoing, prior to the initiation of any electrical load change. This includes the throttle amount which is needed due to any mobility (traction) load and electrical load which was existing before the electrical load was changed. The throttle request (first graph in the figure) shows the new throttle amount needed in order to support the change in electrical load demand. The third graph shows the electrical load demand in kw (which was reflected through some equivalent percentage change in throttle demand).

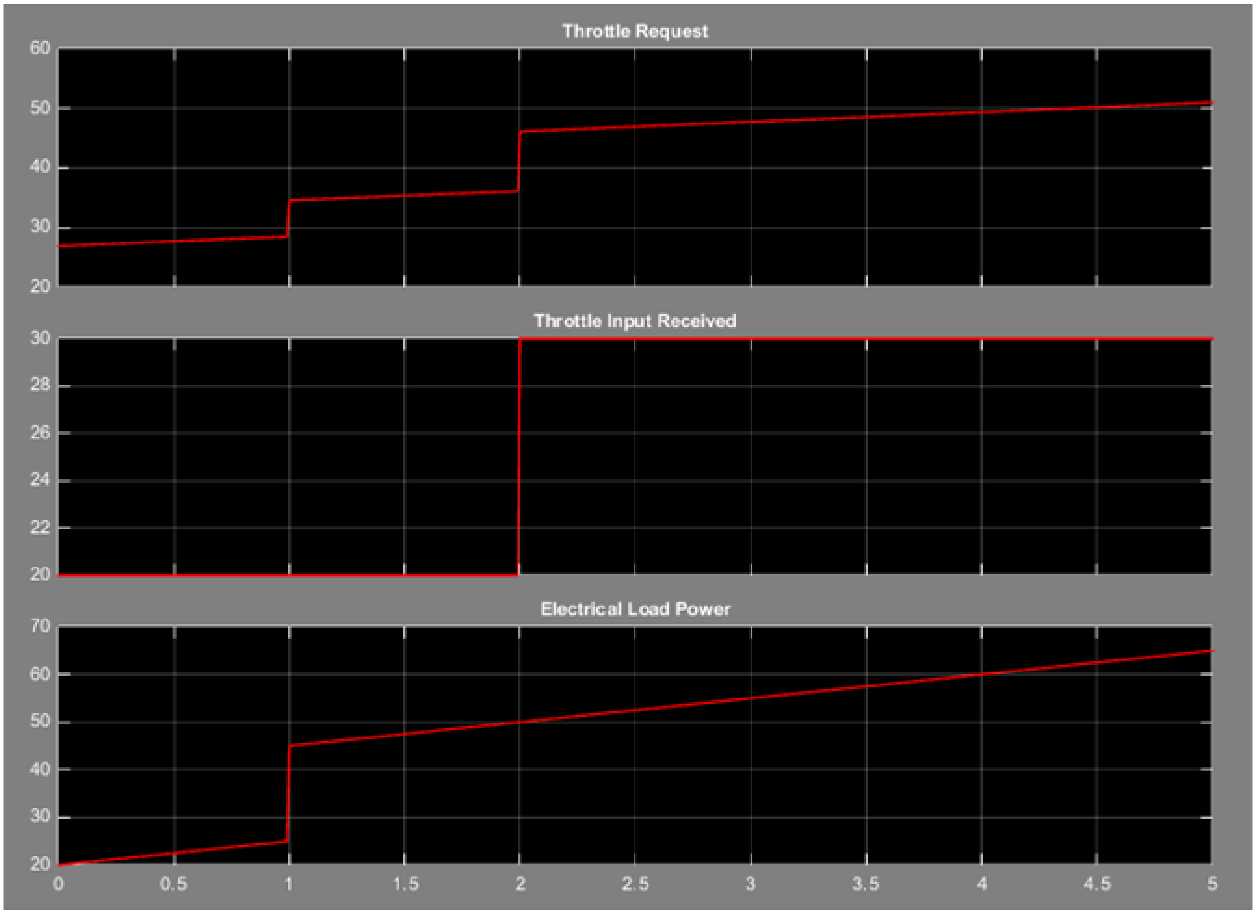

Figure 4(a). Effect of step plus ramp type of change in electrical load on throttle demand, with step variation in throttle input.

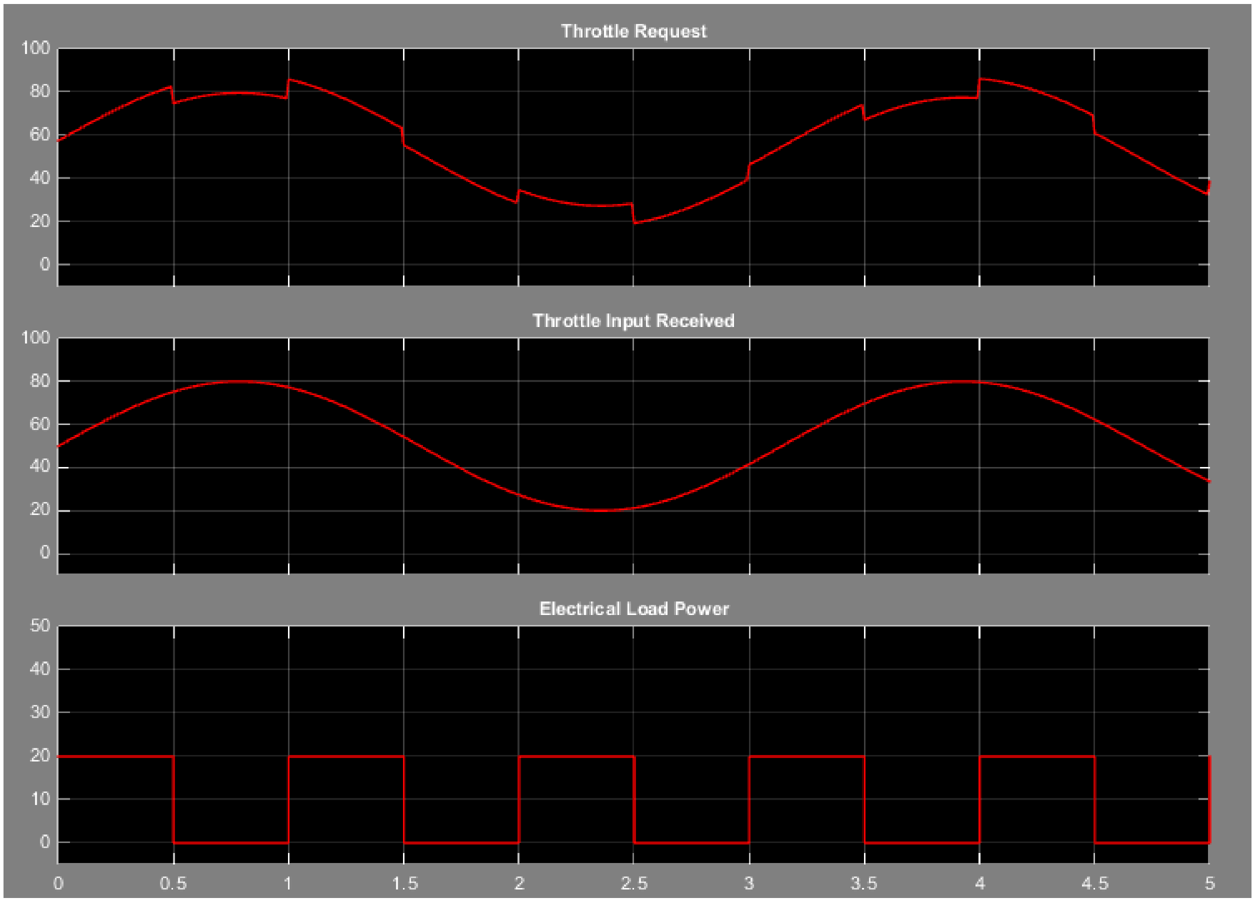

Figure 4(b). Effect of repeating pulse change in electrical load on throttle demand, with sinusoidal variation in throttle input.

FUTURE WORK

Since the M&S work was undertaken very recently, there are quite a few additional activities remaining to be done. These include studies under various driving conditions, dynamic effect of sudden change in electrical load on the mobility (traction) and vice versa, most judicious mechanism to shed load, if at all warranted, and power management to utilize the most efficient operating conditions of the engine and the ISG.

ACKNOWLEDGMENT

The authors greatly appreciate the support received from all levels of TARDEC and GVPM management and associates, and various industry partners involved the fabrication of the APOP vehicle.

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