Development of Design Tool for Hybrid Power Systems of Hybrid Electric Military Combat Vehicles

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***Abstract*— This paper introduces a developed hybrid power modeling and simulation tool for series hybrid electric military combat vehicles. A simulation tool for determining optimal hybrid power in hybrid components such as motor, engine, generator, and storages and for evaluating designed driving control strategy and energy management strategy is essential in designing a hybrid system. The developed tool is based on the MATLAB/Simulink with simple GUI interface. It supports various series hybrid structures of military vehicles, driving cycles, and driving control strategies. It supports two types of analysis methods: a forward facing method and a backward facing method. In this research, in order to determine the motor's power and spec, the developed tool is incorporated with the commercial multibody dynamics software, VirtualLab/Motion developed by LMS International. The objectives of the iterative works between design of optimal hybrid power systems and optimal driving control strategy include reducing the overall fuel consumption and optimizing the mobility performance to cost, mass and volume space claims of the vehicles' power systems, and enabling those vehicles with enhanced electrical power generation and storage capabilities useful for field operations, too. A 20ton 8x8 series hybrid electric vehicle is considered as design example. This paper shows the results of determined hybrid components' power and shows the SOC variation and fuel efficiency for various driving strategies.**

Keywords- series hybrid; military combat vehicle; fuel efficiency; SOC; multibody dynamics

I. Introduction

HE (hybrid-electric) military combat vehicles must have high mobility performance and high maneuverability including skid-steering, trench passing, severe turning stability performance and driving off-road. High power and energy sources are also required in designing the military vehicles for silence driving and all the vetronics including weapon and armor systems. Therefore, the series hybrid architecture is the strongest candidate for the HE military combat vehicles. The reason is that military vehicles must satisfy the given severe requirements and it must drive and have another power source on the battlefield in the case that the battery is fully discharged.

In order to increase the fuel efficiency and energy efficiency of HE wheeled vehicle, the following three strategies can be generally considered: 1) increasing component efficiency, 2) constructing optimal hybrid power systems, and 3) developing optimal driving control strategy for the given vehicle. The driving control strategy is the strategy for optimal power and energy management. Increasing the component itself efficiency is limited by the current manufacturing technology and cost. However the second and the third strategies have lots of margins about improving the efficiencies. Even though the hybrid power systems are designed optimally, different driving control strategy leads to different fuel efficiency and energy efficiency. Since it is nearly impossible to do these works through real experiments and tests using real vehicle, a simulation tool for optimal hybrid power systems and calculating the fuel and energy efficiency is essential. In recent years, lots of physics-based tools such as AVL CRUISE [1], MSC Easy5 [2], LMS International AMESim [3], Dynasim Dymola [4], and MATLAB SimDriveline [5] are available. These physics-based modeling tools are very attractive because it makes easy to create models of even very complicated systems. However, in the case of multi-wheeled military combat vehicles such as 6x6 or 8x8 vehicles, it is relatively hard to use these commercial programs. There are small literatures for designing HE military combat vehicles because of its specialty and limited environment [6~9].

In this paper, a new design tool, STW H-Drive, for series hybrid power systems of military combat vehicles is introduced. The developed tool is based on the MATLAB/Simulink. A simple GUI interface is also developed. Only series hybrid architecture is considered but several variations for series hybrid electric vehicle are taken in consideration for example, in-wheel motor systems and two types of storage systems;

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battery only and battery and ultracapacitor system. Various types of military vehicles are supported such as 4x4, 6x6, and 8x8 wheeled vehicles.

In this research, in order to determine the in-wheel motor power and spec, the developed tool is incorporated with the commercial multibody dynamics software, LMS International VirtualLab/Motion [10].

It supports a lot of commercial driving cycles and it is possible to write or import user defined driving cycle. Another important feature of this tool is to support various driving control strategies and energy management strategies. It is also possible to design user defined driving strategy.

The developed tool has two types of approach for hybrid power system design and calculation of fuel efficiency: a forward facing method and a backward facing method. A new driving control and energy management strategy is evaluated through the forward facing method and quick design for hybrid power components can be done by using the backward facing method.

The objectives of the iterative works between design of optimal hybrid power systems and optimal driving control strategy include reducing the overall fuel consumption and optimizing the mobility performance to cost, mass and volume space claims of the vehicles' power systems, and enabling those vehicles with enhanced electrical power generation and storage capabilities useful for field operations.

II. STW H-Drive Tool

The figure 1 shows the main GUI interface of the developed tool, STW H-Drive M&S tool. The developed tool has 6 steps. The first step is to choose the vehicle type such as 4x4, 6x6, 8x8 and track. The second step is to choose the series hybrid structure type.

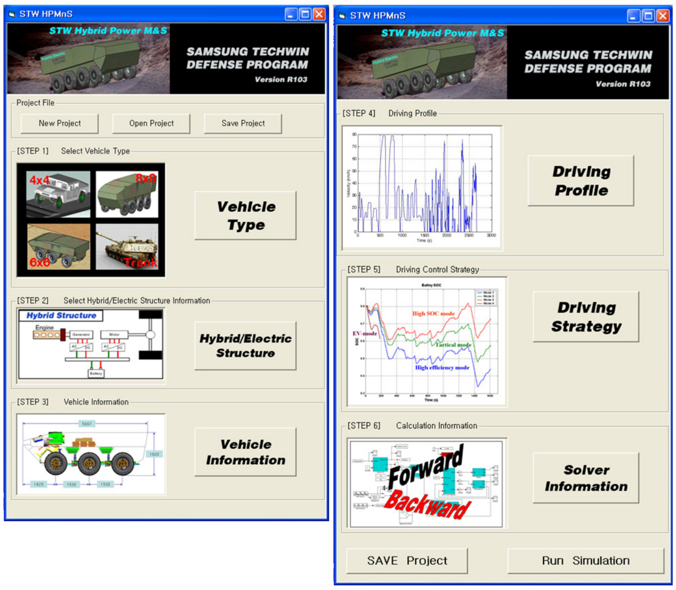


Figure 1. Main GUI of the developed tool

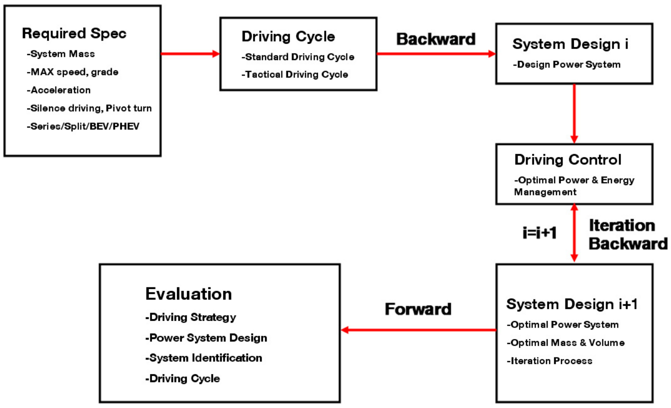


Figure 2. Optimal system design process

The third step is to write vehicle detail information for the calculations for example, maximum speed, cruise speed, maximum allowable slope angle, and various constants and coefficients. The fourth step is to choose the driving cycle. The fifth step is to choose the driving control strategy. The sixth step is to choose simulation type between the forward facing and backward facing methods.

The figure 2 shows the analysis process for obtaining the optimal power system which satisfied with the given conditions, mobility performance to cost, and mass and volume space claims of the vehicles' power systems.

The figure 3 shows the results of STW H-Drive. It gives basically appropriate power and energy components' specs and SOC and fuel efficiency variation information. As a evaluation tool, the developed new driving strategy and a new driving cycle can be evaluated.

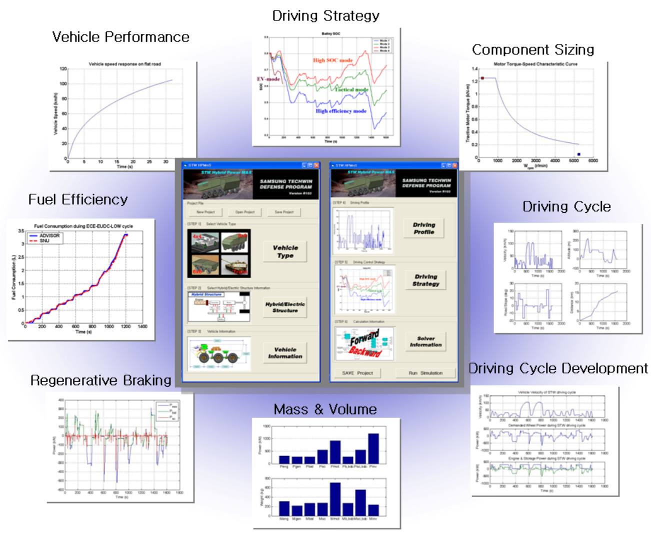


Figure 3. Results and applications of STW H-Drive

III. DEVELOPMENT OF TACTICAL DRIVING CYCLE

The standard driving cycle for the combat vehicle is essential in determining the hybrid power system. The developed driving cycle and profile must represent the assignment that the system satisfies.

The Korean army has also developed this standard tactical driving cycle for the HE military combat vehicles. The figure 4 shows one of standard tactical driving cycles developed.

This driving cycle is composed of the blend of cross-country mode and city driving mode. The grade variation is -23% to +29%. The total driving distance is 15.65 km closed-loop.

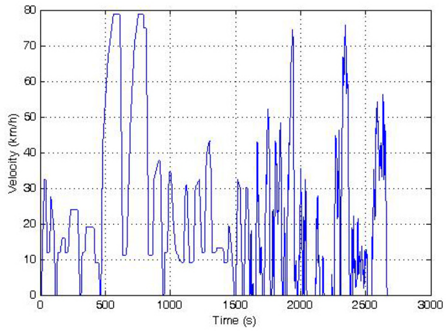


Figure 4. Developed tactical driving cycle

IV. 8X8 COMBAT VEHICLE EXAMPLE

This chapter shows the results of the developed tool for a 8x8 in-wheel series hybrid combat vehicle with battery and ultracapacitor. Figure 5 shows the multibody model of 8x8 test vehicle. Figure 6 shows the MATLAB Simulink model of STW H-Drive tool. Figure 7 shows the results of given driving cycle's information. Figure 8 shows power distributions of the engine and the storage parts which include battery and ultracapacitor. Figure 9 shows the designed storages specs which satisfies the imposed driving strategy and given tactical driving cycle.

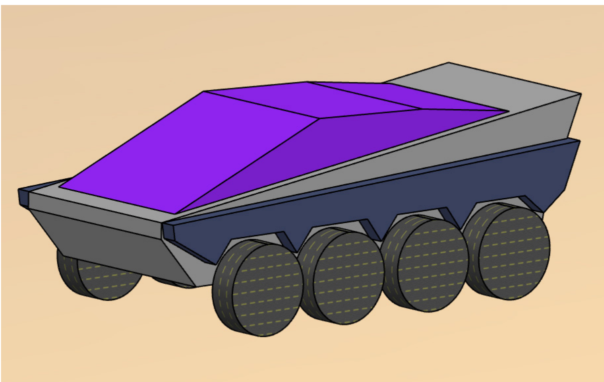


Figure 5. 8x8 wheeled combat vehicle

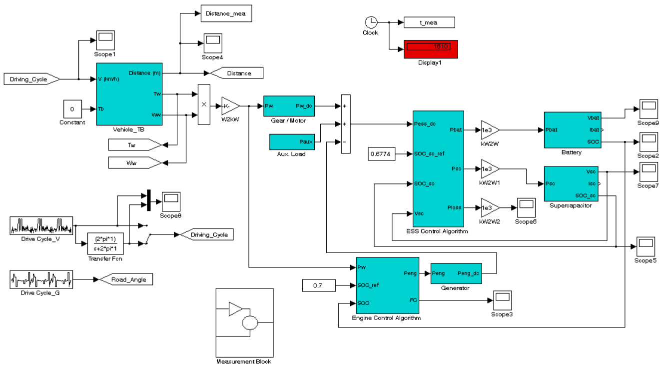


Figure 6. System configuration of 8x8 series hybrid vehicle

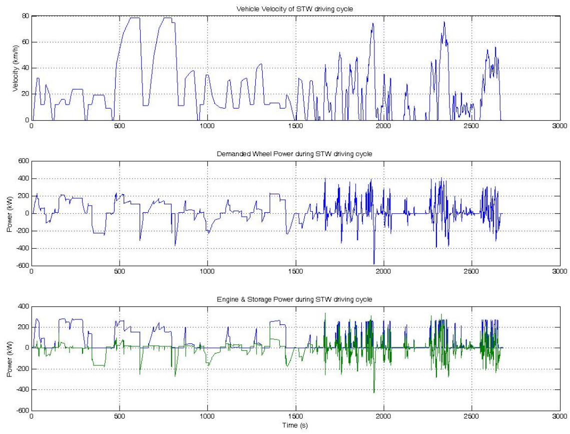


Figure 7. Driving cycle information

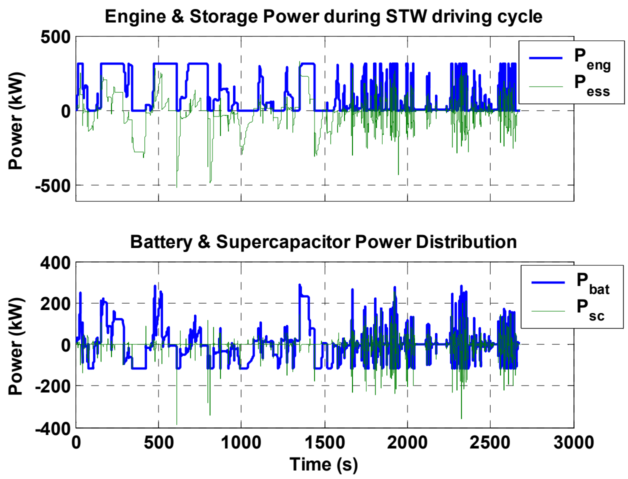
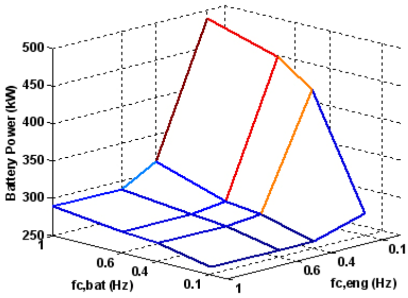
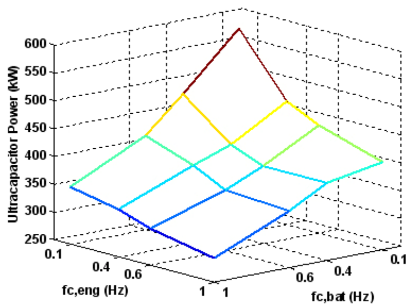


Figure 8. Engine and storages power variation



(a) Battery maximum power



(b) Ultracapacitor maximum power

Figure 9. Storages power

The first step to determine the motor spec is to choose the worst case scenario such as skid-steering, ascending the slope, and maximum speed driving. In order to find the worst case among given requirements for this combat vehicle, this tool is incorporated with the multibody dynamic model from simulated in the VirtualLab/Motion. The ascending the slope with constant speed is turned out the worst case. Figure 10 shows the multibody dynamics simulation results of the 8x8 vehicle when the vehicle run at constant 4km/hr speed on 60% slope. Figure 11 shows the determined motor's spec.

Figure 12 shows the comparison results of 4 different driving control strategies, as follows:

1. High Efficiency Mode
2. Tactical Mode
3. High SOC Mode
4. EV Silence Mode

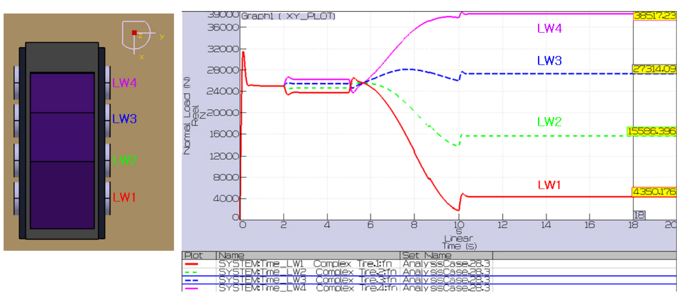


Figure 10. Multibody simulation results

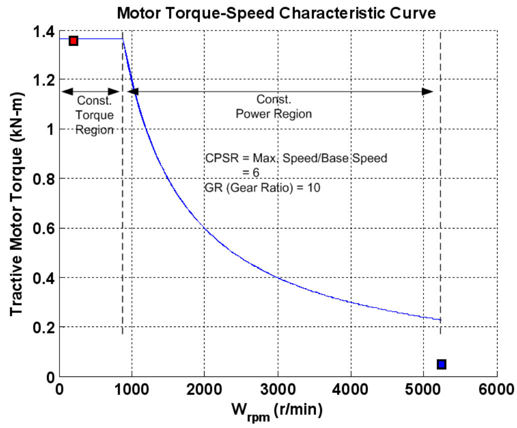


Figure 11. Motor torque-speed characteristic curve

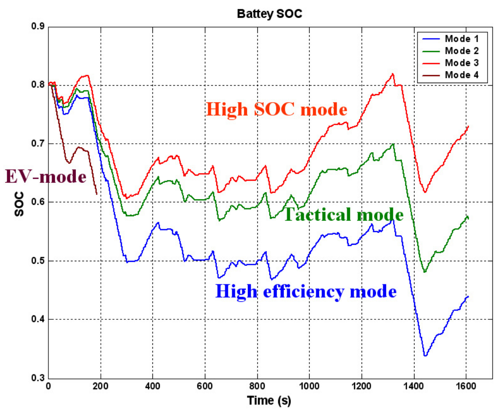


Figure 12. SOC comparison

The first high efficiency mode is a driving mode for obtaining better fuel efficiency. In this mode, 50% of battery SOC region is used and engine on-off strategy is imposed in the case of highway and paved road driving.

The second tactical mode represents combat driving mode. This driving control strategy maintains high SOC (state of charge) level and always considers high power and energy situation.

The third high SOC mode is a prior stage of EV silence mode. In this mode, the system charges battery rapidly up to high SOC level.

The fourth EV silence mode is a EV mode in which the engine is turned off.

V. Conclusions

This paper presents the developed hybrid power modeling and simulation tool for series hybrid military combat vehicles. The developed tool is based on the MATLAB/Simulink with simple GUI interface. It has lots of features; supporting various types of military vehicles such as 4x4, 6x6, and 8x8, supporting various driving cycles, and driving control strategies. The two key roles in design hybrid vehicle of this tool are to determine the optimal power of hybrid components such as motor, generator, engine, and storages and to design the optimal driving control strategy and energy management strategy. Finally, the objectives of the iterative works between design of optimal hybrid power systems and optimal driving control strategy is to choose the best set of hybrid components which reduces the overall fuel consumption and optimizes the mobility performance to cost, mass and volume space claims of the vehicles' power systems and to evaluate the designed driving strategy. A 20ton 8x8 series hybrid electric vehicle example is introduced to shows the results of determined hybrid components' power and shows the SOC variation results for various driving strategies.

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