Optimal Drivetrain Component Sizing for a Plug-in Hybrid Electric Transit Bus Using Multi-Objective Genetic Algorithm[1]

Chirag Desai, *Student Member*, *IEEE*, Florence Berthold,
and Sheldon S. Williamson[2], *Member*, *IEEE*

P. D. Ziogas Power Electronics Laboratory
Department of Electrical and Computer Engineering
Concordia University
1455 de Maisonneuve Blvd. W.
Montreal, Quebec H3G 1M8, Canada
Phone: +1/(514) 848-2424, ext. 8741
Fax: +1/(514) 848-2802
EML: sheldon@ece.concordia.ca
URL: http://www.ece.concordia.ca/~peer/

Abstract–Plug-in Hybrid Electric Vehicles (PHEVs) can significantly reduce petroleum consumption and the only difference from hybrid electric vehicles (HEVs) is the ability of PHEVs to use off-board electricity generation to recharge their energy storage system. The fuel economy of PHEV is highly dependent on All-Electric-Range (AER), drivetrain component size and control strategy parameter. In this study we consider PHEV version of parallel hybrid NOVA transit bus model developed with the Powertrain System Analysis Toolkit (PSAT).A genetic based derivative free algorithm called Multi-Objective Genetic Algorithm (MOGA) is used to optimize conflicting drivetrain and control strategy parameters. The AER, fuel economy, emissions and main performance constraints of the PHEVs will be compared for the initial design and final optimal design.

<u>Introduction-</u> The combination of increasing cost of fossil fuel, it's availability as well air quality issues related to vehicle emissions are driving interest in "plug-in" hybrid electric vehicles (PHEVs). PHEVs are similar to conventional hybrid electric vehicles, but equipped with a larger battery and plug-in charger that allows electricity from the grid to replace a portion of the petroleum-fueled drive energy [1]. PHEVs may derive a substantial fraction of their miles from grid-derived electricity, but without the range restrictions of pure battery electric vehicles. In addition to reducing petroleum consumption PHEVs have the potential to also reduce total energy expenses for the owner and the electric power industry. Existing commercial hybrid

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[2] Corresponding author.

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vehicles have proven to be successful components of the transportation system worldwide. Plug-In Hybrid Electric Vehicles use grid-supplied electricity from diverse domestic energy sources such as renewable, coal and nuclear, and reduce the nation's demand for imported oil.

The drivetrain of a parallel PHEV NOVA transit bus is illustrated in Fig. 1. For modeling and simulation, a NOVA low floor transit bus is modeled using Powertrain System Analysis Toolkit (PSAT) [2]. In a parallel HEV, both the ICE and EM deliver power to the wheel. The electric motor works as a generator either during regenerative braking or absorbing additional power from the ICE, when its output is greater than the required power to drive the vehicle [3]. Ultra-capacitors can also be hybridized with a battery pack, to further enhance the vehicle dynamic performance.

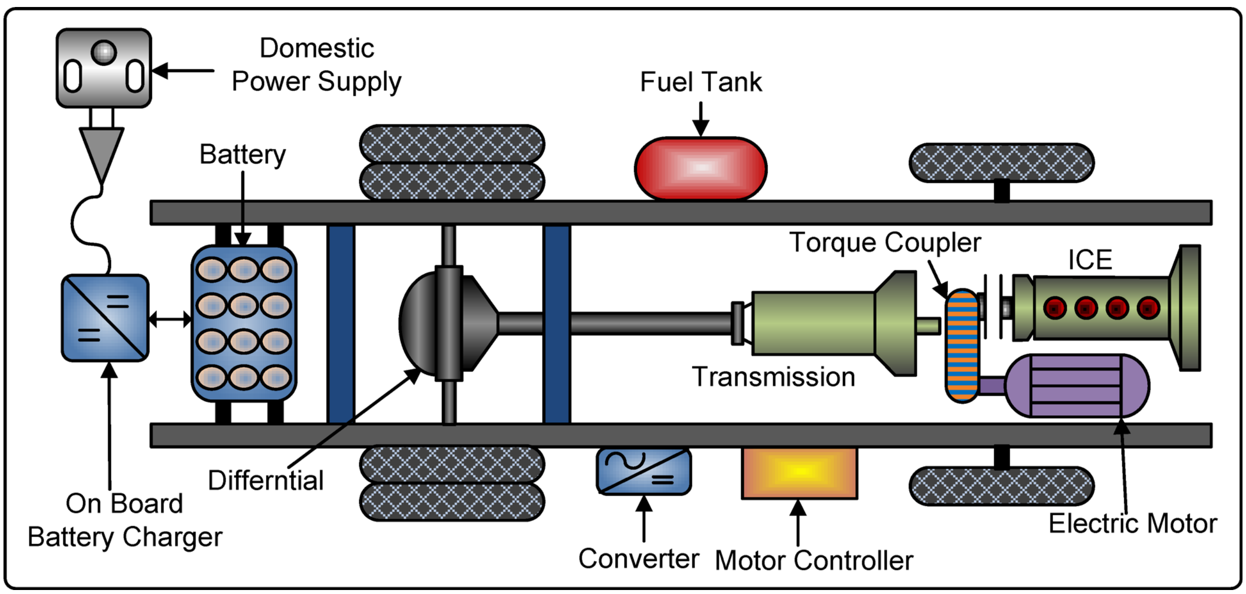


Fig. 1: Parallel Hybrid Vehicle configuration

Lithium-ion (Li-ion) batteries are selected as the energy storage system for the modeled transit bus. Drivetrain component sizing depends mainly on driving requirements of the vehicle. For testing of the modeled NOVA transit bus, the Montreal Pie-IX bus drive cycle (UDDS) using an electric, ESS/motor-dominant blended strategy is utilized. The electric-dominant blended strategy only uses the engine to satisfy the transient load demand beyond the power capabilities of the motor and energy storage. The motor and ESS supply most of the power demand during charge depleting (CD) operation, while the ICE supplies a small amount of additional transient power.

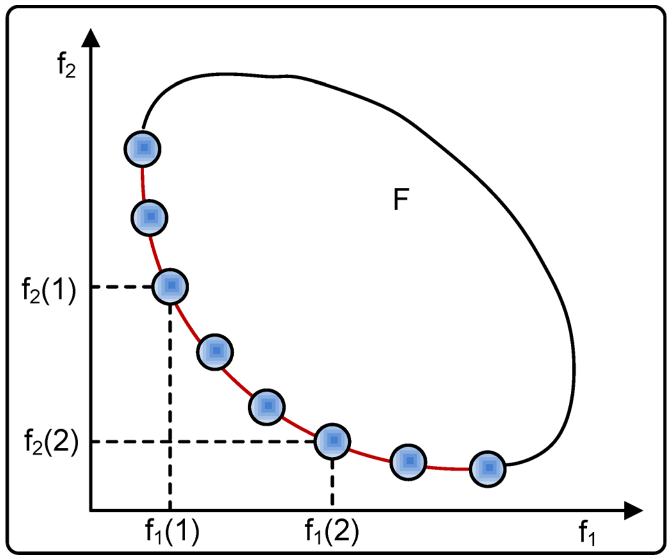
The coordination between drivetrain and control strategy parameters has a significant impact on the operating performance of an HEV. The effects of these design parameters on the objectives are non-continuous and non-convex. Moreover, many performance constraints should also be satisfied simultaneously [4]. Hence, HEV drivertrain component optimization can be treated as a multi-objective constrained nonlinear optimization problem.

Significant portion of recent research work in the field of HEV parameter optimization considers a singular objective, such as drivetrain components or fuel economy or emissions, which are mainly conflicting parameters. Moreover, conventional methods convert multi-objective optimization problems into a single objective optimization problem, by allocating weights to each of the objective functions. Invariably, it is difficult to find suitable weights, capable of accurately indicating practical working scenarios. Hence, conventional methods have restricted capability in exhibiting a real trade-off relationship between the objectives [5].

Various gradient-based algorithms and derivative-free methods of optimization have been proposed, to solve the above mentioned problems. The major drawback of gradient based algorithms is that they are weak in obtaining global optimization. Moreover, these search methods require strong assumptions of the objective function, such as continuity and differentiability, which cannot be specifically assumed for PHEV optimization problems. Genetic algorithms (GA) have been proved to be an efficient, derivative-free approach, to solve design optimization problems [6]. GA is good at searching the global optima, without getting stuck in local optima.

In this paper parameter optimization of plug-in hybrid version of NOVA parallel hybrid transit bus, using newly designed multi-objective genetic algorithm (MOGA) is proposed, considering drivetrain components, fuel economy, AER as well as emissions, as design objectives; a suitable set of vehicle performance criterions represent constraints. Performance of the modeled PHEV NOVA transit bus is evaluated using PSAT. Multi-objective optimization algorithm (MOGA) and PHEV problem formulation are explained in following sections.

Multi-Objective Genetic Algorithm- Most real world engineering problems involve simultaneous optimization of multiple incommensurable and contradicting objectives. Various multiple-objective optimization models have been found in related literature. Classical optimization methods suggest converting multi-objective optimization into a single-objective optimization, by focusing on a particular optimal solution at a time. Adopting such a procedure not only entails repetition of the same process many times, to find multiple solutions, but also lacks high-quality solutions. Therefore, this method has been replaced by pareto optimal solutions. A set of points is said to be pareto optimal, if any improvement in one of the objectives inevitably leads to deterioration of at least one of the other objectives. For a pareto optimal solution shown in Fig. 2, there is no solution which dominates another with respect to all design objectives involved



Genetic algorithms are stochastic global search techniques which mimic the process of natural biological evolution (survival of the fittest). They have been proven to be an effective strategy to solve complex engineering optimization problems, characterized by non-linear, multi-modal, non-convex objective functions. Over the past decade, a number of multi objective evolutionary algorithms (MOEAs) have been suggested, to find multiple pareto-optimal solutions in a single simulation run [7]. Since evolutionary algorithms (EAs) work with a population of solutions, hence, a simple EA can be used to find true multiple pareto-optimal solutions in a single simulation run.

Multi-Objective Problem Formulation for Modeled PHEV NOVA parallel hybrid transit bus

Equation 1 shows the mathematical model of the multi-objective parallel HEV transit bus problem, with 7 variables and 4 objectives.

Fitness function:

f(x) = [fc_trq_scale, mc_trq_scale, ess_cap_scale, cs_off_trq_frac,
cs_min_trq_frac, cs_charge_trq_frac, cs_electic_launch_speed]

$X1 \in [0.3, 1], X2 \in [0.4\ 2], X3 \in [0.2, 3], X4 \in [0,1], X5 \in [\ 0,1]\ , X6 \in [\ 0,30], X7 \in [0, 9]$

Objective Function:

Minimize: {fuel economy; HC; CO; NO_X}

Vehicle Performance Contraints:

Accelartion time $t_1 = 50$ sec;

Gradeability > 10 %

All Electric Range = 20 km

In the above equation, fc_trq_scale, mc_trq_scale, ess_cap_scale, are the scaled factors that decide the ICE, motor/controller, and battery size, respectively. The default values of engine power, motor/controller torque, and battery capacity are multiplied with the scaled values, to obtain instantaneous ICE power, motor torque, and battery capacity.

The full paper will deal with detailed drivetrain optimal sizing using NSGA-II multi-objective genetic algorithm, for a suitably modeled and designed PHEV NOVA parallel hybrid transit bus. Furthermore, the optimization will also consider the most efficient electric dominant control strategy design to increase fuel economy, AER with reasonable cost increment. In addition, System Analysis Toolkit (PSAT) various critical design parameters will be validated.

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