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OPTIMAL SIZING OF PHEV POWER TRAIN COMPONENTS

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Abstract:

Plug-in hybrid electric vehicles (PHEVs) are gaining attention due to their ability to reduce gasoline or diesel consumption by using electricity from the grid as an alternative energy source. This paper deals with the optimization of powertrain component while sizing of a parallel PHEV. The problem is formulated as to minimize an objective function, which is a weighted sum of component costs. The component cost includes the cost of the battery, electric motor (EM), and internal combustion engine (ICE). The powertrain model includes quadratic losses for the powertrain components. Improved Wind driven Optimization (IWDO) algorithm was used for optimality. The result of the IWDO is expected to be the variables of the global optimal energy management for every time instant and optimal component sizes. The proposed method also considers the study of the effect of some performance requirements, i.e., acceleration, top speed, and all-electric range, on the component sizes and total cost.

Key words: Plug-in hybrid electric vehicles, Optimization, Drive Cycle, Wind driven optimization, Component size.

Introduction

In recent years new, eco-friendly, technology within the automotive industry has been focusing on the realization of zero pollution and the development of green vehicles by increasing system energy efficiency and significantly reducing exhaust emissions.

Nowadays, V2G, the bidirectional connection between vehicle and smart grid application, is the most important application for all the countries because of the high CO_2 emission. According to global EV outlook 2017, the on road CO_2 emission caused by the conventional vehicle (CV) which is propelled by an internal combustion engine (ICE) diesel and gasoline is very high between 2015 and 2030. As a result, the word will suffer to insupportable global warming from the transport sector. In addition, the increase of fuel cost caused by the limited coexist fossil sources, lead to the green energy sources as a solution. All these factors explain the potential growth up of electric vehicle (EV) in many countries [1,2].

Plug-in hybrid electric vehicle (PHEV) is a modified version of a Hybrid electric vehicle (HEV) in which the vehicle has a larger battery pack that can be charged by external sources e.g., home electric outlets, and by internal sources such as regenerative braking, and an engine driven generator.

PHEVs are hybrid electric vehicles that can draw and store energy from an electric grid to supply propulsive energy for the vehicle. This simple functional change to the conventional HEV allows a PHEV to displace petroleum energy with multi-source electrical energy. And it has important and generally beneficial impacts on transportation energy sector petroleum consumption, criteria emissions output, and carbon dioxide emissions, as well as on the performance and makeup of the electrical grid. Because of these characteristics and their near-term availability, PHEVs are considered as one of the most promising means to improve the near-term sustainability of the transportation and stationary energy sectors [3,4].

Electric Vehicles (EVs) were introduced as a viable solution to noisy, gas guzzling internal combustion engine (ICE) vehicles. Relying exclusively on electrical energy from the battery system for power, EVs completely eliminate the need for direct fossil-fuel consumption and produce no noise or tailpipe emissions [5]. However, despite these advantages, EVs have not 1made a significant impact on global vehicle markets, where conventional ICE vehicles continue to dominate. This is largely due to the high cost and limited electric range of electric vehicles [6].

PHEVs are essentially HEVs that can connect to the electrical grid and store electric energy using rechargeable batteries [8]. PHEVs have larger battery capacities than HEVs and as a result offer an extended electric range. Therefore, PHEVs offer combined advantages of HEVs and EVs, making them the best solution on the market today [9]. The power train components includes ICE, Electric motor, Generator and Battery pack. Therefore, equipped with a PHEV model in one hand and an optimization algorithm in the other, our aim in this study was to find the optimized sizing for powertrain components with the objective of minimizing fuel consumption. As a result, we have created a framework that integrates a high-fidelity model and optimization technique and can be used to address a broad range of objectives, design variables and constraints [10].

IWDO Algorithm

The step by step procedure for using IWDO is described in the following steps [11].

Step 1: Initialize I-WDO algorithm and problem specific parameters.

Step 2: Define the Objective function for the considered problem.

Step 3: start with initial population i.e. position and velocity randomly with in the search space. Step 4: Obtain the fitness value of each air parcel.

Step 5: The current velocity of the particle should be updated using

$$V_{t+1} = (1-\alpha)V_t - g\,x_t + RT\left|\frac{1}{r}-1\right|(x_{opt} - w_f \times x_t) + \frac{c\,u_t^{other\,\mathrm{dim}}}{r}. \qquad (1)$$

Step 6: Check if there is any violation in velocity limit.

Step 7: The current position of air parcel should be updated using

$$x_{t+1} = x_t + V_{t+1}. \qquad (2)$$

Step 8: Check if there is any violation of position limit.

Step 9: Increase the iteration count and check for the maximum iteration limit has been reached. Step 10: Repeat the steps from 4 to 9 until the convergence condition is satisfies.

Objective Function

The optimization objective function includes the power of electric motor, the number of battery modules, and the fuel consumption. All variables were normalized and weighted to form the objective function as:

$$F(P_M, P_E, N_{BM}) = w1\frac{P_M}{P_{M,max}} + w2\frac{P_E}{P_{E,max}} + w3\frac{N_{BM}}{N_{BM,max}} \qquad (3)$$

Where w_i is weighting factors of the objective function variables. Boundaries have been determined by the dynamic-equation representation of the performance requirements, and the design constraints.

Constraints

Maximum acceleration determines the peak power of the electric motor as:

$$P_{M,max} = \frac{1}{2tf}\,mv_f^2 \qquad (4)$$

The minimum power of the electric motor is determined by the power required to run the vehicle at a constant speed on a road with a gradient slope as C_d

$$P_{M,max} = mgfv_1 \cos\alpha + mgv_1 \sin\alpha + \frac{1}{2}\rho C_d A v_1^3 \qquad (5)$$

The number of battery Modules is determined by the minimum voltage required to run the electric motor as follows:

$$N_{BM,min} = \mathrm{round}\left(\frac{Um,min}{Ub,min}\right) \qquad (6)$$

The peak power required by the electric motor determines the maximum number of battery modules as follows:

$$N_{BM,max} = \frac{Pm,max}{DpmM\eta_T} \qquad (7)$$

The minimum power required from the engine can be calculated with mean cruise speed as follows:

$$P_{E,min} = \frac{P_{M,max}}{D_{Pm}M\eta_T}(mgfv + \frac{1}{2}\rho C_d A v_1^3) \qquad (8)$$

The maximum power required from the engine can be determined by either at the maximum cruise speed or the power required on the road with a slope at a constant speed going uphill as follows:

$$P_{E,max} = \max(P_{E,1}, P_{E,2}) \qquad (9)$$

$$P_{E,1} = \frac{1}{\eta_T}(mgfV_{max} + \frac{1}{2}\rho C_d A V_{max}^3) \qquad (10)$$

$$P_{E,2} = \frac{1}{\eta_T}(mgfV_{max}\cos\alpha + mgVmax\sin\alpha + \frac{1}{2}\rho CdAV_{max}^3) \qquad (11)$$

Where v_1 is speed at 6% grade; V_{max} is maximum cruise speed; V_h is constant high speed; F is the coefficient of rolling resistance; M is the mass of the vehicle; C_d is the air drag coefficient; ρ is the air density; V_f is the acceleration speed; $U_{M,min}$ is the minimum voltage of the battery; η_T is the powertrain efficiency; D_p is the specific power of the battery; m_M is the mass of the battery module.

Proposed optimization methodology

In our approach, IWDO simulation tool to create a framework that can optimize PHEV powertrain components. IWDO is considered an efficient method for optimal sizing of HEV and PHEV platforms. A power-split PHEV was modeled using Prius model 2012 specifications. P_E, P_M, and N_{BM} denote the engine power, motor power and number of battery cells, respectively. The initial points of the power train specifications are given in below table:

Table 1: Initial Powertrain Specifications

Components	Model
Generator	52kW(peak) PM motor
Energy storage	50 Li ion battery
Motor	50kW PM motor
Gearbox	Planetary gear
Engine	57kW Engine

These values were calculated using initial conditions and dynamic equations of the performance requirements.

Table 2: Parameters for test functions

Bound	P_M /kW	P_E /kW	N_{BM}
Lower	30	40	6
Upper	75	85	20

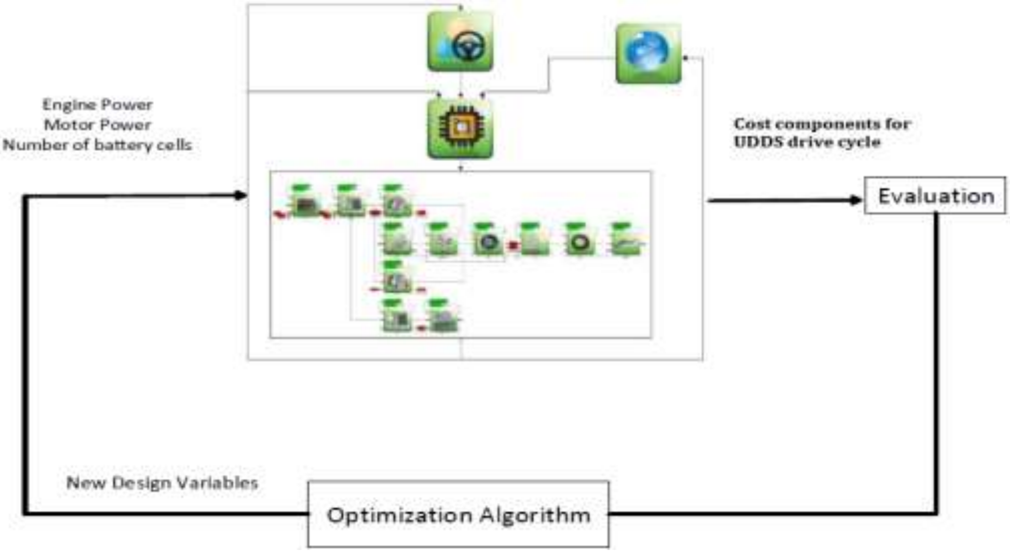


Fig 1: Block diagram

Drive cycle

A driving cycle is a series of data points representing the speed of a vehicle versus time. Driving cycles are produced by different countries and organizations to assess the performance of vehicles in various ways, as for instance fuel consumption, electric vehicle autonomy and polluting emissions.

A driving cycle commonly represents a set of vehicle speed points versus time. An appropriate driving cycle, which properly represents the vehicle behavior, should be selected. The optimization must be run over different drive cycles in order to minimize the fuel consumption across the driving profile. For example, highway driving requires more power and as a result requires larger motor and engine components, on the other hand, driving at low speeds or in urban areas, where frequent stopping, idling and braking is required, does not impose high vehicle performance demands; thus, small engine and motor components would be sufficient to meet performance expectations. In this study, we considered the effect of several different driving cycles, including urban, highway, and a combination of both cycles.

The Federal Test Procedures cycle (FTP) specifications, which characterize the urban driving experience, are given in Table. It is obvious from Figure that during this urban cycle, which has a maximum speed of 96km/h and total distance of 17.77km, the vehicle could be propelled by power derived from the motor and batteries, with very little input from the engine. Therefore, we used a multiple of this cycle in order to achieve nonzero fuel consumption.

Table 3: FTP Characteristics

Description	Value
Total Time	2477s
Distance	17.77km
Average Speed	42.2km/h
Max Speed	91.2km/h
Max Acceleration	1.47m/s^2

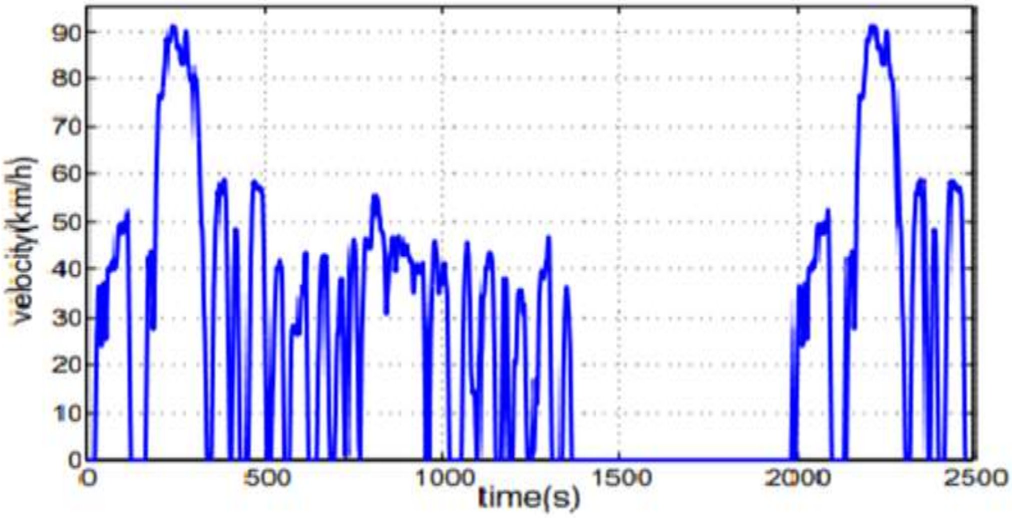


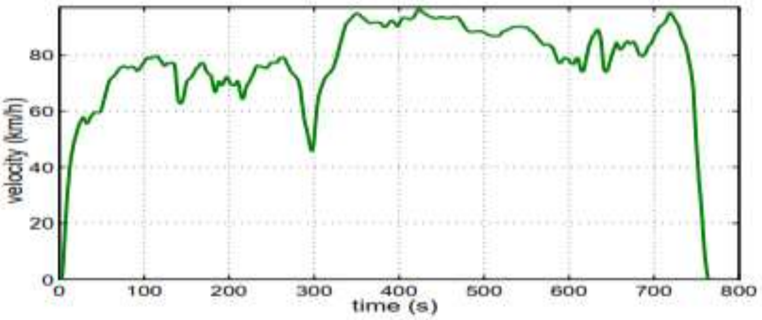
Fig 2: FTP drive cycle

The Highway Fuel Economy Cycle (HWFET) cycle is a chassis dynamometer driving schedule, developed by the US EPA for the determination of fuel economy of light duty vehicles. The HWFET is used to determine the highway fuel economy rating. The HWFET drive cycle is shown in Figure 3, and the specifications are given in Table 4.

Table 4: HWFET Characteristics

Description	Value
Total Time	2477s
Distance	17.77km
Average Speed	42.2km/h
Max Speed	91.2km/h
Max Acceleration	1.47m/s^2

Fig 3: HWFET drive cycle



Environmental Protection Agency (EPA) is responsible for the protection of human health and the environment. EPA: Provides technical assistance to support recovery planning of public health and infrastructure, such as waste water treatment plants. The EPA drive cycle is shown in Figure 4 to represent combined urban and highway driving cycles. EPA drive cycle characteristics are given in Table 5.

Table 5: EPA characteristics

Description	**Value**
Total Time	2135s
Distance	28.5km
Average Speed	54.8km/h
Max Speed	96.4km/h
Max Acceleration	1.47m/s^2

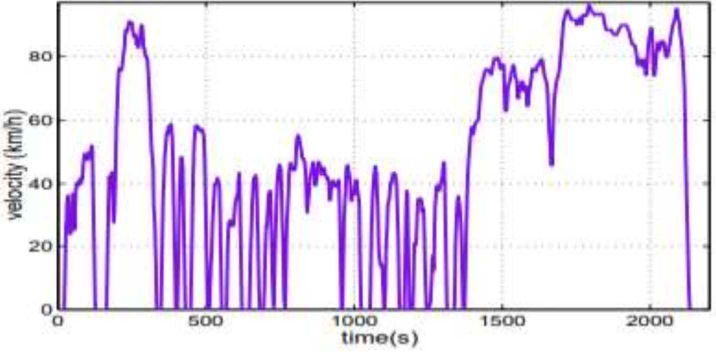


Fig 4: EPA drive cycle

The EPA Urban Dynamometer Driving Schedule (UDDS) is commonly called the "LA4" or "the city test" and represents city driving conditions. It is used for light duty vehicle testing. This cycle should not be confused with the UDDS schedule for heavy-duty vehicles. The EPA UDDS drive cycle is shown in Figure 5, and the specifications are given in Table 6.

Table 6: USSD characteristics

	v/(km.h^{-1})	a/(m.s^{-2})
Maximum	91.25	1.475
Average	31.49	0.505
Standard deviation	23.64	0.450

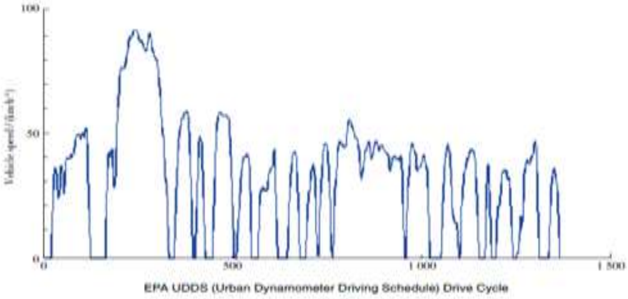


Fig 5: EPA USSD drive cycle

Results:

This constrained problem was formulated and solved using IWDO algorithm. The extremes of the problem and the objective function were implemented together. In addition, the population size for the PSO was set to be 50, the maximum number of iterations 50. The main reason to limit the iterations and population number was the limits in simulation time.

It was considered the existing configuration and component sizing of a Toyota Prius as initial condition. These values are listed in Table 7. The component limit values are listed in respective Tables. These values were calculated using initial conditions and dynamic equations of the performance requirements. Since PHEV's major focus is urban driving, the simulations were obtained using the EPA (USA Environmental Protection Agency) Urban Dynamometer Driving Schedule (UDDS), for 5 times consecutively. The UDDS drive cycle is 12 km in 1 369 s. Table 6 shows the characteristics of this specific drive cycle. Figure 5 shows the driving cycle.

The optimized size of components and the original values of a Toyota Prius are tabulated in Table 7

Table 7: Comparisons of the Component Sizes and Cost Functions

	PSAT default [7]	Optimal with IWDO
P_M / kW	52	58
P_E / kW	57	51
N_{BM}	7	9

In order to validate the configuration that has been found through the optimization process, the default model and the optimized model were simulated in IWDO. The results show a significant improvement in the power of electric motor, power of engine, number of battery modules of the vehicle with the components that were sized by using IWDO optimization algorithm compared to the default configuration of the vehicle model. Thus, the main objective of the study, optimizing Power of the electric motor, power of the engine, number of battery modules has been achieved.

Conclusion:

The meta-heuristic algorithm IWDO was used to determine the optimal configuration of the component sizes. Therefore, a simplified model of a power split plug-in hybrid electric vehicle powertrain was developed for a plug-in hybrid electric vehicle using IWDO. This simplified model was used along with IWDO algorithm to determine the optimal sizes of the major components of the vehicle such as, engine power, motor power, and battery energy capacity. These values were constrained by the performance requirements. The computed optimum component sizes were then implemented on the IWDO model. The simulation results from this new configuration were compared with those from the default IWDO model configuration.

References

[1] Galdi V, Ippolito L, Piccolo A, et al. A genetic-based methodology for hybrid electric vehicles sizing [J]. Soft Computing, 2001, 6: 451-457.

[2] WU Xiaolan, CAO Binggang, WEN Jianping, et al. Application of particle swarm optimization for component sizes in parallel hybrid electric vehicles, IEE Congress on Evolutionary Computation, 2008: 2874-2878.

[3] ZHU Zhengli, ZHANGJianwu, YIN Chengliang. Optimization approach for hybrid electric vehicle powertrain design [J]. Chinese Jof MechEng, 2005, 18(1): 30-36.

[4] LIU Xudong, WU Yanping, DUANJianmin. Optimal sizing of a series hybrid electric vehicle using a hybrid genetic algorithm, Proc of the IEEE, Int'l Conf on Automation and Logistics, Jinan, China, August 18-21, 2007

[5] GAO Wenzhong, Porandla SK. Design optimization of a parallel hybrid electric powertrain, IEEE Vehicle Power and Propulsion Conference, VPPC, 2005: 530-535.

[6] Banvait H, Anwar S, Chen Y. Plug-in hybrid electric vehicle energy management system using particle swarm optimization, The 24th World Electric Vehicle Symposium and Exposition (EVS24), May 13-16, 2009, Stavanger, Norway.

[7] Argonne National Laboratory, US Department of Energy (DOE). Powertrain Systems Analysis Toolkit (PSAT) [EB/OL]. [2008- 01-01]. http://www.transportation.anl.gov/modeling_simulation/ PSAT/tech_info.html.

[8] Banvait H, Anwar S, Chen Y. A rule-based energy management strategy for plug-in hybrid electric vehicle, American Control Conference, June 10-12, 2009, St Louis, Missouri.

[9] LIU Xudong, WU Yanping, DUAN Jianmin. Optimal sizing of a series hybrid electric vehicle using a hybrid genetic algorithm, IEEE Int'l Conf Automation and Logistics, Jinan, China, October 2007

[10] Kennedy J, Eberhart R. Particle swarm optimization, Neural Networks Proceedings, IEEE Int, Conf, 1995, 4: 1942-1948.

[11]. M.S.Syed et al. "Power System Performance Enhancement with FACTS Devices", Journal of Engineering Science and Technology Review, 2022 Vol. 15, No.4, PP: 134-139.

[12]. Maryyeh Chehresaz, 2013, Modeling and Design Optimization of Plug-In Hybrid Electric Vehicle Powertrains, PhD thesis, University of Waterloo, 2013.