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Grey wolf algorithm for multidimensional engine optimization of converted plug-in hybrid electric vehicle

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ABSTRACT

The paper presents the application of grey wolf algorithm for multidimensional engine optimization of converted parallel operated diesel plug-in hybrid electric vehicle to optimize specific fuel consumption (FC) and emissions. All emissions hydrocarbon (HC), carbon monoxide (CO), nitrogen oxide (NOx) and particulate matter (PM) are considered as optimization parameters. Offline engine maps of FC, HC, CO, NOx and PM are generated for 70 hp engine by data obtained from Oak Ridge National Laboratory for study. MATLAB program is used for simulation. A grey wolf coding is developed and tested extensively for various values of speed and torque. The optimization results obtained are verified by available engine maps. The optimization performance and its environmental impact are discussed in detail. It is observed that grey wolf optimizer (GWO) gives the global minimum value with slight deviation, although least computation time and simplicity makes this algorithm a potential candidate for real-time implementation.

1. Introduction

1.1. Motivation and literature survey

The transport sector is the fastest growing consumer of energy and producer of greenhouse gasses, despite advances in transport technology and fuel that have resulted in marked decreases in emissions of certain pollutants. Although a rapid increase in transportation has crossed the emission standard set by vehicle regularity board (Guttikunda and Mohan, 2014). The transport sector contributes 22% of the total CO2 emissions in the world according to the latest estimates from the International Energy Agency (IEA). India stands fourth with CO2 emission in the top 10 emitting countries followed by China, USA and European Union (CIA). 154 out of 168 cities in India does not comply with World Health Organization (WHO) and National Ambient Air Quality (NAAQ) standards. Also, the compound annual growth rate (CAGR) of the total registered motor vehicles in India during the period 2002 to 2012 was 10.5% (Statistical Year Book, India, 2016). Hence urgent attention and steps are required to be taken to reduce emissions of the present vehicle. Considering the available options hybridization of the conventional vehicle can be one of the promising and necessary options in reducing the environmental impacts of automobile use without losing comforts, performance and storage room with the benefit of extended driving range. Compared to available sources, the hybrid electric combination provides better and efficient option which combines an IC engine with the electrical power-driven motor to provide benefits of conventional & electric technologies. Electrification is the best way towards clean and efficient transportation. Hence conversion of a conventional vehicle to hybrid electric vehicle (HEV) or plug-in hybrid electric vehicle (PHEV) can be one of the efficient, viable and better solutions for

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Indian transportation system which has the capability of complying norms and keep emissions under control.

Plug-in Hybrid Electric Vehicles (PHEVs) consist of two power sources, that is, (1) Internal Combustion Engine (ICE) and (2) Electric Motor. Power split (decide operating points of engine and or motor) between these two is of utmost importance to minimize the specific fuel consumption and emission without affecting the vehicle speed. The hybrid electric powertrain itself does not guarantee an improved fuel economy and reduction in emission with a poorly designed Energy Management System (EMS). The task of the EMS is consequently to decide the preferred operating points for the different powertrain subsystems (i.e. set points for the engine and motor as per the state of battery) so that the overall cost of operating the vehicle (specific fuel consumption) and or emissions is minimized. Most of the available energy management strategies consider only fuel economy of HEV (Zhang et al., 2012; Chen et al., 2014; Gong et al., 2008; Wu et al., 2014; Padmarajan et al., 2016; Stockar et al., 2011), even if a small amount of energy management strategies takes into account other performance indices such as emissions (Salisa et al., 2011; Khoucha et al., 2010) and few both emissions and fuel economy (Kum et al., 2013; Nüescha et al., 2014).

It is observed from literature study that most of the strategies are used in optimization with a variety of system parameters for power split of the vehicle to obtain best fuel economy and some with a reduction in emissions. However, after power split, if the engine needs to be operated, there is no contribution from any author on in-depth optimization of all emissions (HC, CO, NOx and PM) of the engine. Hence there is a need of investigating engine which optimizes both fuel economy and emissions. Another need of engine optimization for converted PHEV is the difference in size of the engine. Selection of optimum engine and motor size is possible in PHEV whereas the size of the engine is fixed and high while converting conventional vehicle in PHEV, hence more attention should be on optimization of the engine for minimizing emissions and fuel consumption. Hence in this paper engine optimization is done considering all emissions (HC, CO, NOx, and PM) along with FC. However, FC and emissions minimization are conflicting objectives and hence multi-objective multidimensional problem becomes very complex.

In recent years, swarm intelligence has proven its importance for the solution of those problems that cannot be easily dealt with classical mathematical techniques. Grey wolf optimization (GWO) Algorithm is an evolving optimization algorithm based on social hierarchy and hunting behavior introduced by Mirjalili et al. (2014). The results showed that GWO was able to provide highly competitive results compared to well-known heuristics such as Particle Swarm Optimization (PSO), Gravitational Search Algorithm (GSA), Differential Evolution (DE), Evolutionary Programming (EP) and Evolution Strategy (ES). It has been shown that it can be applied to multimodal and engineering complex problem. Because of its simplicity and fewer control parameters, GWO has initiated much attention and has been used to solve a number of practical optimization problems. Some of the recently reported GWO papers in electrical engineering are in power systems like automatic generation control (AGC) (Mallick et al., 2016), unit commitment problem (Rameshkumar et al., 2016), economic dispatch (Wong et al., 2014), tuning damping controller parameter of unified power flow controller (UPFC) (Mallick and Nahak, 2016), tuning of neural network (Mohamed et al., 2015), fuzzy PID controller for AGC of multi-area power system with TCPS (Lal et al., 2016), maximum power point tracking of doubly-fed induction generator based wind turbine (Yang et al., 2017), placement and sizing of multiple distributed generation in the distribution system (Sultana et al., 2016), MPPT design for photovoltaic system (Mohanty et al., 2016) and weak bus determination with power loss minimization (Raj and Bhattacharyya, 2016). Paper reported on vehicles are unmanned combat aerial vehicle path planning (Zhang et al., 2016) and estimating equivalent circuit parameters of battery (Sangwan et al., 2016). Also, due to its fast convergence capability, it has a strong potential towards use for real-time complex problems. Hence this paper highlights the use of grey wolf optimization algorithm for multiobjective and multidimensional optimization of the operating point of the engine to minimize fuel consumption and emissions for converted PHEV. It decides torque delivered by the engine for the required speed so as to balance all emissions along with fuel consumption. The algorithm is initialized to get feasible solutions and GWO is proposed to get the best solution. This paper is part of work carried out for conversion of the conventional vehicle into the plug-in hybrid electric vehicle by retrofitting means in order to comply emission norms for present conventional vehicles in India.

1.2. Contribution

The paper contributes towards mitigation of emission problem caused by a present vehicle running on the road by application of optimization algorithm to real-world problem i.e. for engine optimization of converted PHEV. The work differs from existing work as below

(1) It considers all emissions- HC, CO, NOx, and PM along with FC as five optimization parameters to optimize the engine, if the engine is required to operate after power split for converted PHEV.
(2) GWO is applied for the first time to optimize the engine.
(3) GWO is modified in initialization to get feasible solutions instead of generating random values and also during updating of best search agents.

The performance of proposed GWO and its environmental impacts are presented in detail.

In addition, it investigates the two recent issues stated in (Zhang et al., 2015) regarding optimization of PHEV: First, development of optimized solution with less computation complexity without compromise of optimization performance and second, overcoming a gap of two main concerns: optimality and implementation issue in designing EMS towards real-time use.