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Analytical and Experimental Study of Micro Gas Turbine as Range Extender for Electric Vehicles in Asian Cities

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Abstract

This paper presents the development of a Micro Gas Turbine (MGT) as range extender (RE) engine for electric vehicles (EV). A computational vehicle model was developed to analyze the impact of driving condition to the driving range of an EV and the sizing of range extender of the REEV, specifically for Malaysian Urban Drive Cycle (MUDC). The simulation shows that the driving range of an EV is greatly reduced when operating in MUDC condition. However, with a RE of as small as 10kW, the REEV could have the driving range which is comparable to conventional internal combustion engine (ICE) vehicle. Following this, a prototype MGT was designed and developed based on a commercial turbocharger and custom built combustor. Experiment of the MGT operating at self-sustaining operating point has been carried out to evaluate the system performance. The experimental data obtained from the MGT test rig is used to validate the computational model, which is the used to further explore the operational capability of the MGT as RE.

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Keywords: Micro gas turbine; range extender; electric vehicles; drive cycles analysis;

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1. Introduction

In the past few years, intensifying effort is shown by automotive industry to push electrical powertrain as part of the transportation matrix in major cities of the world. However, certain drawbacks have hindered a wide deployment of the Electric Vehicles (EVs). For examples, the prolong battery charging time, the lacking of charging facilities especially in most of the developing countries and the limited driving range due to the energy density of Lithium-Ion (Li-Ion) batteries [1], [2].

To overcome the shortcomings of EVs, the concept of REEVs has been introduced. Unlike EVs which purely rely on energy provided by battery pack, REEVs have an engine on board to recharge the battery to extend the driving range [3], [4]. The engine is hence called as Range Extender (RE). In the REEV the traction power is provided by the electric motor only whereas the engine is purely used as electric generator. Its powertrain has two operating modes: the main one is the Charge Depleting (CD) mode in which the battery supplies all the required power for the vehicle (zero emission); the second is the Charge Sustaining (CS) mode in which the RE is activated when the battery's State of Charge (SOC) reaches a low level [5]. REEVs are able to greatly displace the consumption of fossil fuel when operating in CD mode especially when the sources of the electricity production have high energy efficiency and are made of clean energy [6]. During CS mode, REEVs are no longer considered zero emission vehicles. The RE will maintain the SOC in a predefined range until the external charging is available. As the result, the driving range of the REEV is largely extended and is comparable to that of vehicles powered solely by combustion engines.

Since the RE is decoupled from the vehicle powertrain, the use of engine types other than conventional reciprocating engines as RE are hence possible. The examples of the potential alternative engines are fuel cells, rotary engine and gas turbine [2]. In the recent years, there is increasing interest from both research institutions and industries to apply Micro Gas Turbine (MGT) technology in the portable power generation applications [7], [8]. This is due to the advantageous associate with the MGT [9], [10], which it has multiple fuel capability, clean emission, low maintenance requirement and the system packaging can be light and compact. However, commercially available MGTs in the market are costly and the MGT development is time consuming and expensive. On the other hand, there is wide range of commercial turbochargers, which have been manufactured with good reliability. A commercial turbocharger could be a good alternative to build a MGT due to the similar working principal. The conversion of turbocharger into MGT has been discussed and demonstrated by Colin (2011), Visser et al. (2011) and Al-attab et al. (2014). The approach of developing a MGT using a commercially available turbocharger is adapted by the authors to exploit the potential and feasibility of using turbocharger technology in the MGT system.

REEV's powertrain can be designed in such a way that its battery is downsized to a capacity which is sufficient to cover the drivers' daily driving range while its RE has the capability to sustain the battery SOC for occasional long distance driving until the next charging opportunity [2], [4], [14], [15]. Many studies have shown that the driving conditions have significant impact on the REEV's powertrain components sizing [14]–[18]. However, the research work done based on the driving conditions in the Asian cities is scarce. Therefore, the performance of the REEV in this region is unknown and could not be represented by the studies which are mostly based on drive cycles such as NEDC or HWFET.

In this paper, the effort of developing a MGT based RE for the REEVs in Asian cities is presented. The research starts with the drive cycle analysis using an in-house developed vehicle simulator to identify the RE power requirement based on the Malaysia urban driving condition. By using the results from the drive cycle analysis, a turbocharger converted MGT is developed and is tested experimentally. Then, an experimentally validated MGT computational model is used for MGT performance prediction.

2. Drive Cycle Analysis

Drive cycle analysis is a useful method in analyzing vehicles performance in certain driving conditions. In this paper, it is used to study the performance of the REEV especially the power requirement on the RE to sustain the battery SOC. In order to carry out the analysis, a REEV simulator which solves vehicle dynamic equations to simulate the operation of the vehicle in real world has been developed. The details of the simulator development