Applied Energy 146 (2015) 279–287

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Energy consumption and cost analysis of hybrid electric powertrain configurations for two wheelers

Paul D. Walker *, Holger M. Roser

School of Electrical, Mechanical and Mechatronic Systems, University of Technology, Sydney, 15 Broadway, Ultimo, NSW 2007, Australia

HIGHLIGHTS

- We analyse several driving cycles to for the preliminary design of hybrid two wheelers.
- Simulation of alternate configurations to compare achievable driving range and economy.
- Demonstrate that pure electric vehicles provide cost benefits over the vehicle life.
- Hybrid and plug-in hybrid two wheelers have comparable costs to conventional vehicles.

ARTICLE INFO

Article history:
Received 11 August 2014
Received in revised form 7 January 2015
Accepted 2 February 2015
Available online 6 March 2015

Keywords:
Electric vehicle
Hybrid electric vehicle
Plug-in hybrid electric vehicle
Life cycle cost
Scooter
Two wheeler

ABSTRACT

The development of hybrid electric two wheelers in recent years has targeted the reduction of on road emissions produced by these vehicles. However, added cost and complexity have resulted in the failure of these systems to meet consumer expectations. This paper presents a comparative study of the energy economy and essential costs of alternative forms of small two wheelers such as scooters or low capacity motorcycles. This includes conventional, hybrid, plug-in hybrid and electric variants. Through simulations of vehicle driving range using two popular driving cycles it is demonstrated that there is considerable benefit in fuel economy realised by hybridising such vehicles. However, the added costs associated with electrification, i.e. motor/generator, power electronics, and energy storage provide a significant cost obstacle to the purchase of such vehicles. Only the pure electric configuration is demonstrated to be cost effective over its life in comparison to conventional two wheelers. Both the hybrid electric and plug-in equivalents must overcome significant upfront costs to be cost competitive with conventional vehicles. This is demonstrated to be achieved if the annual driving range of the vehicle is increased substantially from the assumed mean. Given the shorter distances travelled by most two wheeler drivers it can therefore be concluded that the development of similar hybrid electric vehicles are unlikely to achieve the desired acceptance that pure electric or conventional equivalents currently achieve.

1. Introduction

The convenience of motorcycles, scooters and mopeds in metropolitan areas combined with low operating costs present commuters an attractive alternative to motorcars and public transport. In Australia nationwide sales of two-wheelers continue to grow, for instance, scooter sales increasing by 8.9% in 2011 and 12.6% for 2012 [1]. In Australia, at least, it is suggested in [2] that this is driven by reduced costs and convenience in comparison to passenger cars and public transport, environmental concerns were not a primary factor in scooter and moped uptake. Furthermore, in Yang [3], the main driving force behind uptake of electrified two wheelers in China is identified as legislated bans on the use of engine powered equivalents in many cities. Furthermore, it is suggested that cost based subsidies were also shown to fail in promoting uptake, particularly as technology failed to meet the expectations set by the existing platforms [3]. A study of multiple forms of transport, ranging from electrified bicycles and scooters through to busses in [4] demonstrates a substantial benefit of this form of transport in terms of emission in comparison to conventional scooters or passenger vehicles.

Perhaps the most significant consideration in the development of hybridized and electrified scooters is the need to do so. Whilst the main driving force behind larger passenger vehicle hybridization is the need for high efficiency and significantly lower fuel

* Corresponding author at: PO Box 123 Ultimo, NSW 2007, Australia. Tel.: +61 2 9514 2412; fax: +61 2 9514 2567.

E-mail addresses: Paul.Walker@uts.edu.au (P.D. Walker), Holger.Roser@uts.edu.au (H.M. Roser).

http://dx.doi.org/10.1016/j.apenergy.2015.02.009
0306-2619/

consumption, balanced by a reasonable increase in vehicle cost, anecdotally two-wheelers are generally not expensive to operate in terms of fuel consumption. Government legislation, on the other, has had a significant influence on limiting the use of these vehicles, generally as a consequence impact on traffic congestion and/or low quality exhaust emissions [3]. However, it is shown in [5] that the day-to-day operational costs of a simple electric scooter are significantly less than those of a comparable conventional motorcycle or passenger car. In an evaluation of common two wheeler forms of transportation in various cities of China Weinert et al. [6] depicts the major limitation of conventional and electric two wheelers. Discussion indicates that whilst electric two wheelers are significantly more efficient in terms of energy storage (battery vs fuel tank) to wheels, these vehicles are limited in terms of both top speed and overall range. Conventional scooters possess five times the range of electric equivalents and twice the top speed, and are therefore considerably more flexible in terms of day-to-day use.

In recent years the automotive industry has introduced different hybrid electric vehicles (HEV) and electric vehicles (EV) to meet these needs. This has also extended into two wheeled vehicles, including motorcycles, scooters, and electrified bicycles [6]. These vehicles are designed to reduce emissions at the exhaust pipe through a combination of methods, including (1) operation of the engine in more fuel efficient regions, (2) the use of on-board stored electricity, and (3) energy recovery through regenerative braking [7]. The development of hybrid electric and pure electric two wheeled vehicles, such as scooters and motorcycles, has been under development for over ten years now, with a range of electric and parallel hybrid electric configurations developed [6,8–11]. Whilst electric two wheelers provide a compact efficient configuration, they are severely limited by range, with limited storage capacity for on-board energy storage [6,12,13], thus battery sizing and integration are crucial for a balanced vehicle platform. Parallel hybrid scooters overcome this with combined engine and motor/generator configurations for increased range with lower efficiencies. However, these configurations are limited by complex mechanical subsystems to manage energy distribution [10–13], which are referred to as a source of customer complaints in [3].

Several hybrid scooter and motorcycle designs have been developed to overcome limitations of conventional and electric two wheeler designs; these are dominated by parallel designs where electric motor and engine are connected to the wheels for independent or combined driving [7–12], see examples in Fig. 1. Nevertheless, limitations exist in parallel hybrid electric two wheeled vehicles. Assessment of a range of hybrid electric two wheeler designs in literature indicates that mechanical power splitting required in these configurations add to vehicle complexity, contributing to higher development, purchasing and ongoing maintenance costs. Thus conventional, electric and even parallel hybrid electric configurations are not ideal for the development of compact, green energy two wheeled vehicles that meet the needs of consumers. This project proposes a simple series hybrid electric powertrain configuration for achieving a combination of high efficiency and driving range through the optimal application of motor, engine/generator, and on-board energy storage, including batteries and fuel.

The purpose of this paper is to develop and analyse a series of alternative powertrain configurations for two-wheelers and study the comparative costs of each. In the next section different powertrain configurations for hybrid vehicles are discussed, this is followed by detailing the alternative configurations being studied for this paper. Statistical analysis of driving cycles are then used to investigate needs for powertrain power and stored energy requirements. This is followed by a simulation based analysis of the different configurations to determine energy consumption for alternative driving cycles. To complete the analysis alternative configurations and lifecycle costs are evaluated for (1) capital component costs, (2) maintenance costs, and (3) energy consumption costs. These are used to evaluate the consumer benefits of each configuration in terms of financial requirements and vehicle driving range.

2. Powertrain configurations and Modelling

In conducting this study several alternate powertrain configurations have been identified as suitable to the development of a compact HEV. Two factors are considered in the selection of initial configuration, powertrain layout and application of energy sources. These are detailed below, beginning with a summary of different powertrain layouts. There are three conventional hybrid vehicle powertrain layouts, series, parallel, and series–parallel, each with specific advantages and weaknesses. The series HEV uses an engine-generator to provide power to a traction motor to drive the wheels, see Fig. 1(a). The parallel HEV utilises a single motor/generator in conjunction with an engine and power-splitting transmission to drive the wheels with the engine or motor, or both, Fig. 1(b). The series–parallel HEV utilises two motor/generators and a power-splitting transmission to achieve a combination of both series and parallel operating configurations depending on driving requirements, Fig. 1(c). The benefits and weaknesses of each of these configurations have been discussed at length in numerous HEV studies [6–13].

For a compact HEV powertrain, where efficiency, capital costs and ongoing maintenance costs are all considered as important factors in selection of a particular configuration, it is considered that the series configuration not requiring a power-splitting transmission but needing a larger traction motor outweighs other benefits of other HEV configurations. This can be realised in [8] where series–parallel powertrains are developed for hybrid scooters. One may consider the complexity introduced in these parallel type powertrains, and how this will impact on upfront and maintenance costs. Alternatively, a series type configuration, whilst requiring a larger motor, and potentially generator, benefits from greatly reduced mechanical complexity, overcoming some issues raised in [3]. Thus, making it suitable to compact and cost effective powertrains.

The other major consideration, and the main theme of this paper, is the alternative options available for energy storage in

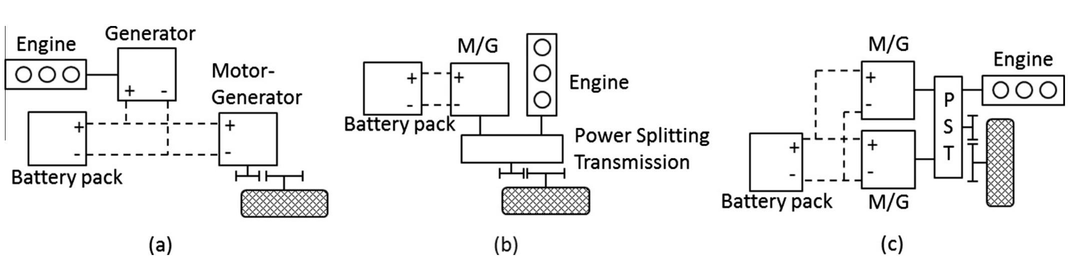

Fig. 1. Alternative powertrain configurations (a) series, (b) parallel, and (c) series–parallel.