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A Review of Range Extender Technologies in Electric Vehicles

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Abstract

With the increasing global concern on negative environmental effect from the transportation sector, conventional automobile technologies will not be viable for much longer. Countries like the EU and China have introduced emission related regulations which are stricter than ever. This has compelled automotive manufacturer to turn to Electric Vehicles (EV) as the most effective solution to this issue. There are mainly two types of EV, namely Battery Electric Vehicle (BEV) and Hybrid Electric Vehicle (HEV). Both has its own strength and shortcomings, BEV with zero emission but limited range while HEV has better range at the expense of higher emission. Extended Range Electric Vehicle (EREV) provides a midpoint between these options. This option provides the best of both worlds by allowing users to switch between both systems depending on the vehicle's operating condition. This paper aims to presents a variety of Range Extender (RE) configurations based on its working principle and type of fuel used. Internal combustion engine, fuel cell, and microturbine are what RE is commonly powered by. The advantages and disadvantages are evaluated and compared to determine the optimal option. It was concluded that depending on fuel availability, space, and efficiency requirement, each configuration has its own merit.

Keywords

Electric vehicles; Range extender; Internal combustion engine; Fuel cell; Microturbine

1 Introduction

Over the past several years, the usage of Electric Vehicles (EV) has experienced a consistent increase in popularity. This trend occurs mainly as a result of global concern on how emission from an Internal Combustion Engine (ICE) has significantly contributed to the global warming phenomena. In fact, based on the Paris Climate Agreement drafted by United Nations Framework Convention on Climate Change (UNFCCC), global warming needs to be limited to under 2^{0}C to ensure the sustainability of planet earth [1]. The signatories of this agreement consist of 195 countries, which cover nearly every country on earth.

In conjunction with this agreement, some countries have come out with sets of regulations designed to reduce emissions. For example, in China, where the vehicle population has seen a 26-fold increase in the past 25 years [2], the government has drafted the China 6 emission standard, which was released in May 2016. In Beijing, the capital city of China, the emission standard has been tightened towards China 6, starting from 2017. This standard is even more stringent than Euro 6 as it comes with the protocol for real-world emission testing and a 48-hour evaporation testing procedure [3].

While in the European Union (EU), some cities have implemented the Low Emission Zones (LEZ). Certain types of vehicles, depending on their emission level, will either be restricted from or required to made payment to enter LEZ. This regulation aims to reduce the exhaust emissions of Particulate Matter (PM) and Nitrogen Oxides (NOx) and has been proven to be quite effective in some areas. In London, Ellison et al. [4] reported 2.47% - 3.07% reduction in PM10 emissions while NOx concentration remains equal. On the other hand, PM 10 and NO_2 concentrations are recorded to have up to 7% and 4% reduction respectively in German cities [5].

This emission limiting regulations have been the main driving force behind the invention and developments of EV. In 1990, The California Air Resources Board (CARB) introduced Zero Emission Vehicle (ZEV) regulation, forcing automakers to incorporate a percentage of ZEV in their annual sales or risk facing financial penalties [6]. A case study has also shown that when a firm is required to commercialize an innovation

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based on a certain regulation, they tend to produce higher levels of patents [7].

In general, there are two types of EV, Hybrid EV (HEV) and Pure EV (PEV) or also known as Battery EV (BEV). PEV/BEV solely depends on the electric motor, while HEV also adds on an ICE as an alternative power source. Emission wise, BEV is the better option as it eliminates any need for fossil fuels. However, it also presents several problems such as limited driving range, higher initial cost, and lack of charging infrastructures [8,9]. Unlike conventional refueling, which can be done in an instant, charging up BEV might take hours [10]. Additionally, charging stations might not be as commonly available, especially in rural areas and developing countries, thus making the driving range even more limited. To tackle that restriction, there are several proposed solutions from previous study, such as optimized structural EV design [11-13]. Besides, mutual integration between EV and grid service might be done to solve limited charging infrastructure and charging time [14-15].

On the other hand, HEV still gives the option of utilizing conventional fuels with improved efficiency from the presence of an electric motor. This is a more feasible option for areas where access to charging stations are more limited. However, the disadvantage of this configuration is that it fails to utilize the maximum potential of electric motors as the ICE still plays a major role. For this reason, the concept of Range Extender (RE) is created. It is essentially an auxiliary power unit (APU) that can be installed within a BEV. The APU has no direct role in propulsion of the vehicle, and its sole purpose is to charge the battery. As a result, the APU can be operated at maximum efficiency and only when necessary.

The main concerns deterring potential buyers from purchasing BEV are the high initial cost and range limitation. Even the official driving range published by the manufacturers are often based on a standard driving cycle, which is almost always too optimistic [16]. This concern is justifiable since recharging BEV cannot be done in an instant and will not be a viable option in a hurry. However, people tend to anticipate the maximum range they might need even if it will only be on rare occasions [17]. In fact, the daily mileage recorded by existing vehicles is less than 35 km in Portugal [18] and 48 km in the U.S. [19]. This means that the majority of the driving distance can be covered without the need for an excessively large battery.

Therefore, instead of the additional price tag and weight of a larger battery, an Extended-Range EV (EREV) might be a better solution when long-range driving is seldomly required [20-21]. This design will help reduce the cost and environmental effect of manufacturing the battery while still maximizing the advantage of BEV [22]. The vehicle can operate fully as BEV during daily usage, and on the few occasions calling for a longer drive, the RE can be activated.

Since the concept of RE is based on occasional usage, further cost reduction can be achieved by having a rental RE unit than can be plugged in whenever necessary. The objective is for a renter to be able to experience affordable BEV for everyday usage and only bear the cost of RE when taking long journeys [23]. A prototype of this concept is developed by EP Tender [24]. The RE is mounted on a small trailer, which will then be mechanically connected to the BEV through a hitch.

2 Classification of Range Extender

2.1 Internal Combustion Engine (ICE)

2.1.1 Free piston engine

The concept of a Free Piston Engine (FPE) first came up in 1928 by Pescara in his patent [25]. Unfortunately, the idea was soon abandoned and has just started gaining popularity again recently for its potential in EV [26]. The part that sets FPE apart from conventional ICE is the elimination of the crankshaft mechanism to allow for a fully linear piston motion. This configuration provides some advantages such as reduced friction losses as well as adjustable position and acceleration of the piston dead centers for better efficiency and reduced emission [27].

A prototype of a two-stroke FPE utilized as a generator currently under development in Universiti Teknologi PETRONAS is shown in Figure 1 [28]. Electricity is generated by the linear alternator from the movement of piston with magnets attached to its shaft. Fuel is ignited at the combustion chamber to propel the piston motion towards the bounce chamber, where high-pressure air will push it in the opposite direction, creating a continuous reciprocating motion. The current challenge of this technology is to obtain a stable starting and control mechanism that used to rely mainly on the now-eliminated crankshaft mechanism [29-30].

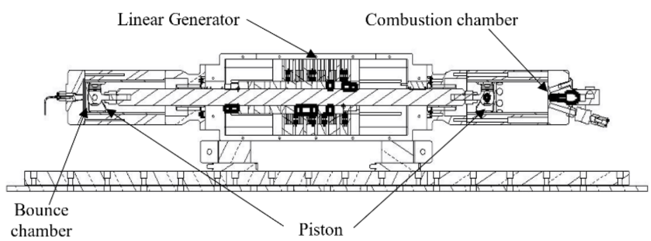

Figure 1 Free piston engine cross-section [28]

2.1.2 Wankel engine

The Wankel engine is a type of rotary internal combustion engine with a triangular-shaped rotor which moves in an oscillatory path. As a result, vibration and other rotational speed induced mechanical stresses can be avoided [31]. It has good potential as RE because of its high volumetric power densities from the absence of a crankcase [32]. There have been a few Wankel engine range extender prototypes, such as the 18kW single-rotor Wankel engine by FEV Motorentechnik GmbH Aachen or the AVL range extender with 15kW power output modifiable up to 25kW [33].

The additional driving range of at least 200 km up to more than 300 km can be achieved using these RE without significant extra weight. The production cost is also relatively low as it can be easily mass-produced and does not require particularly high-tech systems. However, this engine also has some shortcomings, such as poor fuel economy and high level of emission [34]. These inefficiencies might result from the inflexibility of its geometry, combustion chamber sealing, heat losses, and high oil consumption during the warm-up phase [35]. Therefore, proper optimization is still required to eliminate these issues for it to be a more feasible option.

2.1.3 Otto cycle engine

This type of RE is the most commonly known as it is very similar to the ICE in conventional automobiles available worldwide. Some companies such as Lotus Engineering – Fagor Ederlan [33] and Mahle Powertrain [36] each have their own version. They are both an in-line spark ignition engine which is mounted directly to a generator. The one by Lotus has a power output of 35 kW at 3500 RPM or 55 kW for the supercharged version while Mahle's version produces 30 kW at 4000 RPM. Both are capable of improving driving range by more than 400 km with a total weight of approximately 70 kg. The downside of this option is equal to any other conventional ICE on the usage of fossil fuels and its harmful emissions.

2.2 Fuel cell

For those who would like to own EREV without sacrificing the zero-emission characteristic of BEV, fuel cell might be the ideal option. The fuel used by this system is in the form of gaseous hydrogen stored in high pressured tank. Electricity will then be generated from the hydrogen by the fuel cell stack [37-38]. The energy conversion process will also produce heat, which can be diverted for use in cabin heating [39]. The schematic of an extended-range fuel-cell electric vehicle (ERFC-EV) is shown in Figure 2.

Besides emission, an additional advantage of a fuel cell is that refueling can be done just as rapidly as fossil fuel. However, there is also concern about the availability of refueling stations, which is a common problem amongst Alternate Fuel Vehicle (AFV) [40]. To overcome this issue, there have been several policy initiatives to develop better hydrogen refueling networks. There is currently a funding commitment to develop 100 hydrogen refueling stations by California state, while Japan has also proposed $71 million to the same cause [41].

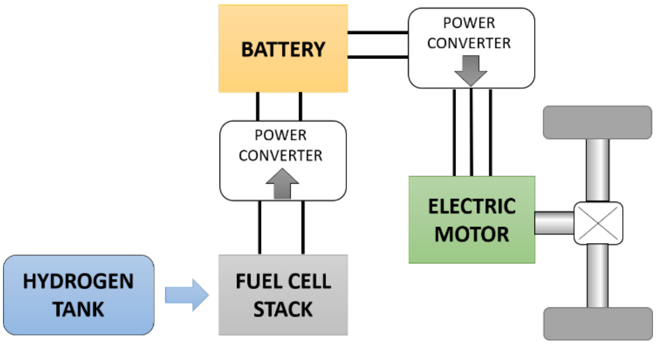

Figure 2 Schematic of ERFC-EV

2.3 Microturbine

This type of RE is the most commonly known as it is very similar. Turbines are another type of device capable of driving a generator. Microturbine, which is a smaller version of the gas turbine, is a more suitable option to reduce weight and space requirements. Its components are similar to regular gas turbines but with only one set each of compressor and turbine blades [42]. Capstone Turbine Corporation, with its C30, is one of the examples of successful application of microturbine as RE [43].

Microturbines are a good alternative to ICE because it produces less gaseous emission such as HC and CO [44]. Additionally, it also weighs less than a similar-sized ICE as it is possible to omit cooling and the oil circuit. Since it is also a system with only a single moving component, it has high reliability and potentially lower maintenance cost [32]. However, it also has certain disadvantages such as low efficiency and high acquisition cost, especially for those with extreme compactness without a cooling system [33].

3 Conclusion

To prevent global warming from worsening to the point of no return, countries across the earth have come together to draft regulations restricting harmful emissions. Automotive manufacturers have come out with a wide variety of electric vehicles in order to comply with these regulations. BEV is the most suitable choice to achieve zero-emission. However, until battery technologies and charging facilities can be further improved, its range limitation is still an issue. The alternative option is HEV, which allows usage of fossil fuel but with the consequence of emission and only partial advantage from the electric motors.

The middle ground between these options is the EREV, which is basically a BEV with an additional supporting generator that will only be operated when necessary. As a result, the potential of electric motors can be exploited optimally during normal usage without requiring an excessively sized battery. On extraordinary circumstances calling for the longer driving range, the RE can be activated to provide the required additional power.

Depending on the fuel used and working principle, there are several types of RE, namely internal combustion engine, fuel cell, and microturbines. ICE is the most common since it is arguably the most common technology in the automotive industry. However, it has limited efficiency and the highest emission amongst the other options. The fuel cell produces no emission and has relatively better efficiency. The downside is the limited availability of refueling stations, especially in developing and rural areas. Lastly, microturbines have lower emission with compact packaging but in the expense of efficiency and acquisition cost. Eventually, the optimum technology would depend on operating conditions or even personal preferences.

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