Potential of range extender electric vehicles (REEVS)

Potential of range extender electric vehicles (REEVS)

I Veza, M F Roslan, M F M Said[1] and Z A Latiff
Automotive Development Centre, School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia.

E-mail: mdfarid@utm.my

Abstract. Battery Electric Vehicles (BEVs) is a promising technology. However, it suffers from low range characteristics thus increasing the anxiety to prospect customers and hindering its market penetration. To overcome this challenge, a range extender that can generate additional power to charge the battery could be the solution. This brief review article will highlight the prospects and challenges of range extender technology for electric vehicles. A number of automobile manufacturers have launched their Range Extended Electric Vehicles (REEVs) models and the detailed comparison will be given. Several types of range extenders will be discussed, including the internal combustion engine, microturbine, and fuel cell. Lastly, this report will suggest the use of Low Temperature Combustion (LTC) i.e Homogeneous Charge Compression Ignition (HCCI) engine be utilised as range extenders for electric vehicles.

1. Prospects and challenges of REEVS

One advantage of using range extender technology is its ability to lower the capital costs of BEVs by downsizing the battery. It is generally known that the battery capacity of BEVs will be compromised in design. If the battery is over-capacity, the weight and the initial cost will increase. Yet, if the battery is under-capacity, the overall efficiency will decrease. This is because the engine will be used more frequently than the battery. As a result, the overall efficiency will be lower as the output of mechanical energy by the engine in REEVs must be converted further by the power converter. Therefore, the progress in range extenders will greatly affect the design of battery capacity for electric vehicles.

An example of an electric vehicle equipped with a range extender is Chevrolet Volt released in 2014. As can be seen in table 1, its battery capacity can only cover less than 60 km driving range. For comparison, Renault Fluence ZE (an electric vehicle without range extender) can achieve as far as 185 km. However, the range extender used in Chevrolet Volt is able to increase its total driving range to more than 480 km despite its battery capacity is 27% lower than the Renault Fluence. Table 2 shows the comparison between REEVs and EVs as well as ICE vehicles. Normal EVs without range extender has driving range maximum up to 210 km, while ICE vehicles can be driven to more than 700 km. The application of EVs in real-world has long been limited by this range anxiety issue. However, with the assistance of range extenders, the driving range can increase significantly.

[1] To whom any correspondence should be addressed.

Table 1. Comparison between two electric vehicles with and without a range extender [1].

Model	**Released Year**	**Range extender**	**Battery capacity**	**Battery range**	**Total range**
Chevrolet Volt	2014	1.4 L SI engine	16 kWh	< 60 km	> 480 km (with range extender)
Renault Fluence ZE	2015	N/A	22 kWh	185 km	185 km (without range extender)

Table 2. Comparison of several EV models [2].

Model	**Year**	**Price**	**Driving Range**
Ford Focus ICE	2014	$20,000	760 km
BMW i3	2013	$41,350	160 km (with range extender 310 km)
Chevrolet Volt (E-REV)	2010	$34,995	80 km (with range extender 670 km)
Opel Ampera (E-REV)	2011	€39,990	80 km (with range extender 500 km)
Nissan Leaf	2010	$28,980	200 km
Ford Focus Electric	2013	$35,995	120 km
Renault Zoe	2013	€20,990	210 km
Fiat 500e	2013	$31,800	60 km
Chevrolet Spark EV	2013	$26,685	130 km

2. Types of range extenders systems

2.1. Internal combustion engine (ICE)

The range extender for electric vehicles in the form of an internal combustion engine is available in numerous engines. Figure 1 shows the basic concept of range extended electric vehicles (REEVs) using conventional internal combustion engine concept.

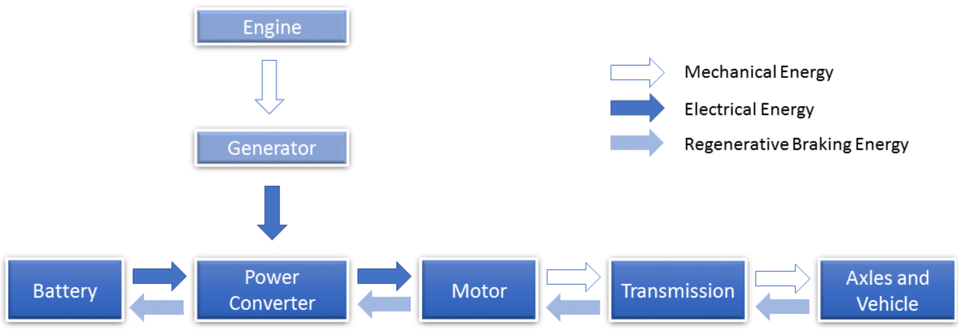

Figure 1. Principle of REEVs with internal combustion engine, adapted from [1].

IOP Conf. Series: Materials Science and Engineering **884** (2020) 012093 doi:10.1088/1757-899X/884/1/012093

The engine and a generator are connected to the power converter. If the battery is sufficient, the engine will not be used. On the contrary, when the battery is running low, the engine will be activated to generate mechanical energy. A generator then converts the mechanical energy into electrical energy that can either be stored or used by the electric motor to run the vehicle.

Despite the common use of Spark Ignition (SI) engine as a range extender, one interesting option is offered by Wankel engine. The concept of the Wankel engine used for range extender is shown in figure 2. As for diesel engine, its high emission characteristics and bigger construction hinder its application as range extenders.

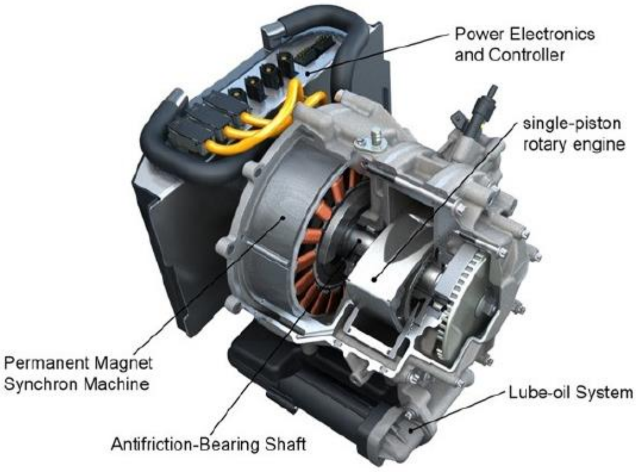

Figure 2. Wankel range extender system [3].

2.2. Free piston

The concept of free-piston motors is like conventional internal combustion engine except that the piston and connecting rod move linearly as shown in figure 3.

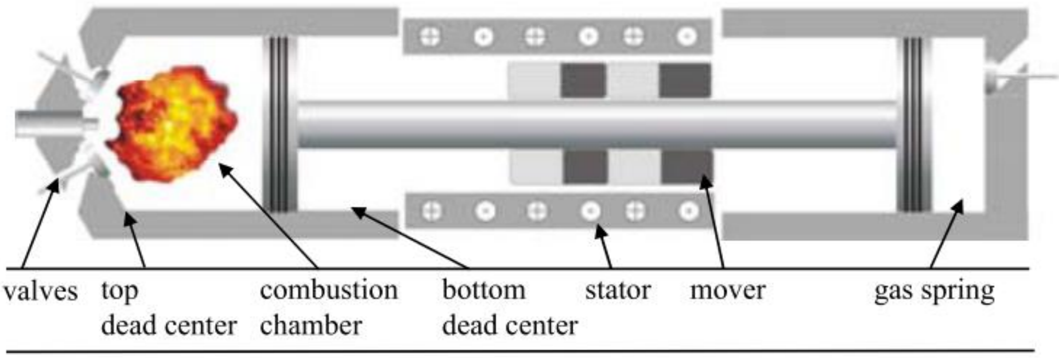

Figure 3. The basic principle of free-piston motors [4].

The German Aerospace Center developed free-piston motors by combining 2-stroke combustion with a linear generator and a gas spring with two pistons moving in opposing directions [4]. The valves are controlled electromagnetically. Since the movement of the free piston enables for a variety of stroke and compression ratio, the engine could be optimised for different performance needs. Therefore, the efficiency of free-piston motors will be higher compared to the conventional engine. In addition to that, noise and vibrations can be reduced as the pistons move linearly in opposite directions.

Figure 4. shows the two types of Free Piston Linear Generator (FPLG) developed for the range extender. Figure 4 (a) is a separate FPLG in which the system has two separate FPLG modules with two combustion chambers, while figure 4 (b) is a central FPLG where the system has one central combustion chamber.

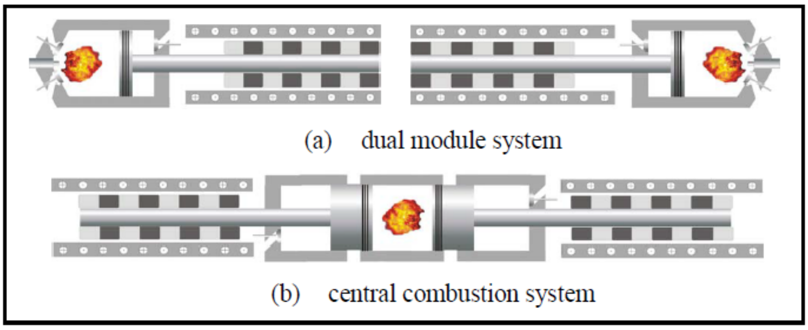

Figure 4. Two types of free-piston motors (a) separate (b) central [5].

2.3. Micro turbine

The Micro Turbine works in the same way as internal combustion engine in which it converts the chemical energy into mechanical energy. This energy is then used by the generator to produce electricity. The advantages of MGT is its continuous burning, fuel flexibility and very low emissions thus eliminating exhaust after treatment. Since the exhaust after treatment is not required, the oil circuit can be omitted and the unit becomes compact, light and relatively affordable [5].

2.4. Fuel cells

In addition to using conventional engine and turbine, the range extender can be supplied by the fuel cell. Unlike other range extender technology, a fuel cell converts the chemical energy directly into electrical energy thus eliminating the necessity of mechanical energy conversion. Moreover, compared to BEVs and Fuel Cell Electric Vehicles (FCEVs), a report from Offer et. Al. [6] suggested that normal EVs with a downsized fuel cell as a range extender will be more economically attractive by 2030. Imperial Racing Green project in Imperial College, UK has designed and tested a fuel cell range extender on a motorsport electric vehicle [7]. A polymer electrolyte membrane was selected as the fuel cell range extender and connected to the battery pack. Polymer electrolyte is considered a sophisticated technology to be implemented as a range extender. Hydrogen can be the alternative to substitute the polymer electrolyte. However, this study has shown the possibility of fuel cell extender to be used in an electric vehicle using polymer electrolyte.

2.5. Summary

Table 3 below compares the four range extender systems mentioned above. For the most lightweight and compact, Wankel offers the best feature with a power density of 860 W/kg. However, its efficiency is the lowest with only 19-27%. The highest efficiency can be achieved using a fuel cell. The fuel cell also gives relatively high density with 650 W/kg, the second in the list. Moreover, a fuel cell does not need exhaust after treatment and has very good characteristics in terms of noise, vibration and harshness. However, its production cost is very costly and suffers from the flexibility of the fuel that can be used. As for microturbines, it is more suitable to be applied in REEVs with small batteries since the turbine requires relatively bigger space and volume. Therefore, the use of conventional internal combustion engine, in this case, SI engine, is still the preferred choice. Although its efficiency is not as high as fuel cell, the efficiency of the SI engine is comparable to other range extender systems and more affordable due to its mass production unit.

Table 3. Comparison of range extender technologies [5].

	Micro Turbine	Free Piston		Fuel Cell	Wankel	SI
		Separate	Central			
Efficiency	25 – 35 %	31 – 33 %	33 – 34 %	60 %	19 - 27 %	20 - 30 %
Packaging variability	some	some	some	large amount	none	none
Volume power density	95 W/l	250 W/l	280 W/l	825 W/l	640 W/l	315 W/l
Power density	400 W/kg	290 W/kg	350 W/kg	650 W/kg	860W/kg	430-500 W/kg
Production cost	over ICE	slightly over ICE		very expensive	cheap due to easy mass production	cheap due to easy mass production
Emissions – after treatment	no after treatment	catalyst		no after treatment	catalyst	catalyst
Flexibility of fuel	is possible	is possible with full advantage		not possible	is possible but not full advantage	is possible but not full advantage
Noise – Vibration – Harshness (NVH)	good	mid		very good	mid	slightly bad
Scalability	mid-good	good		mid-good	good	good
Dynamics	slow, 10 - 90 s	fast, < 1 s		mid, 3 - 30 s	fast, < 1 s	fast, < 1 s

3. Research opportunity in REEVs technology

As previously discussed above, the internal combustion engine is still the preferred choice to be used as range extenders for electric vehicles. However, most researches investigating ICE engine as range extender units are mainly conducted using conventional SI engine. Low Temperature Combustion (LTC) concept has received much attention in the last decade due to its prospects. Yet, its application is not widely used in electric vehicles as the range extender.

One of LTC technology that attracts numerous attentions is Homogeneous Charge Compression Ignition (HCCI) engine [8]. HCCI is developed to contend the existing SI and CI engines. The major concept of HCCI is to combine the best features of both SI and CI engines, offering a promising high-efficiency engine with low NOx and PM emissions. Not only can HCCI engines be operated using gasoline fuels, but it is also compatible with diesel conventional fuels, making it possible with most alternative fuels such as biofuels and biodiesels. HCCI engine has surely the prospect to provide gasoline-like low emissions, while at the same time achieve diesel-like efficiencies.

The implementation of HCCI engines is, however, hard to be implemented due to two reasons. Firstly, the primary difficulty is their auto-ignition timing. HCCI engine does not have an external device to start the ignition such as spark plug (SI engine) or injector (CI engine), thus the timing of auto-ignition for HCCI engine is more complex. The timing for air and fuel to auto-ignite in HCCI engine is controlled by the chemical kinetics of the mixtures. Therefore, HCCI engines require more complicated combustion control.

The second challenge with HCCI engines is their narrow operating ranges. This is the result of the difficulties to control its combustion phasing, especially at low and high loads. At low loads, the temperature of combustion is too low to achieve complete combustion. Misfire will occur and the incomplete combustion will increase the emissions of carbon monoxide and hydrocarbons. At high loads, the heat release is too fast leading to noisy and unstable combustion. Consequently, knock will occur, and thermal efficiency will decrease due to the increase of heat losses. Therefore, the HCCI engine operating range is limited by a misfire at low loads and knock at high loads.

The use of HCCI engine as range extenders allows the engine to run in a narrow operating range without having to switch the engine to conventional mode i.e. SI or CI mode. One research group that initiated studies utilising HCCI engine as range extenders in electric vehicles is Michigan Technology University. Their published papers can be found in these references [9-11].

Acknowledgment

The authors would like to acknowledge the Universiti Teknologi Malaysia (UTM) for financial support under the research university grant Q.J130000.3509.06G97.

References

[1] Andwari A M, Pesiridis A, Rajoo S, Martinez-Botas R and Esfahanian V 2017 *Renew. Sust. Energ. Rev.***78** 430
[2] Bohnsack R and Pinkse J 2017 *Calif. Manage. Rev.***59** 96
[3] Fischer R, Fraidl G K, Hubmann C, Kapus P E, Kunzemann R, Sifferlinger B and Beste F 2009 *MTZ World.***70** 44
[4] Rinderknecht F and Kock F 2012 *World Electric Vehicle Journal***5** 481
[5] Heron A and Rinderknecht F 2013 *8th. Int. Conf. and Exhibition on Ecological Vehicles and Renewable Energies (EVER)* (Monte Carlo: IEEE) pp 1-6
[6] Offer G J, Contestabile M, Howey D, Clague R and Brandon N P 2011 *Energy Policy***39** 1950.
[7] Cordner M, Matian M, Offer G, Hanten T, Spofforth-Jones E, Tippetts S, Agrawal A, Bannar-Martin L, Harito L and Johnson A 2010 *J. Power Sources***195** 7848
[8] Veza I, Said M F M, Latiff Z A, Hasan M F, Jalal R I A and Ibrahim N M I N 2019 AIP Conf. Proc. (Pahang: AIP Publishing) p 020017
[9] Solouk A, Tripp J, Shakiba-Herfeh M and Shahbakhti M 2017 *Energ. Convers. Manage.***148** 1496
[10] Solouk A, Shakiba-Herfeh M, Arora J and Shahbakhti M 2018 *Energ. Convers. Manage.***155** 115
[11] Solouk A, Shahbakhti M and Mahjoob M J 2014 *Proc. of the ASME 2014Dynamic Systems and Control Conference* (Texas, ASME) p V002T020A005