ED5160 - Automotive Engines and Systems
Analyzing the Efficiency of Electric Vehicles

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1 Introduction

There may be disagreements as to *who* built the first electric vehicle (EV), but the *when* can be reasonably estimated to be in the 1830s. At that time, electric vehicles competed with, and even came out in front of, their gasoline counterparts largely due to their dual advantage of having very less noise, smell and vibrations and not requiring manual effort to start up; whereas their competition was noisy, smelly, required manual cranking at start-up and needed rigorous gear shifting. Things changed rapidly though in the 1920s, with many factors contributing to their decline. The greatest limitation of the electric vehicles of the time, though, was the extremely limited range that they offered when compared to the internal combustion engine vehicles(ICEVs) that operated on gasoline. Their recharging time was also a significant drawback when compared to ICEVs, which could refuel in minutes. Over time, the development of EVs slowed down and fell behind that of ICEVs, and the world moved on.

Now, environmental concerns have once again brought EVs to the forefront, their main advantage being the non-existent tail pipe emissions when compared to the petrol and diesel engines. The push was initially regulatory, but now has gained traction in the minds of the public as well due to the change in perception brought about by the beautifully designed Tesla vehicles. The EVs are no longer the boxy chunks of metal that automotive companies made to comply with government regulations, they go toe to toe with conventional ICEVs in Industrial Design. The infrastructure is also slowly catching up, with more charging stations being built on highways every day. Hence, having learnt about the efficiency of the various components of the internal combustion engine's power-train, we now analyze the various components of the electric vehicles power-train to gauge their efficiency.

2 Power-train

The power-train of the electric vehicle can be broken down into four major parts, namely the battery, transmission, motor and the generator.

2.1 Battery

The battery is the weakest link in the electric power-train, accounting for most of the losses in energy. Batteries today are of four types:

- Lead Acid Batteries (Pb/A)

  These have a typical efficiency of around 85%, but are not suited for use in EVs due to a low energy density of around 60-110 Wh/L[1].

- Nickel Metal Hydride Batteries (NiMH)

  The efficiency of NiMH batteries is in the range of 66%, but these have an energy density of 140-300 Wh/L[2].

- Lithium Ion Batteries (Li-ion)

  These have a high efficiency of 90-95% and also have a high energy density of 250-676 Wh/L[3].

- Sodium Ion based ZEBRA Batteries

  These to have a high efficiency of 90-95% and have an energy density of 166-300 Wh/L[4]. These are not prevalent in EVs as these are high temperature batteries which need to be maintained at high temperatures of 270-350C for optimal operation.

2.2 Transmission

The transmission in an EV is greatly simplified as compared to a ICEV, with need of only a single speed reduction gear to meet the speed and power requirements in a typical use case. This means that the losses in transmission are also greatly minimized by the decades long research leading to optimizations made in the vehicle gear-box design and gear manufacturing. The typical efficiency of the gearbox is around 98%[2][5].

2.3 Motor

The motors in EVs can be used in various configurations, such as a single motor powered rear wheel drive, a single motor powered front wheel drive, a dual motor powered RWD/FWD and a setup with four motors for each of the wheels. The last configuration allows for greatest control and optimization of power allotment and also allows us to use the motor itself as generators for power regeneration during braking. The efficiency of such systems thus ranges from 86-89%[6].

2.4 Generator

The various generators that are/can be used in EVs are fuel cells, photo-voltaic cells, thermo-electric generators and regenerative braking. Of the aforementioned generators, only regenerative brakes are used extensively in the EVs of today, as it is quite easy to use the existing motor as a generator to recover energy during the braking process while reducing the vehicle speed. Apart from this, flywheels are also used for regenerative braking. The efficiency of these processes typically range from 85-92%[2].

2.5 Overall Efficiency

The overall efficiency of the power-train of EVs can be estimated by multiplying the various efficiencies of the four parts listed above. This turns out to be in the range of 57-76% based on the various choices of battery packs, motor configurations and choice of one or more generators. Multiplying these mean efficiencies is a simplification for calculating the system mean efficiency, but given the uncertainties the figures represent good indicators on the mean efficiency.

3 Conclusion

From the above analysis, we see that the typical efficiency of an electric vehicle is around 60% and is expected to go up to around 70% in the near future. Corresponding efficiencies of internal combustion engine vehicles are in the range of 20% and are expected to go up to 30% in the future. Hence it may be said by advocates of EVs that electric vehicles are significantly much more efficient as compared to ICEVs, but they would be painting only a part of the whole picture. Some people refer to electric vehicles as *Energy Elsewhere Vehicles*, referring to the fact that the raw energy input of electric vehicles is not liquid oil but *electricity,* which has to be both *generated* and *transmitted* to the vehicle before it can be used, and this can mask drastic inefficiencies. Typical electricity generation methods include fossil fuel based thermal power plants, wind farms, hydroelectric power plants, nuclear power plants and solar cells. Each of these processes have inefficiencies of their own, and cause a drastic drop in the overall efficiency number of the EVs. Taking into account these losses and transmission losses, the efficiency of EVs turns out to be 23-30%[7], which is not significantly different from that of ICEVs. Thus it can be argued that the electric vehicles are just as efficient, if not less efficient, than their IC counterparts. This assessment, however, would be

Table 1: Vehicle efficiency calculated as consumed energy at the wheels divided by the total energy supply to vehicle[7]

Vehicle	Consumed energy at the wheels	Energy out from power-train	Energy to power-train	Energy used for extra loads	Energy during idling	Total Energy supplied	*Vehicle* Efficiency
BEV	100	95	146	17	0	163	61
HEV parallel	100	95	327	14	0	340	29
HEV series	100	95	327	14	0	340	29
FCEV methanol	100	95	327	14	0	340	29
FCEV hydrogen	100	95	279	14	0	293	34
ICEV developed	100	100	452	10	27	489	20
ICEV today	100	100	625	10	75	700	14

highly erroneous, as it completely overlooks the fact that we are moving towards a future that is going to be powered by green renewable sources such as solar and wind.

Electric vehicles thus are a very powerful concept in that they can use energy obtained from *any means*, and hence is not limited by the technology at the time of its creation as all internal combustion engines are. It is a very powerful idea that the efficiency of ICEVs are limited by the technology *at the time of creation*, whereas that of EVs are only limited by the technology *at the time of its use*.

4 Bibliography

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