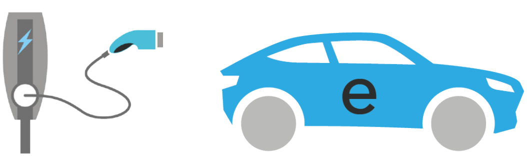
Electric cars: Technology

Lecture notes: Lecture 1.3

Selecting the power rating of an electric machine for use within an EV depends on the vehicle mass and the desired acceleration performance. Many types of electric machines exist, which can be used to provide the necessary propulsion power. Some general requirements of electric machines for use within both (P)HEV's and EVs, are as follows:

- Ease of control
- Fault tolerance
- High efficiency
- High power at high speed (cruising)
- High power density
- High low-speed torque (accelerating)
- Peak torque 2-3 times the continuous torque rating
- Extended constant power region of operation
- Low acoustic noise Low Electromagnetic Interference (EMI)

Electric machine design should be optimized so that the kinetic energy of the vehicle generates as much electrical power as possible and that the stored energy from the battery can be delivered to the road wheels as efficiently as possible. EV motors differ from industrial motors, as they generally require high low-speed torque, enabling the vehicle to meet acceleration requirements. A wide range of operating speed is also required. In contrast, industrial motors are generally optimized for specific rated conditions and have less dynamic operating conditions.



As mentioned, there are only three types of motors that are being used in EVs today:

- Induction motor
- Permanent magnet motor
- Synchronous reluctance motor

Brushed DC motor

Let’s start with the simple, classic brushed DC motor. This motor has a stator and a rotor with an electric coil in it. When this coil is connected with the battery, producing a direct current, the coil produces a magnetic field which causes the rotor to rotate to have the poles face the opposite poles of the permanent magnets in the stator. To keep this momentum, the polarity of the coils is switched. The image on the next page shows how this works.

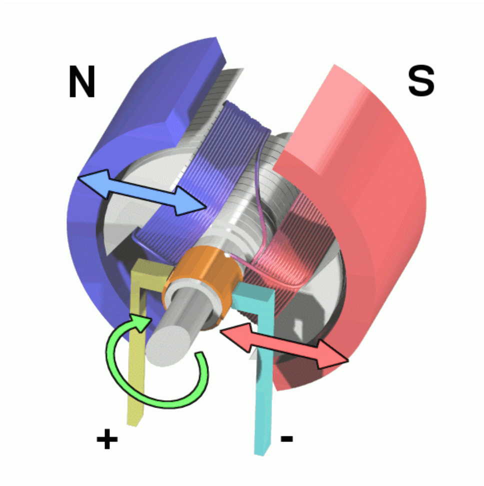


Image Source: By Abnormaal [GFDL or CC-BY-SA-3.0], from Wikimedia Commons

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Induction motor

The AC induction motor needs no permanent magnets. Instead the magnetic field is produced by a current that flows through the windings in the housing or stator. Now if you connect the stator to an alternating current, this means the magnetic field in the stator will also alternate. If a three phase AC input is used, a so called *rotating magnetic field* or *RMF* is produced.

The magnetic field from the stator will *induce* a voltage and current in the windings of the *rotor*. That's why it's called the induction motor. This in turn leads to the rotor producing its own magnetic field, and this magnetic field will make the rotor turn so as to align itself with the magnetic field from the stator. The rotor will follow this rotating magnetic field in the stator, without the need for a commutator with brushes.

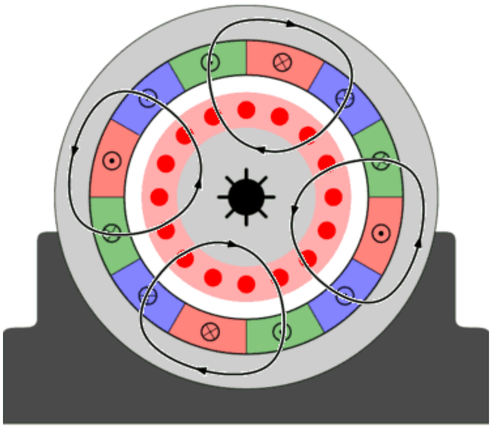


Image source: By BurnsBurnsBurns [CC BY 3.0], from Wikimedia Commons

Advantages	Disadvantages
Simple and rugged	Induced currents in rotor casue losses and heat
No brushes	Not the lightest and most compact motor
No permanent magnet	
No position sensor	
No starting mechanism	
Easy speed control	

Permanent magnet motor

If we construct a rotor with permanent magnets, we no longer need to induce a magnetic field in the rotor. This avoids losses and heat development in the rotor. Because of all this, permanent magnet motors are currently the smallest and lightest electric motors you can buy. Because the rotor is already magnetized it is always in sync with the rotating magnetic field. That's why permanent magnet motors are also classified as *synchronous motors*.

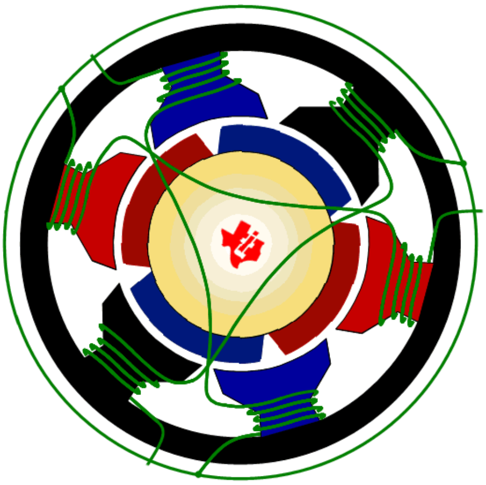


Image source: InstaSPIN™-BLDC Motor Control Solution - Courtesy of Texas Instruments.

Advantages	Disadvantages
Light and small	Permanent magnets (cost + environment + can demagnetise)
Silent	Position sensor
Efficient (esp. at lower speeds	Starter mechanism
	Electronic controller

Synchronous reluctance motor

The synchronous reluctance motor has only recently been developed and seems to have best of both worlds. It has a rotor that contains metal that is formed in such a way that it wants to align itself naturally to the surrounding magnetic field. This means it doesn't need to produce its own electric field through induced currents, like the induction motor, whicht means less losses. Finally, it doesn't need permanent magnets which makes it much cheaper than a permanent magnet motor.

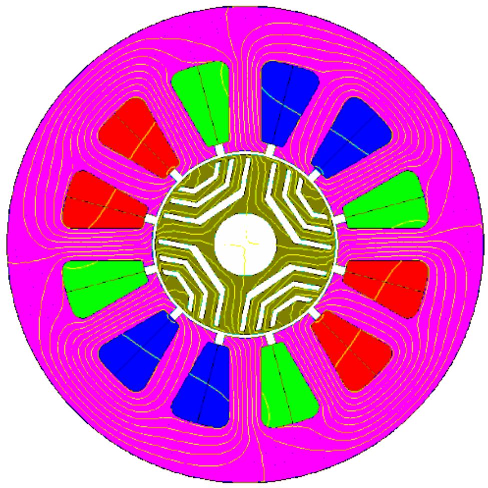
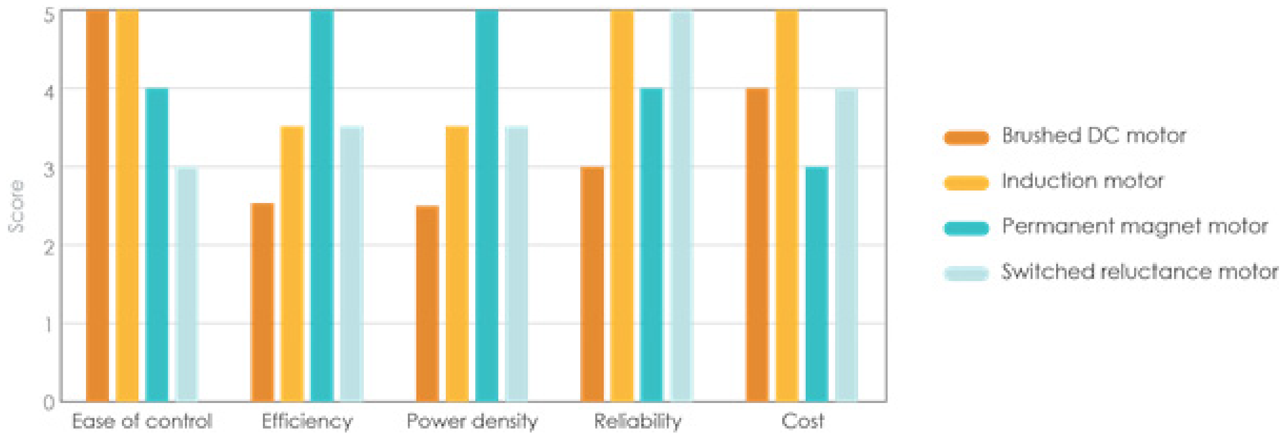


Image source: Synchronous Reluctance Motor – Technelec

Advantages	Disadvantages
Torque comparable to permanent magnet motor	Lower efficiencies at lower speeds
Efficient at higher speeds	Higher inherent noise and torque ripple (but increasingly dampened by advanced controllers
Cheap and clean to produce (no permanent magnets)	

Comparison

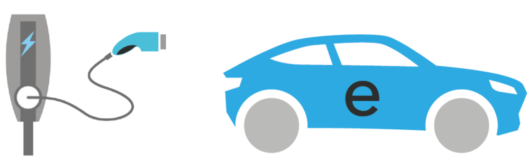


Evaluating the benefits of different machine designs for use within BEV's is a complex process. In:

- Zeraoulia, M., Benbouzid, M.E.H., and Diallo, D., (2006). Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study. *IEEE Transactions on Vehicular Technology, Vol. 55, No. 6,* pp. 1756-1764

a scoring system was applied to the four main types of electric machines used in BEV's, the results of which are shown in the figure. It was concluded that both induction motors and permanent magnet motors are the most suitable, and it was suggested that both technologies could be applied to achieve an optimum BEV driveline configuration.

An overview is also provided of the various electric machine technologies applied to currently available PHEV's and BEV's in:



- L. Kumar and S. Jain (2014). Electric propulsion system for electric vehicular technology: A review. *Renew. Sustain. Energy Rev., vol. 29,* pp. 924–940

as shown in the figure below.

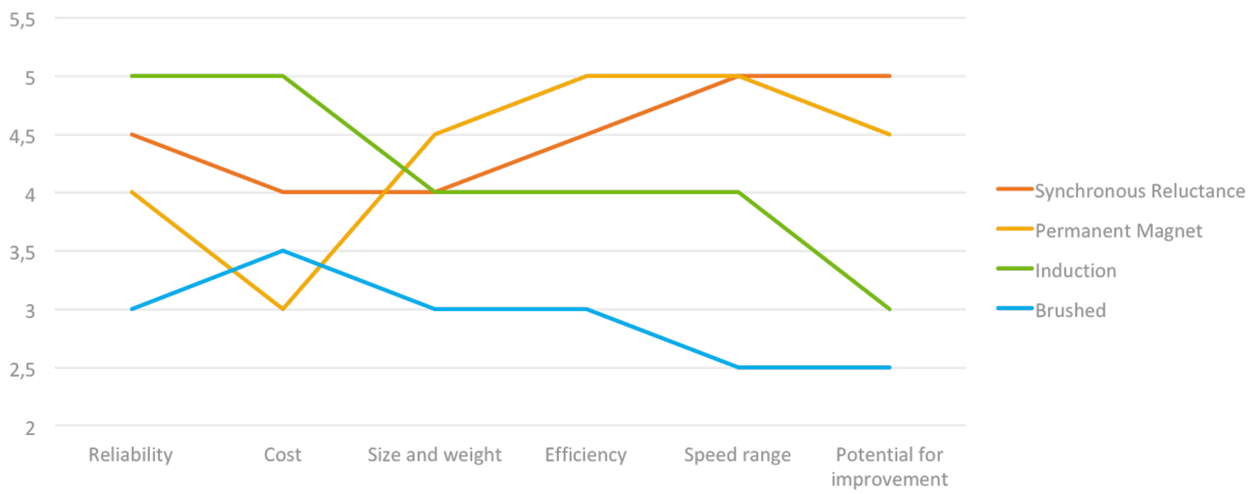
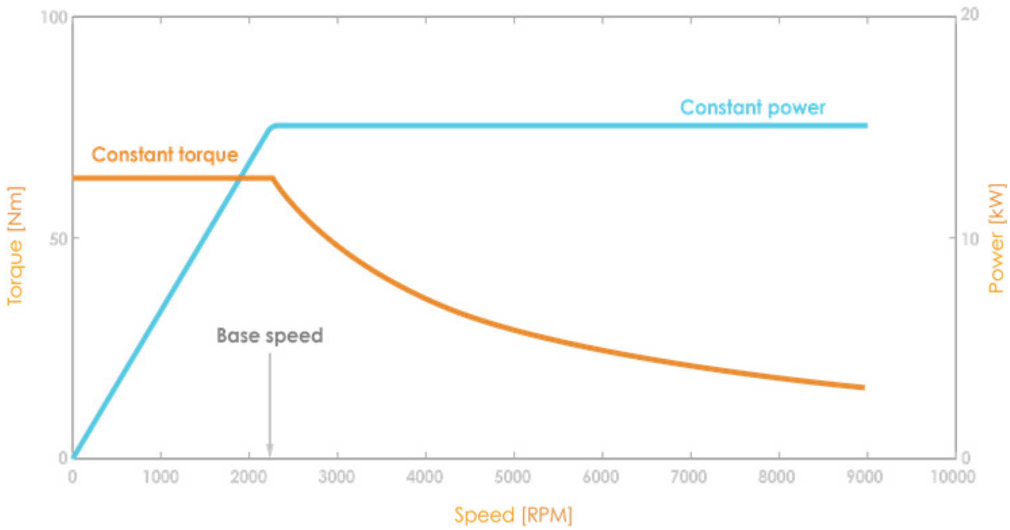


Image source: L. Kumar and S. Jain, *"Electric propulsion system for electric vehicular technology: A review,"* Renew. Sustain. Energy Rev., vol. 29, pp. 924–940, Jan. 2014.

Torque-speed characteristics of a motor

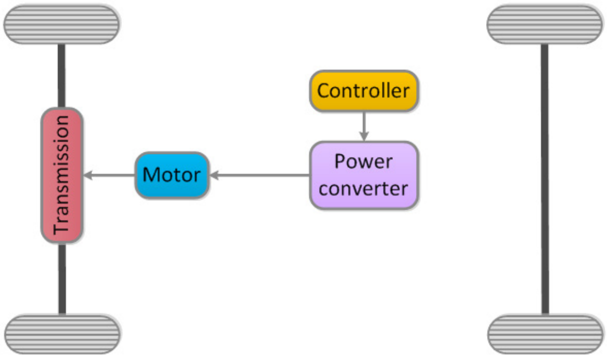


With reference to figure, electric machines are sometimes characterized with respect to the speed range, constant torque range and constant power range. At speeds above the base speed, the torque decreases resulting in a constant power. The effects of extending the constant power operating region of an electric machine on the performance of a simple BEV model were examined in:

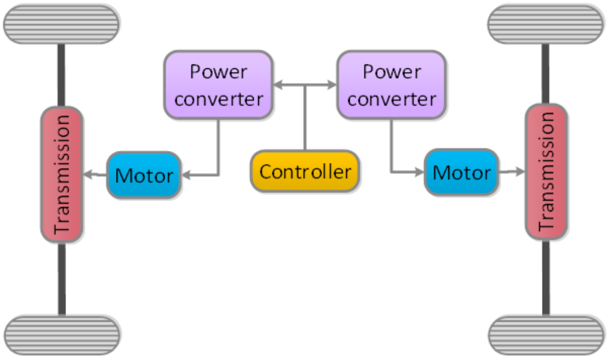
- Moore, S.W., Rahman, K.M., and Ehsani, M., *Effect on Vehicle Performance of Extending the Constant Power Region of Electric Drive Motors*. SAE 1999-01-1152.

Performance parameters examined were acceleration time and distance, and overtaking time and distance. For high speed cruising, it was generally found that electric machines with higher extended range ratios (ratio of constant torque region to constant power region), the acceleration time and distance increased.

Configuration of motor layout



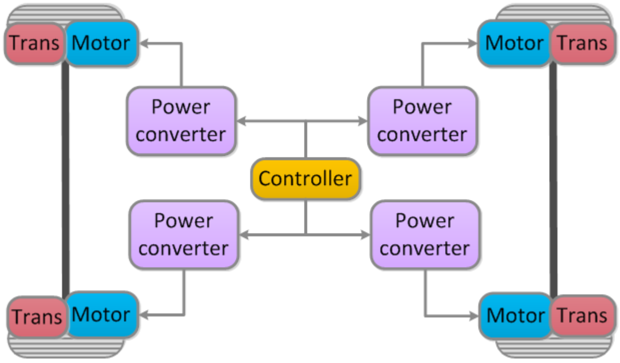
Single motor configuration



Dual motor configuration

A number of motor configurations are possible for EV's, which provides more flexibility for the driveline layout. Single motor configurations use one motor that drives either the front or rear axles.

With a dual motor configuration, two motors are used to drive the EV and this can be done in different ways. One possibility is that one motor can power the front axle and the other the rear axle. Second, both the motors can be placed on either the front or rear axle to provide increased torque compared to the single motor configuration. Alternately, the two motors can be used to drive the left and right wheel independently on either the front or rear axle, meaning there is more control over the vehicle when cornering/turning. Although, most EV manufacturers currently adopt the single motor configuration, the dual motor configuration has also been used for vehicle models with higher torque capability.



In-wheel motor configuration

Using a separate motor to drive each of the four wheels independently is another possibility. This can be achieved using an in-wheel where the motor that is placed within the wheel of the car. The in-wheel motors can be either geared or gearless, as represented in the figure. The gearless option has the potential to improve the overall efficiency of the driveline, but additional controller complexity and hardware required make such a system more complex. A good example is the in-wheel drive system used in a concept Ford Fiesta with the following specifications: 700 Nm, 2x40 kW, 45 kg motor, with wheel 53 kg. You can click here for more information about this motor.