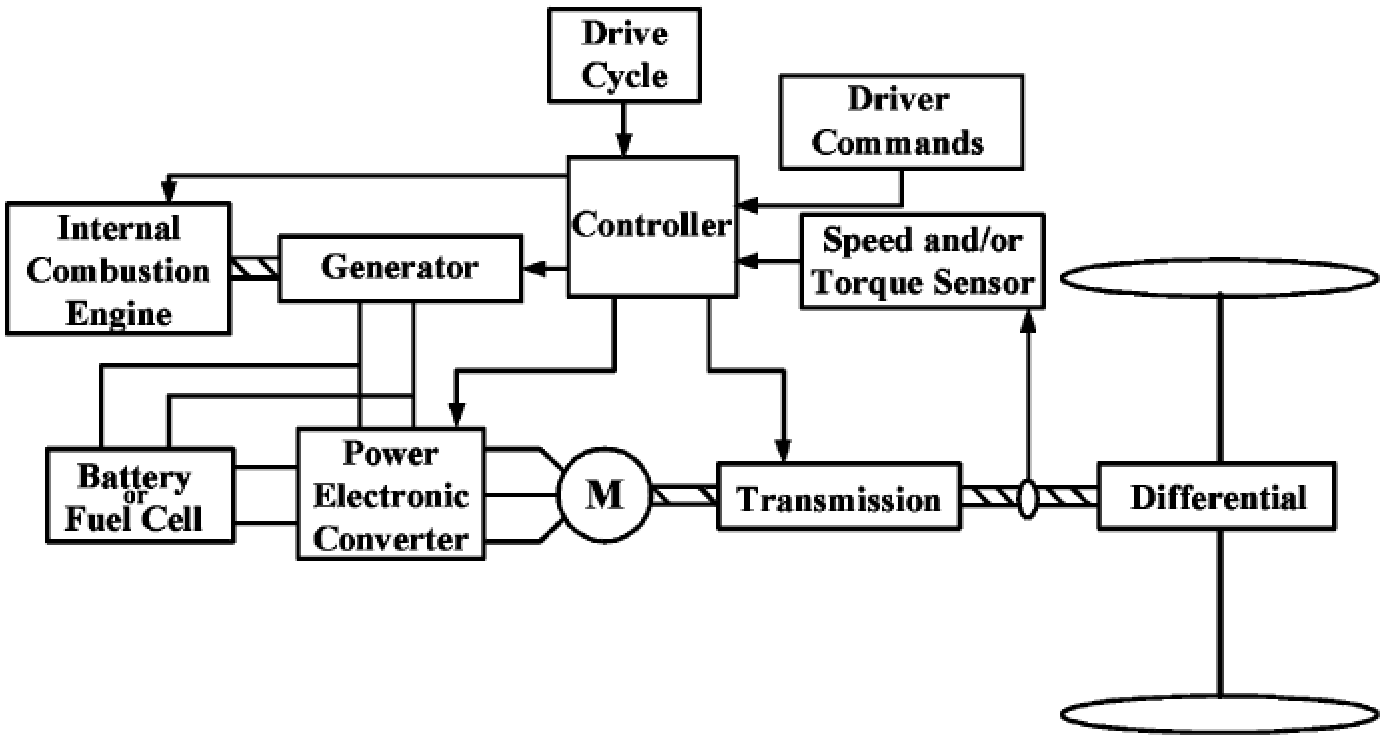
ELG4156
State Space Modeling of Hybrid Electric Vehicle



Introduction

- The electric vehicle (EV) system consists of two subsystems, an electric machine as drive system and the vehicle platform.
- The main components include electrical energy sources, control systems as a central control, and power converter as a device that converts electrical energy source with variable needs of the electric vehicle by switching devices.

Electric Motor Modeling

- The main motive force provider is electric machine (motor).
- EV motion control is simplified to an electric machine motion control.
- In order to guarantee the speed-up time, the electric motor is required to have large torque output under low speed and high over-load capability.

System of Electromagnetic Equations

$$u_s = R_s i_s + \frac{d\psi_s}{dt} + j\omega^k \psi_s$$

$$u_s = R_R i_R + \frac{d\psi_R}{dt} + j(\omega^k - P_b \omega_m)\psi_R$$

$$\psi_s = L_s i_s + L_\mu i_R$$

$$\psi_R = L_R i_R + L_\mu i_S$$

$$G_{speed}(s) = \frac{\omega(s)}{V_{in}(s)} = \frac{K_t}{\left\{\left[(L_a s + R_a)(J_m s + b_m) + K_t K_b\right]\right\}} = \frac{K_t}{\left[(L_a J_m)s^2 + (R_a J_m + b_m L_a)s + (R_a b_m + K_t K_b)\right]}$$

State Space Modeling

$$R_a * I_a + L_a * I_a = V_{in} - V_{EMF} = V_{in} - K_b \omega$$

$$J_{equiv} * \frac{d\omega}{dt} = T_m - T_{fric} - T_{load},$$

$$\frac{d\omega}{dt} = \frac{K_t * I_a(t)}{J_{equiv}} - \frac{b_m * \omega(t)}{J_{equiv}} - \frac{T_{Load}}{J_{equiv}}$$

$$\frac{di_a}{} = -\frac{R_a * I_a(t)}{} - \frac{K_b * \omega(t)}{} - \frac{V_{in}(t)}{}$$

$$\begin{bmatrix} I_a \\ \dot{\omega} \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} & -\frac{K_b}{L_a} \\ \frac{K_t}{J_{equi}} & -\frac{K_f}{J_{equi}} \end{bmatrix} \begin{bmatrix} I_a \\ \dot{\omega} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} & 0 \\ 0 & -\frac{1}{J_{equi}} \end{bmatrix} \begin{bmatrix} V_{in} \\ T_{load} \end{bmatrix}$$

$$\begin{bmatrix} I_a \\ \omega \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ \omega \end{bmatrix}$$

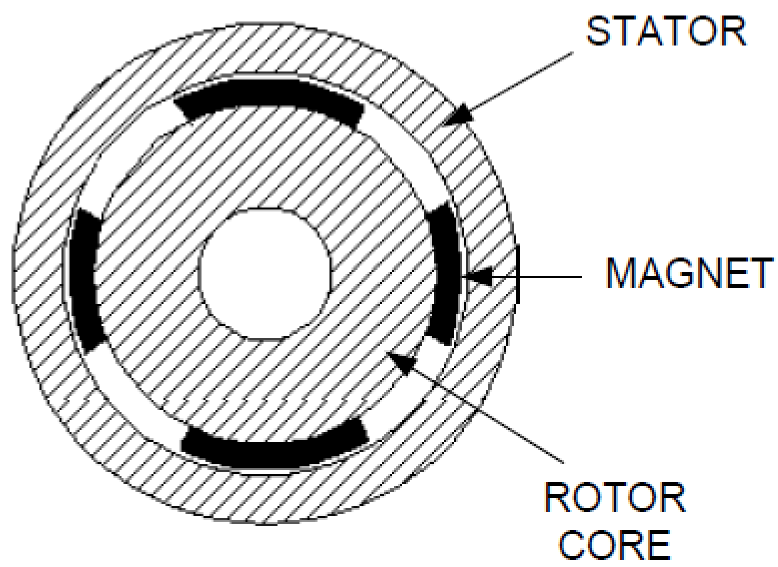
Electric Motors Used in Hybrid Cars

- Hybrids are found with AC motors, of which three types are used:
  - Permanent magnet synchronous motor (PMSM)
  - Three-phase induction motor
  - Multi-phase (more than three) induction motor

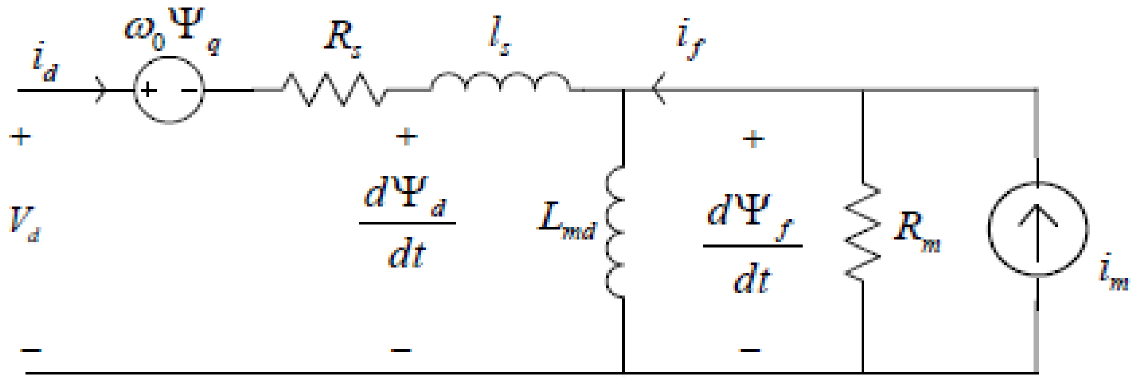
- Each type has its advantages and disadvantages. For example, the permanent magnet electric motor is ideal for a series hybrid like the Prius, but requires a cooling system that adds weight.
- A three-phase electric motor can be air-cooled but requires a more complex transmission.
- The recent development of the Chorus Meshcon multi-phase electric motor seems to have solved the main problem facing electric motors used in hybrids, specifically their inability to offer operation at low speed with high torque while maintaining the capacity for high-speed operation as well.

Permanent Magnet Synchronous Motors (PMSMs)

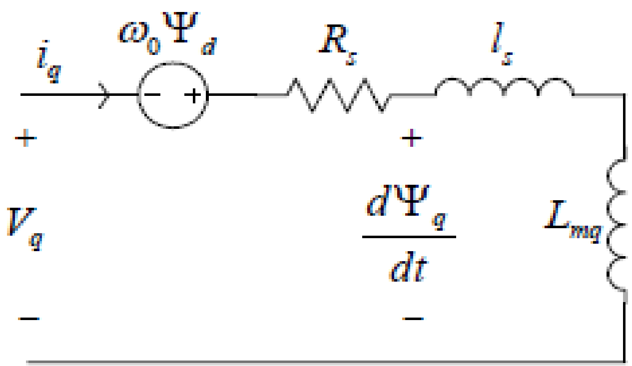
The stator carries a three-phase winding, which produces a near sinusoidal distribution of magneto motive force based on the value of the stator current.



Equivalent Model of the PMSM



a)



b)

$$\frac{d\Psi_d}{dt} = V_d - R_s i_d - \omega\Psi_q$$

$$\frac{d\Psi_f}{dt} = R_m i_m - R_m i_f$$

$$\frac{d\Psi_q}{dt} = V_q - R_s i_q + \omega\Psi_d$$

$$\begin{bmatrix} \Psi_d \\ \Psi_f \\ \Psi_q \end{bmatrix} = \begin{bmatrix} L_s + L_m & L_m & 0 \\ L_m & L_m & 0 \\ 0 & 0 & L_s + L_m \end{bmatrix} \begin{bmatrix} i_d \\ i_f \\ i_q \end{bmatrix}$$

PMSM Driven Circuit