Drive Cycle Based Performance Assessment of Multi-phase PMSM for Direct-drive EV Application

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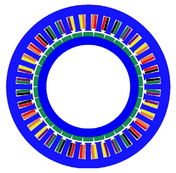
EECOMOBILITY (ORF) & HEVPD&D CREATE

Abstract

- Investigation of specifications for the target electric vehicle (C-Max)
- Electric vehicle model development including multi-phase permanent magnet synchronous motor (PMSM)
- Vehicle simulation for urban and highway drive-cycle to determine whether the developed PMSM meets the drive-cycle requirements



Electromagnetic model of multi-phase PMSM

2017 Ford C-Max Energi SE

Vehicle Dynamics Model

Equations used for vehicle dynamics model

Rolling resistance force:

$$F_f = mgcos\alpha \times f_r$$

$$f_r = 0.0136 + 0.4 \times 10^{-7} v^2 \ (v > 93\text{mph})$$

Grading resistance force:

$$F_g = mgsin\alpha$$

Aerodynamic drag force:

$$F_a = 0.5\rho A_f C_D (v - v_{win.})^2$$

Wheel speed and vehicle speed:

$$v_w = r_{eff}\omega_m \ \& \ v = v_w(1-\lambda)$$

Vehicle dynamic equation:

$$mr_{eff}\dot{\omega}_m = F_t - F_f - F_g - F_a$$

Total force acting on the wheels:

$$F_t = mr_{eff}\dot{\omega}_m + F_f + F_g + F_a$$

Wheel rotational dynamic equation:

$$I_w\dot{\omega}_w = T_w - r_{eff}F_t$$

f_r	Rolling resistance coefficient
g	Gravitational acceleration
α	Road gradient
ρ	Mass density of air
A_f	Vehicle frontal area
C_D	Aerodynamics coefficient
v	Vehicle speed
v_w	Wheel speed
v_{win}	Winds speed
λ	Wheel slip ratio
m	Mass of the vehicle
r_{eff}	Wheel effective radium
$\dot{\omega}_m$	Acceleration of motor
$\dot{\omega}_w$	Acceleration of wheel

Torque on the wheels:

$$T_w = I_w\dot{\omega}_w + mr_{eff}^2\dot{\omega}_m + r_{eff}(F_f + F_g + F_a)$$

Transmission dynamic equation:

$$I_t\dot{\omega}_t = T_t - RT_w \ (\omega_t = \omega_m)$$

Torque on the transmission:

$$T_t = (I_t + I_w + mr_{eff}^2)\dot{\omega}_m + r_{eff}(F_f + F_g + F_a)$$

Motor dynamic equation:

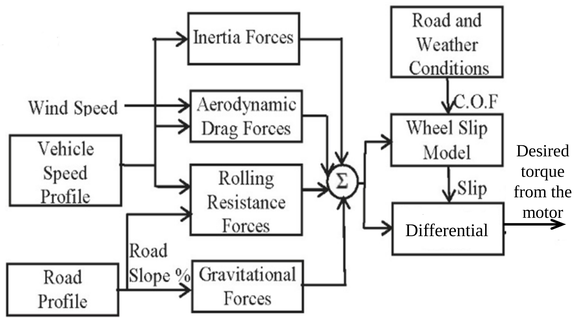
$$I_m\dot{\omega}_m = T_m - T_t$$

Torque on the motor:

$$T_m = [I_m + I_t + I_w + mr_{eff}^2]\dot{\omega}_m + r_{eff}(F_f + F_g + F_a)$$

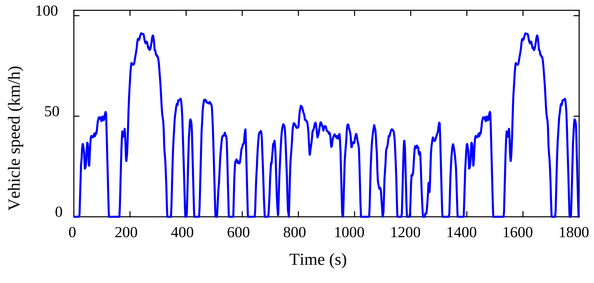
$\dot{\omega}_t$	Acceleration of transmission
F_t	Total force on wheels
F_f	Rolling resistance force
F_g	Gravitational force
F_a	Aerodynamics force
I_w	Wheel inertia
I_t	Motor inertia
I_m	Transmission inertia
T_w	Torque on the wheels
T_t	Torque on the transmission
T_m	Torque on the motor

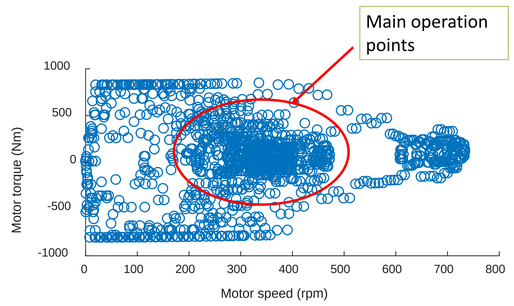
The Schematic of vehicle dynamics model for obtaining desired torque from the motor



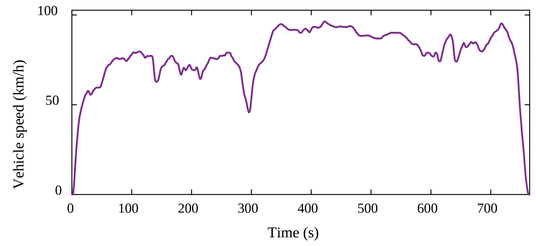
Evaluation of Motor Performance for Urban and Highway Driving Conditions

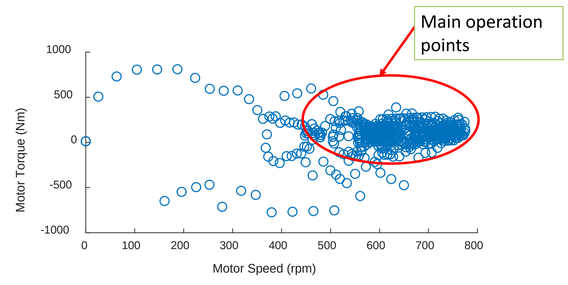
Urban Dynamometer Driving Schedule (UDDS) drive cycle and the required operation points for the multi-phase PMSM



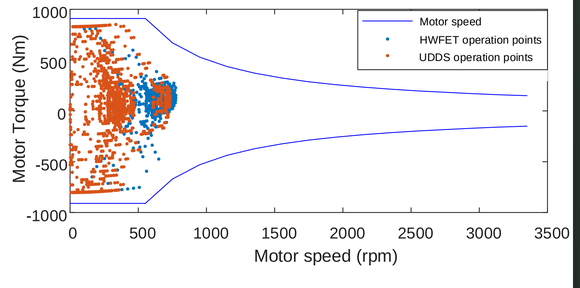


The Highway Fuel Economy Test (HWFET) drive cycle and the required operation points for the multi-phase PMSM



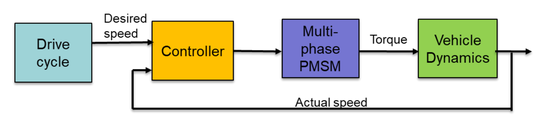


The torque-speed points of multi-phase PMSM for HWFET and UDDS drive cycle

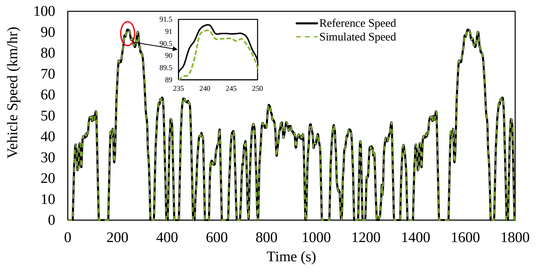


Vehicle Level Evaluation

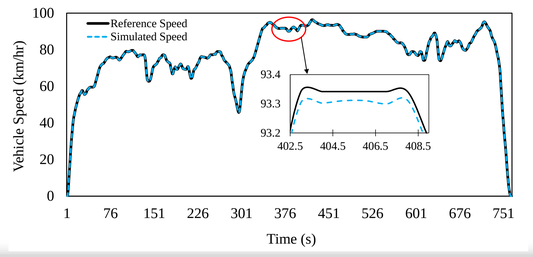
The Schematic of Speed tracking model



Speed tracking characteristics of the vehicle employing multi-phase PMSM for UDDS



Speed tracking characteristics of the vehicle employing multi-phase PMSM for HWFET



Conclusion and Future Work

❖ Conclusion:

- The results show that the multi-phase PMSM has the capability of delivering the torque-speed operation points for UDDS and HWFET
- From the simulation results, the proposed motor is able to drive the vehicle in urban and highway driving conditions

❖ On-going and Future work:

The other performance characteristics of multi-phase PMSM , such as efficiency, maximum speed, and acceleration time for different driving conditions will be analyzed.

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