An Energy Based Model for Optimization of Motor Runtime in Plug-In Hybrid Electric Vehicles

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Abstract

Plug-in Hybrid Electric Vehicles (PHEVs) presently utilize torque–speed characteristics of the electric motor and internal combustion engine (ICE) together with the stored energy available in the battery to determine the running mode of the motor and engine. This decision is based on the real time information provided by the vehicle sensory system. The motor and engine controllers will try to match the torque-speed characteristic of the load in a reactive mode. This type of control is one of the contributing factors that result in battery drain due to unnecessary drive train acceleration needed to meet the torque-speed requirements.

Drive train efficiency maps that emphasize the torque-speed characteristics of PHEVs for highway and city journeys allow for the development of intelligent energy management systems based on a reactive mode of operation. This paper presents a proactive/predictive energy based model for a Parallel PHEV drive train that would have the capability to optimize on motor runtime by forecasting on energy demand through the utilization of real time information provided by Global Positioning Systems (GPS) and elevation maps. Optimizing on the motor runtime will assist in decreasing the fuel consumption and overall cost. In addition, it will help in avoiding the unnecessary acceleration of the motor and engine to satisfy the torque-speed requirements.

The model will be developed from basic mechanics and the law of energy conservation. A vehicle will possess a finite amount of stored energy at any point in a journey. This energy is the potential energy ($PE$) and is given as:

$$PE_{initial} = PE_{fuel} + PE_{batteries}$$  \hspace{1cm} (1)

The potential energy is converted into kinetic energy ($KE$) by the electric motor and ICE. The vehicle potential energy ($PE_{vehicle}$) at any point in time is a function of the initial potential energy ($PE_{initial}$), kinetic energy generated by the engine ($KE_{ICE}$) and motor ($KE_{motor}$), engine loss ($ICE_{loss}$), motor loss ($Motor_{loss}$) and frictional loss as shown in (2).

$$PE_{vehicle} = PE_{initial} - (KE_{ICE} + ICE_{loss}) + (KE_{motor} + Motor_{loss}) + Frictional Loss$$  \hspace{1cm} (2)

The kinetic energy required to travel between any two points $a$ and $b$ can be represented by the potential energy of the body at the two points and the resistance to motion. This kinetic energy as expressed in (3) is a function consisting of the coefficient of dynamic friction ($\mu$) between the wheels and the road surface from which the frictional force $F_f$ is derived, the mass of the vehicle ($m$), the angle of inclination ($\theta$) of the vehicle, the vehicle velocity $v$ and the distance travelled in the direction of the applied force, $S_a$, and can be expressed as follows:

$$KE_{ab} = KE_a - [(\Delta PE_{ab}) + F_f \cos \theta_a \cdot S_a]$$  \hspace{1cm} (3)

$$\Delta PE_{ab} = mgh_a - mgh_a$$  \hspace{1cm} (4)

$$KE_n = \frac{1}{2}mv^2 = \sum_{n=0}^{n}\left[KE_{initial_n} - \left(mgh_{n} - mgh_{a_n}\right) + F_f \cos \theta_n \cdot S_n\right]$$  \hspace{1cm} (5)

Using the mathematical model above, a software program has been developed to solve for the optimal motor runtime for an entire journey. The energy forecasting capability of the software will reduce fuel consumption through the energy based control of the motor and ICE. In addition, it will give drivers added critical information on optimal velocity for each stage of the journey and distances for the next required refuelling and/or plug-in.
Subject Area: Mathematical Modeling of Power Trains

Keywords: Optimization, Energy Conversion, Kinetic Energy, Potential Energy, GPS, Efficiency

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