Renewable and Sustainable Energy Reviews 42 (2015) 517–531

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A comprehensive review on estimation strategies used in hybrid and battery electric vehicles

Mehmet Ugras Cuma, Tahsin Koroglu *

Department of Electrical and Electronics Engineering, Cukurova University, Adana, Turkey

ARTICLE INFO

Article history:
Received 10 July 2014
Received in revised form
3 September 2014
Accepted 18 October 2014

Keywords:
Estimation strategies
Hybrid electric vehicle
Battery electric vehicle
Battery management
Vehicle energy management
Vehicle control

ABSTRACT

In recent years, a significant interest in hybrid and battery electric vehicles has arisen globally due to reducing fuel consumption, mitigating dependence on imported oil and decreasing greenhouse gas emissions. The overall success of these vehicles mostly depends on the performance of sub-systems that they are created. In order to enhance the performances of these sub-systems, estimation of their parameters with high accuracy is required. Furthermore, estimation strategies play an important role in battery management, vehicle energy management and vehicle control by undertaking different tasks. There have been a limited number of review studies related with estimation strategies that are only focused on battery state of charge (SOC) and state of health (SOH) estimation. This paper presents a comprehensive review on various estimation strategies used in hybrid and battery electric vehicles for the first time in the literature. The existing estimation strategies are classified and different methodologies used in each estimation strategy are elaborated. Recent research advances on existing estimation strategies are clearly emphasized by reviewing numerous studies over 200 papers.

Contents

1. Introduction

With the growing concerns on the depletion of earth's petroleum resources, higher CO_2 emission and global warming problems caused

* Corresponding author. Tel.: +90 5379890266, +90 322 338686, +90 322 338138. fax: +90 322 3386326.
E-mail addresses: mcuma@cu.edu.tr (M.U. Cuma), tkoroglu@cu.edu.tr (T. Koroglu).

http://dx.doi.org/10.1016/j.rser.2014.10.047
1364-0321/

Nomenclature

ABS	anti-lock braking system
AEKF	adaptive extended Kalman filter
ANFIS	adaptive neuro-fuzzy inference system
ANN	artificial neural network
ARTE	acoustic road-type estimation
ASAO	adaptive sideslip angle observer
ASGSMO	adaptive switching gain sliding mode observer
AUKF	adaptive unscented Kalman filter
AWNN	adaptive wavelet neural network
BI	bilinear interpolation
BMS	battery management system
BPNN	back propagation neural network
CLO	closed loop observer
DBN	dynamic Bayesian network
DDO	double disturbance observer
DOD	depth of discharge
DFO	driving force observer
DPF	dual-particle-filter
DTC	direct torque control
ECP	equivalent circuit parameter
EFSV	error function based on stator voltage
EIS	electrochemical impedance spectroscopy
EKF	extended Kalman filter
EKFNO	extended Kalman filter-based nonlinear observer
ELO	extended Luenberger observer
ELM	extreme learning machine
EMF	electromotive force
EMS	energy management system
ENN	Elman neural network
EST	error signal technique
EV	electric vehicle
FL	fuzzy logic
FRBKF	fuzzy rule-based Kalman filtering
FRBO	fuzzy rule-based observer
FT	fixed trace
GA	genetic algorithm
GPS	global positioning system
HEV	hybrid electric vehicle
HVAC	heating, ventilation and air conditioning
ICEV	internal combustion engine vehicles
IEKF	improved extended Kalman filter
IM	induction motor
IMU	inertial measurement unit
IPMSM	interior permanent magnet synchronous motors
IR	impulse response
ITEKF	iterated extended Kalman filter
KF	Kalman filter
LLO	Luenberger and learning observer
LO	linear observer
LOLIMOT	locally linear model tree
LPF	low pass filter
LPV	linear parameter varying
LS-SVM	least square support vector machine
MAEKF	model adaptive extended Kalman filter
MARS	multivariate adaptive regression splines
MBNO	model-based nonlinear observer
MEKF	multiscale extended Kalman filter
MKF	multirate Kalman filter
MMAE	multiple-model adaptive estimation
MMTTE	modified maximum transmissible torque estimation
MPE	multilevel Peukert equation
MRAS	model reference adaptive system
MTTE	maximum transmissible torque estimation
NARMAX	nonlinear autoregressive moving average with exogenous variables
NLO	nonlinear observer
NLS	nonlinear least squares
NN	neural network
NTMBO	nonlinear tire model based observer
OCV	open-circuit voltage
OLPM	optimal linear parameterization model
OSL	on-line self-learning
PDF	probability distribution function
PHEV	plug-in hybrid electric vehicle
PIO	proportional integral observer
PWM	pulse width modulated
RBF	radial basis function
RBFNN	radial basis function neural network
RBH	rule-based hysteresis
REKF	robust extended Kalman filter
RLS	recursive least square
RPE	reactive power error
SE	sample entrophy
SKF	series Kalman filter
SMC	sequential Monte Carlo
SMO	sliding mode observer
SNN	structured neural network
SO	state observer
SOC	state of charge
SOH	state of health
SP	subspace parameter
SPI	switched proportional integral
SPKF	sigma point Kalman filter
SVM	support vector machine
SVR	support vector machine for regression
TCS	traction control system
TE	torque error
UIO	unknown input observer
UKF	unscented Kalman filter
UPF	unscented particle filter
YMO	yaw moment observer

by the large number of conventional internal combustion engine vehicles (ICEVs) in use around the world, alternative vehicles such as hybrid and battery electric vehicles draw more attention from both automotive industry and academic community.

Recent studies show that the research of estimation strategies is one of the main interests in the field of electric vehicles as well as battery technologies, vehicle control, charging and grid interaction issues. Estimation of any fault, state or information plays an important role in ensuring vehicle stability and reliability.

Estimation of any variable rather than an accurate measurement that is often difficult in practice and necessitates expensive sensors, facilitates sensing, monitoring and controlling it. Hence, “estimation” has become an expanding research area that supports the technological development of hybrid and electric vehicle market. Consequently, the number of research papers published in conferences and journals have been increasing rapidly in the last few years. Fig. 1 indicates the number of publications per year for each topic of estimation strategies. The data for this figure is obtained with a comprehensive review on the subject of