Two-Stage Optimization Method for Energy Loss Minimization in Microgrid Based on Smart Power Management Scheme of PHEVs

Hamed Nafisi, Seyed Mohammad Mousavi Agah, *Member, IEEE*, Hossien Askarian Abyaneh, *Senior Member, IEEE*, and Mehrdad Abedi

***Abstract*—Utilizing plug-in hybrid electric vehicles (PHEVs) is growing fast and booming nowadays. These vehicles, as portable loads and energy sources, may be connected to standard sockets at home. As a result, those extra electrical loads, grid to vehicle, generations, and vehicle to grid, have several impacts on distribution networks, e.g., network energy loss. This paper presents a two-stage optimization method to minimize the energy loss of microgrid with different penetration levels of PHEVs. In the first stage, a novel convex quadratic objective function for active power management of PHEVs is proposed, and daily required energy of PHEVs is calculated based on stochastic model of PHEV owners' behavior. It is supposed that PHEVs can be employed as distributed capacitors. Therefore, reactive power of PHEVs is specified in the second stage. Afterward, the proposed methodology is applied to a realistic distribution network. It will be illustrated that network energy loss is likely to rise considerably in the case of increasing penetration level of PHEVs without smart charging strategy; in order to minimize network energy loss, a smart management scheme will have to be considered. Also, the significant impact of PHEVs' active and reactive power management on energy loss reduction will be demonstrated.**

***Index Terms*—Active and reactive power management, energy loss reduction, microgrid, plug-in hybrid electric vehicle (PHEV), smart charging.**

NOMENCLATURE

R_i	Resistance of ith feeder.
I_i^t	Current of ith feeder at time t.
L	Set of lines of the power system.
T	Time period.
X, Y, Z	Decision parameter matrices.
N	Set of nodes of the power system.
V	Number of plug-in hybrid electric vehicles (PHEVs).
TS	Number of time steps over a day.
p_n^t	Net injected active power at the nth node at time t.
q_n^t	Net injected reactive power at the nth node at time t.
V_n^t	Amplitude of voltage at nth node at time t.
V_m^t	Amplitude of voltage at mth node at time t.
δ_n^t	Angle of voltage at nth node at time t.
δ_m^t	Angle of voltage at mth node at time t.
Y_{nm}	Amplitude of admittance between nth and mth nodes.
θ_{nm}	Angle of admittance between nth and mth nodes.
S_{customer}^t	Demand of customer load connected to node n at time t.
$P_{\text{PHEV},v}^t$	Active power of vth PHEV at time t.
$Q_{\text{PHEV},v}^t$	Reactive power of vth PHEV at time t.
$S_{\text{PHEV},v}^t$	Apparent power of vth PHEV at time t.
$S_{\text{Rated},v}$	Nominal rating of vth PHEV.
B_v	Battery capacity of vth vehicle.
$V_{\min}$	Minimum permissible bus voltage.
$V_{\max}$	Maximum permissible bus voltage.
$I_{\max,i}$	Current carrying capacity of ith line.
APL_i^t	Active power loss of ith feeder at time t.
P_i^t	Active power flow in the ith line at time t.
Q_i^t	Reactive power flow in the ith line at time t.
c_1, c_2, c_3	Constant values.
V_N	Nominal voltage of power system.
EL_i^T	Energy loss of ith branch over period T.
TE_n^T	Total required energy of nth node during period T.
CEL_n^T	Co-energy loss of nth node during period T.
$X_{C,v}$	Reactance of vth PHEV coupling inductor.
$V_{\text{PHEV},v}^t$	Inverter output voltage.
P_{Loss}	Inverter loss.

Manuscript received October 11, 2014; revised March 16, 2015 and July 1, 2015; accepted September 9, 2015. Date of publication October 13, 2015; date of current version April 19, 2016. The work of S. M. M. Agah was supported by the Science Foundation Ireland under Grant SFI/09/SRC/E1780. Paper no. TSG-01008-2014.

H. Nafisi, H. Askarian Abyaneh, and M. Abedi are with the Department of Electrical Engineering, Amirkabir University of Technology, Tehran 15875-4413, Iran (e-mail: nafisi@aut.ac.ir; askarian@aut.ac.ir; abedi@aut.ac.ir).

S. M. M. Agah is with the School of Electrical, Electronic, and Communications Engineering, University College Dublin, Dublin D04V1W8, Ireland (e-mail: mohammad.mousaviagah@ucd.ie).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TSG.2015.2480999

I. INTRODUCTION

THE SWIFT technological advances in automotive sector, along with the increase in oil price as well as growing environmental concerns, have caused the rapid appearance of electric vehicles (EVs) with expanded energy sources [1]. There are basically two types of EVs: 1) pure battery electric vehicles, which solely work with batteries as electric power source; and 2) PHEVs, which essentially work with a combination of two power sources,