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

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Abstract—Utilizing plug-in hybrid electric vehicles (PHEVs) is growing fast and becoming 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 \( i \)th feeder.
\( I_i^t \) Current of \( i \)th 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 \( n \)th node at time \( t \).
\( q_n^t \) Net injected reactive power at the \( n \)th node at time \( t \).
\( V_n^t \) Amplitude of voltage at \( n \)th node at time \( t \).
\( V_i^t \) Amplitude of voltage at \( n \)th node at time \( t \).
\( \delta_n^t \) Angle of voltage at \( n \)th node at time \( t \).
\( \delta_i^t \) Angle of voltage at \( m \)th node at time \( t \).
\( Y_{nm} \) Amplitude of admittance between \( n \)th and \( m \)th nodes.
\( \theta_{nm} \) Angle of admittance between \( n \)th and \( m \)th nodes.
\( S_{\text{customer}} \) Demand of customer load connected to node \( n \) at time \( t \).
\( P_{\text{PHEV},v} \) Active power of \( v \)th PHEV at time \( t \).
\( Q_{\text{PHEV},v} \) Reactive power of \( v \)th PHEV at time \( t \).
\( S_{\text{PHEV},v} \) Apparent power of \( v \)th PHEV at time \( t \).
\( S_{\text{Rated},v} \) Nominal rating of \( v \)th PHEV.
\( B_v \) Battery capacity of \( v \)th vehicle.
\( V_{\min} \) Minimum permissible bus voltage.
\( V_{\max} \) Maximum permissible bus voltage.
\( I_{\max,i} \) Current carrying capacity of \( i \)th line.
\( APL_i^t \) Active power loss of \( i \)th feeder at time \( t \).
\( P_i^t \) Active power flow in the \( i \)th line at time \( t \).
\( Q_i^t \) Reactive power flow in the \( i \)th line at time \( t \).
\( c_1, c_2, c_3 \) Constant values.
\( V_N \) Nominal voltage of power system.
\( E_L^T \) Energy loss of \( n \)th branch over period \( T \).
\( T_n^T \) Total required energy of \( n \)th node during period \( T \).
\( CEL_n^T \) Co-energy loss of \( n \)th node during period \( T \).
\( X_{C,v} \) Reactance of \( v \)th PHEV coupling inductor.
\( V_i^t \) Inverter output voltage.
\( P_{\text{Loss}} \) Inverter loss.

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,