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ORIGINAL ARTICLE

On the performance of accelerated particle swarm optimization for charging plug-in hybrid electric vehicles

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Abstract Transportation electrification has undergone major changes since the last decade. Success of smart grid with renewable energy integration solely depends upon the large-scale penetration of plug-in hybrid electric vehicles (PHEVs) for a sustainable and carbon-free transportation sector. One of the key performance indicators in hybrid electric vehicle is the State-of-Charge (SoC) which needs to be optimized for the betterment of charging infrastructure using stochastic computational methods. In this paper, a newly emerged Accelerated particle swarm optimization (APSO) technique was applied and compared with standard particle swarm optimization (PSO) considering charging time and battery capacity. Simulation results obtained for maximizing the highly nonlinear objective function indicate that APSO achieves some improvements in terms of best fitness and computation time.

1. Introduction

The vehicular network recently accounts for around 25% of CO_2 emissions and over 55% of oil consumption around the world [1]. Carbon dioxide is the primary greenhouse gas emitted through human activities such as combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation. Several researchers have proved that a great amount of reductions in greenhouse gas emissions and the increasing dependence on oil could be accomplished by electrification of transport sector [2]. Certainly, the adoption of hybrid electric vehicles (HEVs) has brought significant market success over the past decade. Vehicles can be classified into three groups: internal combustion engine vehicles (ICEV), hybrid electric vehicles (HEV) and all-electric vehicles (AEV) [3]. Recently introduced plug-in hybrid electric vehicles (PHEVs) have the potential to increase the total fuel efficiency because of a large size on board battery charged directly from the traditional

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Nomenclature

PHEVs	plug-in hybrid electric vehicles
EPRI	electric power research institute
V2G	vehicle-to-grid
SoC	State-of-Charge
ICEV	internal combustion engine vehicles
AEVs	all-electric vehicles
HEVs	hybrid electric vehicles
AER	all-electric-range
$I_i(k)$	charging current over Δt
$C_{r,i}(k)$	remaining battery capacity required to be filled for i-th PHEV at time step k
C_i	rated battery capacity of the i-th PHEV (Farad)
$T_{r,i}(k)$	remaining time for charging the i-th PHEV at time step k
$D_i(k)$	price difference
$w_i(k)$	charging weighting term of the i-th PHEV at time step
$SoC_i(k+1)$	State-of-Charge of the i-th PHEV at time step $k+1$
$SoC_{i,\max}$	user-defined maximum battery SoC limit for the i-th PHEV
P_{utility}	power available from the utility
$P_{i,\max}$	maximum power that can be absorbed by a specific PHEV
η	overall charging efficiency of the charging station

electric grid, that supports the automobiles to function uninterruptedly in "All-Electric-Range" (AER). All-electric vehicles or AEV is a vehicle using electric power as only sources to move the vehicle [4]. PHEVs integrated with smart grid will possess all of recently introduced strategies. Hence, widely stretched acceptance of PHEVs should play an important role in the sustainable energy addition into existing power grid systems [5]. Effective mechanisms and systems for smart grid expertise are needed in order to solve very diverse complications such as energy management, cost reduction, and efficient charging infrastructure with different objectives and system constraints [6].

According to EPRI – Electric Power Research Institute, almost 62% of entire United States (US) transport will comprise of PHEVs within the year 2050 [7]. Large numbers of PHEVs have the capability to make threats to the stability of the power system. For example, in order to avoid disturbance when several thousand PHEVs are introduced into the system over a small period of time, the load on the power grid will need to be managed very carefully. One of the main targets is to facilitate the proper communication between the power grid and the PHEV. For the maximization of customer contentment and minimization of burdens on the grid, a complicated control appliance will need to be addressed in order to govern multiple battery loads from a numbers of PHEVs properly [8]. The overall demand arrangement will have a significant impact on the power production due to variances in the requirements of the electric vehicles parked in the parking deck at a specific time [9]. Proper management can ensure strain minimization of the grid and enhance the transmission and generation of electric power supply. The control of PHEV charging depending on the locations can be classified into two groups: household charging and public charging. The proposed optimization focuses on the public charging station for plug-in vehicles because most of PHEV charging is expected to take place in public charging locations [10].

Widespread penetration of electric vehicles in the vehicular market is influenced by the systematized charging infrastructures. The power requirement from these new loads actually put extra burden on the existing power systems [12]. For this, some strategies have been proposed by the researchers [13,14] in order to facilitate the PHEV charging infrastructures. Charging infrastructures are required to be constructed at offices, marketplaces and near households. Authors [15] proposed the requirement of constructing innovative smart charging infrastructures with efficient communication networks among the utilities accompanied by well-equipped control infrastructures in order to achieve proper grid stability as well as proper utilization of energy. Moreover, adequate energy storage facilities, cost reduction, Quality of Services (QoS) and optimum power allocation to intelligent charging infrastructures are in progress [16]. As a result, development of dependable, effective, vigorous and cost-effective charging infrastructures is ongoing. Numerous techniques and approaches have proposed for placement of charging infrastructures for PHEVs [17].

State-of-Charge (SoC) is one of the significant constraints for precise charging [11]. A graph of a distinctive Lithium-ion cell voltage versus State-of-Charge is presented in Fig. 1. The figure indicates that the slope of the curve below 20% and above 90% is high enough to result in a significant voltage difference to be depended on by measurement circuits and charge balancing control. Accelerated PSO was developed by Yang [18] at Cambridge University in 2007 in order to accelerate the convergence of the algorithm that is to use the global best only. PSO and APSO-based optimizations have already been studied by the researchers for optimal design of substation grounding grid [19], non-convex optimization [20,21], per-

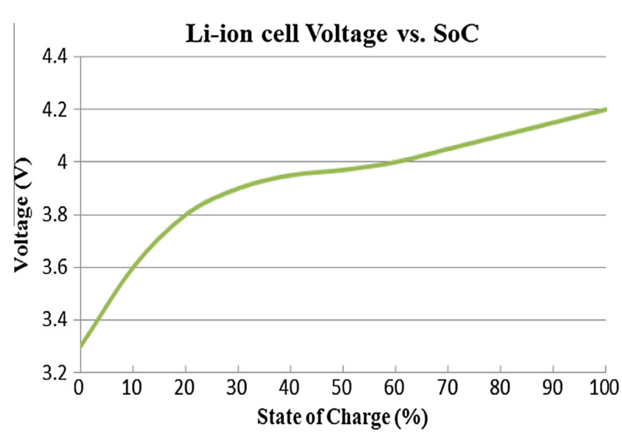

Figure 1 Voltage of Lithium-ion cell versus State-of-Charge [28].