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Computational scheduling methods for integrating plug-in electric vehicles with power systems: A review

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ABSTRACT

Traditional internal combustion engine vehicles are a major contributor to global greenhouse gas emissions and other air pollutants, such as particulate matter and nitrogen oxides. If the tail pipe point emissions could be managed centrally without reducing the commercial and personal user functionalities, then one of the most attractive solutions for achieving a significant reduction of emissions in the transport sector would be the mass deployment of electric vehicles. Though electric vehicle sales are still hindered by battery performance, cost and a few other technological bottlenecks, focused commercialisation and support from government policies are encouraging large scale electric vehicle adoptions. The mass proliferation of plug-in electric vehicles is likely to bring a significant additional electric load onto the grid creating a highly complex operational problem for power system operators. Electric vehicle batteries also have the ability to act as energy storage points on the distribution system. This double charge and storage impact of many uncontrollable small kW loads, as consumers will want maximum flexibility, on a distribution system which was originally not designed for such operations has the potential to be detrimental to grid balancing. Intelligent scheduling methods if established correctly could smoothly integrate electric vehicles onto the grid. Intelligent scheduling methods will help to avoid cycling of large combustion plants, using expensive fossil fuel peaking plant, match renewable generation to electric vehicle charging and not overload the distribution system causing a reduction in power quality. In this paper, a state-of-the-art review of scheduling methods to integrate plug-in electric vehicles are reviewed, examined and categorised based on their computational techniques. Thus, in addition to various existing approaches covering analytical scheduling, conventional optimisation methods (e.g. linear, non-linear mixed integer programming and dynamic programming), and game theory, meta-heuristic algorithms including genetic algorithm and particle swarm optimisation, are all comprehensively surveyed, offering a systematic reference for grid scheduling considering intelligent electric vehicle integration.

Contents

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1. Introduction

It is evident that global demand for fossil fuel resources is intensifying due to the unabated growth in anthropogenic activities. This intensification has led to increasing greenhouse gas (GHG) and pollutant emissions and the associated phenomenon of global warming. To combat this situation, governments have proposed ambitious plans to increase the penetration of renewable and sustainable energy sources to reduce GHG emissions. For example, the US government plans to update the power grid infrastructures and enhance power system intelligence so as to increase renewable generation operation and improve energy efficiency [1]. The European Union (EU) has set up a comprehensive '20–20–20' strategy: to reduce emissions of GHG by 20%, to increase the penetration of renewable energy generation to 20% and to improve energy efficiency by 20% [2]. In China, the renewable energy industry has been proposed among the top five industrial development directions and a special session on smart grid has been involved in its twelfth 'five-year plan' [3,4].

Among numerous energy consumers in the world, transport is one of the biggest fossil fuel users and the largest contributors of GHG and pollutant emissions [5]. According to the International Energy Agency (IEA), transport accounted for 45% of oil consumption in 1973 and this has risen to 62.3% in 2011 [6]. In terms of GHG emissions, transport takes the responsibility of producing over 20% of carbon dioxide (CO_2) emissions [7]. The uncontrolled ever increasing sale of internal combustion engines (ICEs) [8] has the potential to exacerbate global warming further due to ever increasing GHG emissions. Electric vehicles (EV) have long been viewed as an alternative option to replace traditional ICE vehicles. Currently EV uptake has been slow due to the constraints imposed by poor battery performance, prohibitive EV cost and other technological bottlenecks (e.g. shortage of public charging points) and general market uncertainty. However, intense focused commercialisation and political activity may change this. The recent interest by Tesla, General Motors, BMW and some other EV manufacturers more committed than the previous move back in the 1980s, mostly due to the realisation that global warming and increased dependency on fossil fuel for transportation is unsustainable. The Tesla Motor Company has achieved many EV technology breakthroughs with the Roadster in 2008, Model S in 2009 and Model X in 2012. The efforts of Toyota, General Motors and BMW have also made substantial technology advancements through intensive research and development (R&D). Therefore it is highly likely that transport electrification will become a concrete reality in this century. Tesla's range of EVs successfully utilise lithium ion (Li-ion) batteries to extend the driving range to over 300 miles, equivalent to the ICE based vehicles [9]. The policy targets and the many R&D advancements have put EVs under the spotlight in both industry and academia worldwide. According to Thomson Reuters Web of Science index, the academic number of publications referring to EVs has seen a significant increase since 2008, with publications in 2013 and 2014 at approximately 2200 and 2500 respectively as in Fig. 1. Recent research has covered EV power train controls [10,11], battery management systems [12], battery modelling and monitoring [13–16], EV structures [17–19], environment assessment [20–22], driving behaviour evaluation [23,24], and power grid interaction [25–27].

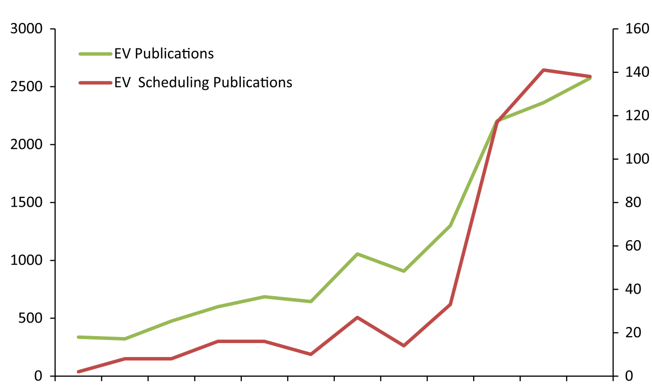

Fig. 1. Publication numbers of EV and EV scheduling in recent years.

Typically EVs can be categorised into pure battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and plug-in hybrid