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Electric vehicles for improving resilience of distribution systems

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ABSTRACT

In this study, improving the resilience of residential customers through employing Electric Vehicles (EV) is investigated. This solution is especially effective in case of unavailability of distribution systems for a considerable amount of time. An example of this situation is the aftermath of a hurricane when existing grid infrastructure may be fully or partially disabled. In this paper, specific attention is paid to hybrid electric vehicles, as their gasoline can be used as a sufficient source of energy during such conditions. In order to have a fair comparison, selected models of both hybrid and non-hybrid electric vehicles are considered. Moreover, based on available data from reliable literature, this paper has generated different load profiles for various consumption scenarios to model the severity of conditions and estimate the required energy. Moreover, two seasonal conditions are considered and the load profiles are developed based on characteristic curves of major household appliances, instead of their rated powers. Then, the selected electric vehicles are considered as the main power supply and the available serving time of each electric vehicle is computed. Results show that a typical hybrid electric vehicle can supply power to residential units for a reasonable amount of time during a power outage.

1. Introduction

Disasters are inevitable, and so are power outages due to storms that affect the distribution network; the only variables are location and severity. Super storm Sandy caused billions of dollars of damage and spawned a power outage for millions of people from several days to weeks (Blake, Kimberlain, Berg, Cangialosi, & Beven, 2012; Sullivan and Uccellini, 2013). The issue could lead to a life-threatening situation during severe weather outbreaks or during medical emergencies, which require special equipment. However, in most cases, power outages cause mere temporary inconvenience. Therefore, a range of different engineering solutions can be considered for different situations, and in the end, it will be a trade-off between capital investment, maintenance expenses and reliability.

While improving the performance of existing structures and increasing their capability to withstand probable extreme weather events can be a solution (Willis and Novosel, 2017; Choobineh, Ansari, & Mohagheghi, 2015), resilience cannot be ensured and a solution is required to restore power locally until service is restored at the large grid level (Gholami, Aminifar, & Shahidehpour, 2016; Choobineh and Mohagheghi, 2016). Hence, while reducing the number of outages is of interest, resilience of the system is also dependent on how the grid will respond to such events. Employing the existing infrastructure has the potential to reduce the capital investment and maintenance expenses significantly. The objective of this paper is to mitigate the issue of supplying power to residential customers while the distribution network is unavailable by employing Electric Vehicles (EV).

Although there are other types of power supplies in emergency cases such as diesel generators, deep-cycle batteries, and other Distributed Energy Resources (DER), in this work EVs are selected since they are now widely available and offer a cost-effective solution to the problem. In September 2014, the governor of California set a goal of placing at least one million zero- and near zero- emissions vehicles on the road in California by January 2023 (Gholami et al., 2016). According to the International Energy Agency, electric vehicles will reach a market penetration of approximately 20 million by 2020 (Trigg et al., 2013). Moreover, scheduled maintenance of EVs (probably by dealerships) can omit any extra Operation and Maintenance (O & M) costs and makes the solution even more economical in comparison to other solutions.

Another advantage of employing electric vehicles is their rapid rate of growth and penetration. Society is also showing more interest in EVs in recent years. Prominent presence of EVs can also be due to the political will behind the deployment of EVs, reducing dependence on fossil fuels and carbon emission. Moreover, environmental and economic benefits of enhanced utilization of EVs make them an impressive player in smart grid structure. As a result, the Department of Energy (DOE) has introduced and highlighted EVs as one of the 20 metrics in measuring the status of smart-gird deployment and impacts (U.S.

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Department of Energy (DOE), 2009).

Valuable research has been performed on different aspects of the Vehicle to Grid (V2G) concept; such as frequency and voltage regulation (Liu, Hu, Song, & Lin, 2013a; Falahi, Chou, Ehsani, Xie, & Butler-Purry, 2013), as well as storage and renewable energy integration (Ma, Houghton, Cruden, & Infield, 2012; Saber and Venayagamoorthy, 2010; Saber and Venayagamoorthy, 2011). However, in this work, it is assumed that the distribution network has been rendered unavailable due to a natural disaster, and the V2G concept is modified to the vehicle to home (V2H) concept. Being isolated from the grid in the V2H scheme relaxes the criteria set by IEEE standards for interconnecting DER with electric power systems (IEEE 1547) (IEEE, 2017). This makes the use of EVs even more economical.

In (Liu, Chau, Wu, & Gao, 2013b), opportunities and challenges of V2H technology are discussed, which highlights the simplicity of the configuration, high cycle efficiency and assistance in the deployment of smart grid. Online optimization control strategy of a Plug-in Hybrid Electric Vehicle (PHEV) connected/disconnected to a home has been studied in (Berthold, Blunier, Bouquain, Williamson, & Miraoui, 2012). The objective of (Berthold, Blunier, Bouquain, Williamson, & Miraoui, 2011) is to minimize the cost function for a V2H configuration. (Xu and Chung, 2016) has evaluated reliability of distribution systems including V2H and V2G, and has shown superior reliability of distribution system with local V2G in case of centralized EV charging as well as distributed EV charging with the V2H concept. In (Alirezaei, Noori, & Tatari, 2016), a combination of solar panels and a battery energy storage system with the V2H concept has been utilized to supply power to a building in order to reduce dependency on the grid. Results have shown the possibility of reducing the energy required from the grid by up to 68% on average. (Shimizu, Ono, Hirohashi, & Kumita, 2016) has used V2H concept in a coordinated scheme with home energy management systems for demand response purposes. Two configurations of combining a photovoltaic system and a PHEV have been studied in (Rahimi and Chowdhury, 2014) to supply power to residential customers. In (Khalghani, Khushalani-Solanki, & Solanki, 2016), optimal integration and location of PHEV aggregators in distribution systems has been assessed. (Jalilzadeh Hamidi and Livani, 2017) has studied real-time decentralized charging management of plug-in hybrid electric vehicles. However, to authors' best understating, no study has considered the use of gasoline energy of Hybrid Electric Vehicles (HEV) in V2H schemes, especially for continuity of service while distribution grid is not available. Moreover, in this work, several top selling and popular PHEVs are selected and a comparison based on the amount of energy they can provide in a V2H scheme is provided.

Even though there have been past reports and research on residential appliance characteristics in detail (Pipattanasomporn, Kuzlu, Rahman, & Teklu, 2014), different objectives are sought such as demand response or residential load control. In this paper, results of previous studies are incorporated into the concept of V2H to investigate the feasibility of the proposed solution. To provide realistic and practical results, three scenarios are developed to consider different severity conditions and the simulations are performed during two different seasonal conditions. Moreover, in most studies, a constant power (rated power) is considered for an appliances power consumption without any cycle or variation. However, in this work, detailed power characteristics are used for each appliance which increases the accuracy.

The main contributions of this work are:

- Use of gasoline energy of HEVs in a V2H scheme.
- Employing detailed power characteristics of major household appliances in order to have an accurate total daily consumption for a typical home.
- Employing a scenario-based approach to calculate energy consumption in different emergency situations based on the severity of the situation.

Moreover, a comparison between different types of EVs in terms of the amount of energy they can supply to a residential customer while distribution grid is not accessible is also presented in this work to analyze the presented concept with real-world examples.

The rest of the paper is organized as follows. Section II is devoted to motivation and a brief review of historical US power outages. Section III explains how electric vehicles can be used as emergency backup power supplies. Section IV discusses the developed scenarios to estimate energy consumption for different situations. In section V, simulation results of two seasonal conditions are presented and discussed. Finally, section VI concludes the paper.

2. Motivation

Power outages always happen, due to the fact that human errors, equipment failures and especially natural disasters are inevitable. Hurricane Sandy caused billions of dollars in damage (in excess of $50 billion) and power outage for millions of consumers (approximately 8.5 million) (Blake et al., 2012; Sullivan and Uccellini, 2013). Another recent example is the northeast snowstorm of October 2011 which caused power outage for more than 3.2 million homes and businesses and a damage estimated approximately between $1 billion and $3 billion (FERC and NERC, 2011).

Fig. 1, (Amin, 2008), shows the number of power outages between 1991 and 2005 which are over 100 MW in size or impacting over 50,000 consumers, revealing an increasing trend over the recent years. An assessment of data from the North American Electric Reliability Council (NERC) has shown that the frequency of blackouts increased during 1984–2006 (North American Electric Reliability Corporation (NERC), 2015). More specifically, a statistically significant increase in blackout frequency was observed during peak hours of the day and during late summer and mid-winter months (Hines, Apt, & Talukdar, 2008).

Severity risk index (SRI) is defined as a stress index, measuring risk impact from events resulting in transmission, generation, and load loss (North American Electric Reliability Corporation (NERC), 2017a). Table 1 shows the top ten severity risk index (SRI) days between 2008 and 2016, which are the days the system was highly stressed (North American Electric Reliability Corporation (NERC), 2017b). As seen in Table 1, all events are caused by weather-related events such as hurricanes or thunderstorms. Another important point seen in this table is the considerable amount of SRI due to the load loss, which in reality means millions of customers without power.

According to data from NERC and analyses from the Electric Power Research Institute (EPRI), average outages from 1984 to 2008 have affected nearly 700,000 customers per event annually (Amin, 2008).

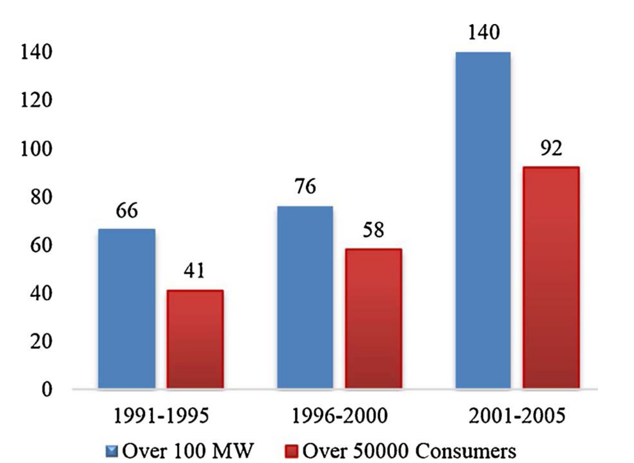

Fig. 1. US Outages over 100 MW and impacting over 50000 consumers (North American Electric Reliability Corporation (NERC), 2015).