Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

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Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

Impact of plug-in electric vehicles and distributed generation on reliability of distribution systems

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ARTICLE INFO

Article history:
Received 14 October 2017
Revised 3 December 2017
Accepted 12 January 2018
Available online xxxx

Keywords:
Distribution system
Reliability
Solar PV
Plug-in electric vehicles
Vehicle-to-grid
Expected Energy Not Charged

ABSTRACT

The use of Plug-in electric vehicles (PEV) are increasing in recent years because of its environmental friendly nature over the conventional vehicles. In the upcoming years, the use of PEVs will increase significantly. The connection of PEVs to the distribution system will lead to the new challenges. This paper evaluates the impact of PEV connection on system reliability. Studies are carried out for different PEV penetration levels to analyze the impact. Some PEVs are operated in vehicle to grid (V2G) mode to support the system peak loads. Distributed generation (DG) units are integrated with charging stations to reduce the PEVs charging impact on the system. In the present study, charging stations are integrated with solar PV units which magnifies the intention of PEV usage. Along with the system reliability evaluation, Expected Energy Not Charged (EENC) is proposed to measure the reliability of the PEVs in the system. The combined effects of PEV charging and DGs are also studied. The impact assessment is done for two practical systems.

1. Introduction

In recent years, the use of electric vehicles (EV) is increasing as a solution for reduction of air pollution and global warming. EVs have the ability to increase energy efficiency and decrease fossil fuel dependency in road transportation [1]. Different types of EVs (e.g. hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV)) are available in the market and these are commonly referred as plug-in-electric vehicles (PEVs). Apart from the environmental friendly nature of PEVs, the charging of PEVs may shows considerable impact on distribution system reliability. The increase of system loading due to the PEVs charging reduces the substation reserve capacity and feeder load transfer capability. Load transfer capacity plays a key role during system restoration using alternate feeders as well. This having a direct impact on the system reliability. In addition to these, if PEVs are charged from the conventional power sources then the objective of the PEVs usage is not met. However, the use of renewable energy sources for PEV charging enhances the benefits of PEVs.

Initially, PEVs are connected to grid for the purpose of battery charging only. However, new smart grid technologies are giving the flexibility of energy discharge to grid and are technically named as vehicle-to-grid (V2G) mode. In this sense, grid connected PEVs virtually act as energy storage devices [2].

The distribution system operators (DSOs) are responsible for providing the services for connecting consumers and DGs according to the European Union (EU) electricity directives [3], in the same way they are also responsible for providing the network upgrades for PEVs charging stations. DSOs have no control over the charging locations and periods. As a consequence, the system operation becomes critical due to uncertainty in PEVs charging. Recently, some valuable research work is being done on the impact of PEVs integration on generation system [4,5]. Reference [6] is concentrated on PEVs charging impact on power generation system and reduction of CO_2 emission. The PEVs impact on emissions from both electricity generation and transportation sector is studied in a fictitious way [7].

Different PEV scenarios and charging management approaches are considered to analyse the impact of PEVs on distribution systems [8]. The work reported in [9] describes the effect of charging strategies on the load profile. Different PEV penetration levels are considered in [10] to estimate the PEV impact on system power losses. Authors in [11] evaluated the PEVs charging impact on distribution transformer aging in the presence of rooftop solar PV system. The charging impact on low voltage residential distribution system is analyzed in [12] with a case study for the year 2030. Reference [13] mentioned different charging strategies and analysed thier impact on dialy peak loads. Authors in [14] calculated the

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https://doi.org/10.1016/j.jestch.2018.01.005
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incremental investments for different PEV penetration levels along with energy losses. Apart from the negative impacts on voltage and power losses, references [15,16] are also focused on PEV impact on distribution system reliability. Surprisingly, V2G mode of operation is not used for reliability evaluation of the system. Electric drive vehicles impact on power system reliability is analyzed in [17].

Some researchers have focused on the mitigation of PEV impact on distribution system [18–20]. Authors in [18] have proposed a real-time smart load management (RT-SLM) control strategy for reduction of power losses and voltage profile improvement. Reactive power compensation is applied in charging stations to improve the voltage profile [19]. The integration of DGs have proved its reliability [21] and techno-economic benefits [22]. So, DGs integration have been considered as a worthy solution to mitigate the PEVs charging impacts [20]. The charging demand of PEVs is compensated using PV units in an unbalanced distribution system [23]. Synchronised planning of charging station and DGs is done considering cost, reliability, power losses and voltage profile [24]. The capacity reienforecement with DGs is proposed to compensate the growing PEVs penetration considering reliability improvement is one of the objective [25]. Design of charging station integrated with wind generation and storage is discussed in [26]. In reference [27], the optimal penetration level of DGs is estimated for a predefined PEV penetration level.

In the literature, most of the research is concentrated on the study of PEVs impact on voltage profile and power losses and has less concentrated on reliability. The PEVs are also one of the type of load to the distribution system and the reliability of these PEV loads are completely ignored.

In the present study, three different PEV penetration levels are used to assess the impact of PEV charging. System load is assumed to be constant for all penetration levels for effective comparison of PEV penetration level impact on system reliability. The V2G mode of PEVs is used in two different ways i.e. scheduled and unscheduled V2G mode. The scheduled V2G mode is used to support the system peak loads during the normal operating conditions and unscheduled V2G mode is used along with the scheduled V2G mode to restore the healthy sections in the system during the system failures. Solar PV units are used to mitigate the PEVs charging impact. The combined impact of PEVs and DG integration is studied for two practical systems. The impact assessment of system reliability is done by measuring the basic system reliability indices i.e. system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) and expected energy not supply (EENS). A new reliability index is proposed and developed to measure the reliability of PEVs and is named as expected energy not charged (EENC).

Finally, summery of the proposed work is as follows:

1. The impact of PEV penetration level on system reliability is analyzed.
2. Scheduled and unscheduled V2G modes are in consideration for discharging.
3. Integration of solar PV unit with charging stations to mitigate the PEVs charging impact.
4. Impact on reliability is studied from the view of both system and PEVs.
5. EENC is determined for both scheduled and unscheduled V2G modes and the impact of solar PV integration on EENC is evaluated.

2. Description of the test distribution systems

To study the proposed assessment approach, two practical distribution systems, namely, area A and area B are considered. In the following section, the main features of each area are given and these details are used as a base case for further analysis.

2.1. Area A

Area A is an urban residential area which occupies 15 km^2. The pictorial representation of area A is shown in Fig. 1(a). The loads of this area are served by single substation and the substation capacity is assumed to have enough capacity to serve the loads for all the scenarios. It is a medium voltage (MV) radial distribution system consisting of 11 kV overhead lines that connects substation with load points through distribution transformers. Consumers are connected to this load points through low voltage (LV) lines. This system serves 6440 low voltage consumers with a maximum demand of 17.45 MW and 5 medium voltage consumers with 10 MW of contractual demand. Total vehicles in this area have been estimated as 3864 i.e., each consumer having 0.6 vehicles.

2.2. Area B

This area consist of both industrial and residential areas. This area covers 6962 km^2, which includes 8 towns and 1356 rural villages and serving more than 62,700 consumers. The residential loads are LV loads and mostly connected within the towns and villages. On the other hand, majority of industrial loads are MV and HV loads. The representation of the area B is shown in Fig. 1(b). The loads in the area are served by a HV transmission substation. This system consists of subtransmission network of 132 kV, 33 kV overhead lines and 11 kV overhead distribution systems. HV loads are directly connected to HV lines and MV loads are served through HV/MV substations. LV loads are having a total demand of 150 MW and 90 MW load at MV level. The total estimated vehicles in the area is 31350. The vehicles per load point is less than that of the area A, as this area presents rural villages which generally have less number of vehicles.

3. Assumptions and considerations for PEV connection

In the following sections, the different types of PEVs that are selected for analysis are explained. These sections also gives the details of PEV charging and discharging patterns, PEV penetration levels and DGs integration.

3.1. PEV penetration scenarios

The total number of PEVs will depend on the percentage of PEV penetration. Several penetration level are used in literature, in this present study, three different penetration levels (35%, 51% and 62%) are used for analysis [14].

Scenario 1: 35% of the total vehicles are assumed to be PEVs. Only PHEV models are considered in this study. Slow (0.2C) and fast (1C) charging are also considered (where C denotes charging).

Scenario 2: 51% of the total vehicles are assumed to be PEVs. In this scenario, both PHEVs and BEVs are included and charging is considered same as scenario 1.

Scenario 3: 62% of the total vehicles are assumed to be PEVs. Here also BEVs are included in the study. This scenario also uses fast charging at 2C. In addition to the above details, some common assumptions are considered for all the scenarios. The total number of vehicles is assumed to be constant. In addition to the charging of PEVs, maximum 10% of the connected PEVs are operated in V2G mode during peak hours. Only fast charging stations are assumed to have V2G operating capability. In order to analyse the effect of increasing PEV penetration, the system load is assumed to be constant.