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Review Article

INVESTIGATING THE IMPACT OF ELECTRIC VEHICLES ON RELIABILITY OF THE DISTRIBUTION SYSTEM

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ABSTRACT
In this paper a structure for analyzing the impact of electric vehicles connected to the network via existing parking lots is presented. One of the main challenges is consideration of the network characteristic to accomplish this study. Much of the efforts in this thesis is dedicated to providing the appropriate framework for a list of required input data so that the final model is detailed enough and yet logical. Finally, after obtaining the appropriate structure, many studies have been carried out. Different reliability indicators, namely, SAIDI, SAIFI and … before and after consideration of electric vehicles are calculated and compared. Moreover, different existence rate for electric vehicles as well as different charging strategies are considered. Obtained results imply the improvement of network reliability in the presence of electric vehicles and indicate that with the optimal utilization of electric vehicles the quality of the power delivered to the customers could be improved.

Keywords: *Distributed Energy Resources (DERs), Electric Vehicles, Imperialist Competitive Algorithm, Loss Reduction*

INTRODUCTION
With the advent of smart grids along with the public craving for reduction in greenhouse gas emissions as well as the need for reducing the operation cost of power systems and improvement of reliability and quality of the power delivered to the customers, an augmented interest in Plug-in Hybrid Electric Vehicles (PHEV) have been observed in recent years.
The Smart Grid is a set of software and hardware tools capable of routing power more proficiently, and therefore reducing the need for excess capacity and upgrade of the existing system. The main difference between the current grid and the smart grid is that the last is a transformed electricity and distribution network which uses two-way communications, advanced intelligent technologies to enhance the efficiency and reliability of power supply. Being equipped with ICT-based (Information and Communication Technologies) optimization technology, smart grids are capable of communicating with demand side loads that offer a variety of options to make the grid load and the production more predictable and adaptable (Battaglini *et al.*, 2009).
In recent years, electric vehicles have been the center of attention, because of their ability in two-way communication with the electrical grid. These vehicles can be used to reduce pollution, improve power quality, increase reliability, control of the frequency and... In this study, the influence of electric vehicles on reliability of the distribution system is studied.
The focuses of Vehicle-to-Grid (V2G) researchers have mainly been on interconnection of energy storage of vehicles and grid (Kempton *et al.*, 2005; Tomic and Kempton, 2007; Kempton and Tomic, 2005; Kempton and Tomic, 2005; Williams and Kurani, 2006). Their aim is to educate about the environmental and economic benefits of V2G and improvement of the power market. However, success of V2G technology mainly depends on the efficient scheduling of Gridable Vehicles (GVs) considered restricted number of parking lots. Ideally speaking, gridable vehicles for V2G technology should be charged from renewable sources. A gridable vehicle can be considered as a small portable power plant (Saber and Venayagamoorthy, 2010). In this paper, we focus on investigating the impact of PHEV deployment on the reliability of the distribution system. To do this, Different reliability indicators, namely, SAIDI, SAIFI and … before and after consideration of electric vehicles are calculated and compared. Moreover, different existence rate for electric vehicles as well as different charging strategies are considered.

The rest of the paper is organized as follows. Section II gives an overview of vehicle to grids. Problem statement is presented in section III. The proposed method is carried out on IEEE 30-bus radial distribution test system, and the results are presented and discussed in detail in section IV. The concluding remarks are drawn in Section V.

Vehicle-to-Grid

Plug-in Hybrid Electric Vehicles (PHEVs) are hybrid electric vehicles that can draw and store energy from an electric grid to supply propulsive energy for the vehicle energy consumption. This simple functional change enables a PHEV to displace energy from petroleum with multi-source electric energy (Quinn *et al.,* 2010). This has important and generally beneficial influence on petroleum consumption, pollution, as well as on the performance and makeup of the electric grid. Because of these characteristics and their near-term availability, PHEVs are seen as one of the most promising means to enhance the sustainability of the energy sectors (Bradley and Frank, 2009).

A widespread adoption of electric vehicles will need to be taken into account in all activities within power systems. However, some activities will more likely be subject to more severe modifications, in technical as well as in operational terms, than others. This can easily be understood since the vehicles will be connected to lower network levels and hence entities active on these levels will be affected more (Galus *et al.,* 2010). Among which UC problem is one of activities that is considerably influenced by the PHEVs. There are several constraints that should be considered in electric vehicles modelling.

State of Charge

This constraint express that each vehicle should have a desired departure state of charge level.

Number of Discharging Vehicles Constraint

All the vehicles cannot be discharged at the same time because of power transfer, current limit. For reliable operation and control of GV, only a limited number of vehicles are assumed to be able to discharge at a time.

Efficiency

Charging and inverter efficiencies should be considered.

Problem Statement

This section explains the problem formulation of the proposed method along with the modelling of the reliability of the power system. In distribition power system reliability evaluation there are several definition and formulation that should be addressed before further analysis.

Contingency in power system is an unplanned event such as fault that is not predictable and is inherently stochastic and random. Fault or short circuit is categorized in two categories, namely, momentary interruption and sustained interruption. Momentary interruption is a single operation of and interrupting device that causes zero voltage. On the other hand, sustained interruption is any interruption that is not classified as momentary interruption. By definition:

λ_s(f/year) is the annual rate (or frequency) of failure.

r_s (hr) is the average outage time (or average duration of failure).

U_s (hr/year) is the average annual outage time.

Using the above dfeinitions several indeces are defined and calculated for reliability evalutions in power system.

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \tag{1}$$

$$U_s = \sum_{i=1}^{n} \lambda_i . r_i \tag{2}$$

$$r_s = \frac{\sum_{i=1}^{n} \lambda_i . r_i}{\sum_{i=1}^{n} \lambda_i} = \frac{U_s}{\lambda_s} \tag{3}$$

In the following different reliability indeces are defined.
System Average Interruption Duration Index (SAIDI):

$$SAIDI = \frac{\sum \text{Customer interruption duration}}{\text{Total no of customer served}}$$

$$SAIDI = \frac{\sum_{i=1}^{n} U_i . N_i}{\sum_{i=1}^{n} N_i} \tag{3}$$

Customer Average Interruption Duration Index (CAIDI):

$$CAIDI = \frac{\sum \text{customer interruption duration}}{\text{Total no of customer interruption}}$$

$$CAIDI = \frac{\sum_{i=1}^{n} U_i . N_i}{\sum_{i=1}^{n} \lambda_i N_i} \tag{4}$$

System Average Interruption Frequency Index (SAIFI):

$$SAIFI = \frac{\text{Total no of customer interruption}}{\text{Total no of customer served}}$$

$$SAIFI = \frac{\sum_{i=1}^{n} \lambda_i . N_i}{\sum_{i=1}^{n} N_i} \tag{5}$$

Average System Availability Index (ASAI)

$$ASAI = \frac{8760 \sum_{i=1}^{n} N_i - \sum_{i=1}^{n} U_i . N_i}{8760 \sum_{i=1}^{n} N_i} \tag{6}$$

Or

$$ASAI = 1 - \frac{SAIDI}{8760} \tag{7}$$

Average System Unavailability Index (ASUI):

$$ASUI = \frac{\sum_{i=1}^{n} U_i . N_i}{8760 \sum_{i=1}^{n} N_i} \tag{8}$$

Or

$$ASUI = \frac{SAIDI}{8760} \tag{9}$$

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Energy Not Supplied (ENS):

$$ENS = \sum_{i=1}^{n} L_{i,a}.U_i \tag{10}$$

Where, $L_{i,a}$ is the average load of substation in ith node and is calculated as follows:

$$L_{i,a} = L_{i,p}.f_i \tag{11}$$

Where, $L_{i,p}$ is the peak load of substation and f_i is the load factor in ith node.
Average Energy Not Supplied (AENS):

$$AENS = \frac{\sum_{i=1}^{n} L_{i,a}.U_i}{\sum_{i=1}^{n} N_i} \tag{12}$$

In the next section using the above indeces the reliability of the distribution in the base case and after deployment of electric vehicles are calculated and using the obtained results the effect of electric vehicles on reliability is investigated.

Case Studies

The proposed method for investigating the impact of EV on reliability of the distribution system is carried out on the RBTS test system (Billinton *et al.*, 1989) which is consisted of 6 buses, and 11 generating units. The system voltage is 230 KV and the total capacity of this test system is 240 *MW* while the peak load is 185 MW. Figure 1 depicts the schematic of this test system.

Two distribution systems are considered for this system for which the reliability data are known. These distribution systems are connected to buses 2 and 4. In this study the one connected to bus 2 is employed (Allan *et al.*, 1991). Depicted in figure 2, is the schematic of this distribution test system.

In this study, two different cases are considered. The first one deals with the reliability evaluation of the system without EVs while the second one investigates the influence of EVs on reliability of the system.

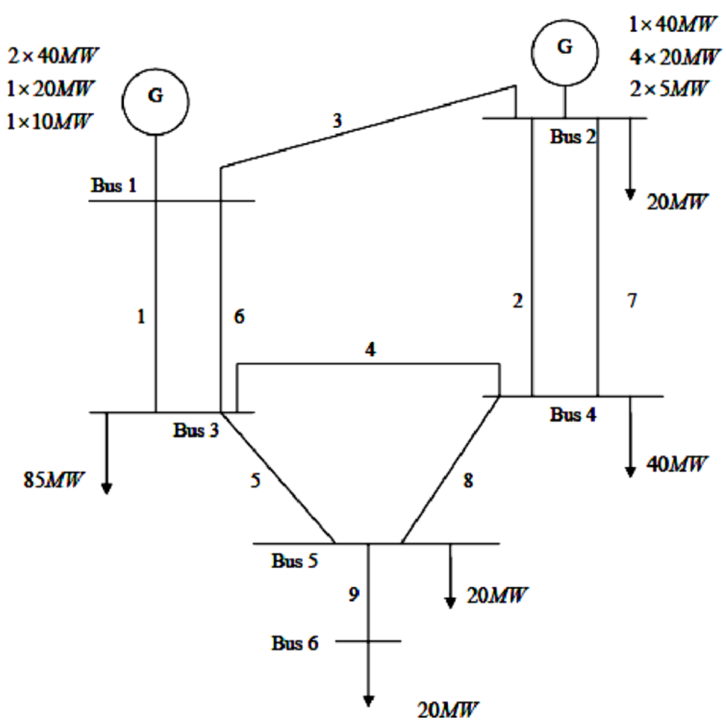

Figure 1: RBTS test system (Billinton *et al.*, 1989)

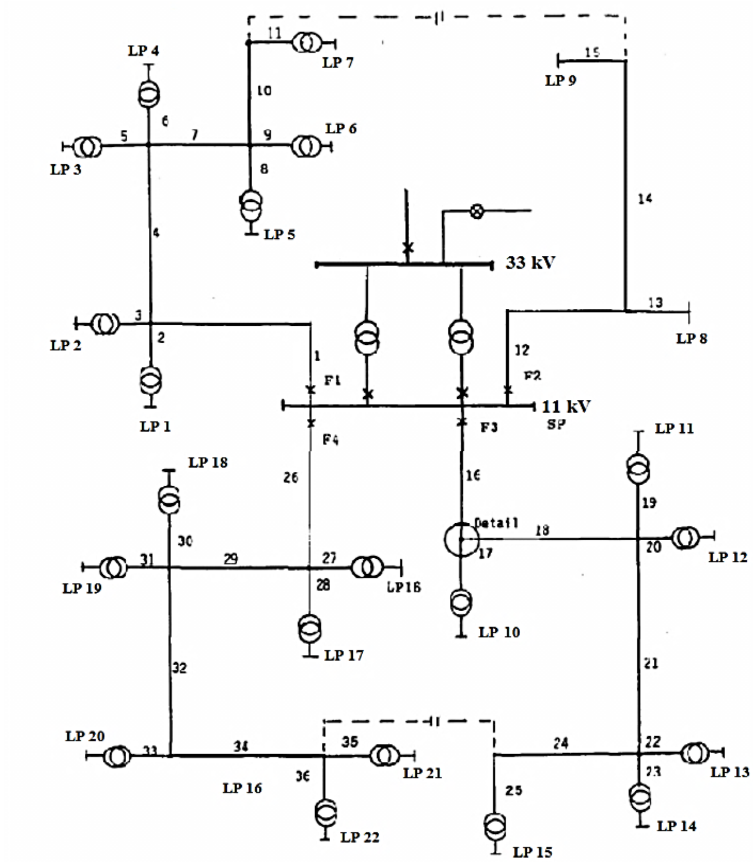

Figure 2: Schematic of distribution system connected to bus 2 of RBTS

Peak load of the system for different load types is presented in Table 1.

Table 1: Different load type peak load Data

Load Type	Peak Load (MW)
Residential	7.25
Small Customers	3.5
Government buildings	5.55
Commercial	3.7
Total	20

Provided in Table 2 are the line data of the system under study.

Table 2: Line Data

Line Type	Line Length	Line Number
1	0.6	2, 6, 10, 14, 17, 21, 25, 28, 30, 34
2	0.75	1, 4, 7, 9, 12, 16, 19, 22, 24, 27, 29, 32, 35
3	0.80	3, 5, 8, 11, 13, 15, 18, 20, 23, 26, 31, 33, 36

In order to evaluate the system and model the behavior of the EVs the geographical schematic of this test system, shown in Figure 3, is taken into account.

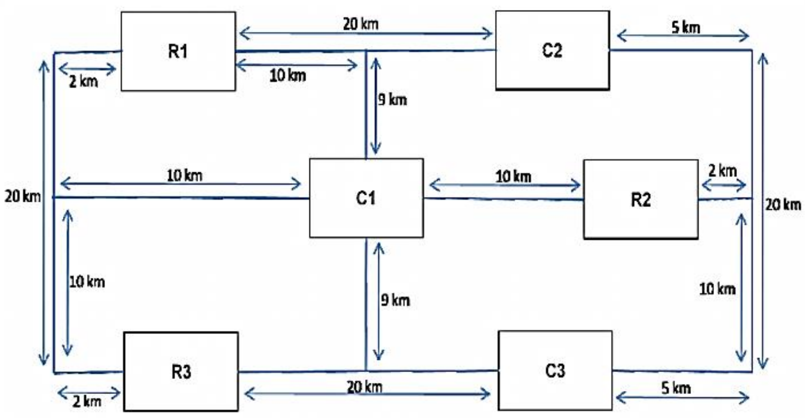

Figure 3: Geographical schematic of the test system

Two different penetration levels for EVs are considered in this study, namely, 30% and 100%. The data for 100% penetration are given in Table 3.

Table 3

Path	Distance (Km)	Number of Vehicles
R1-C1	19	210
R1-C2	20	210
R1-C3	38	210
R2-C1	10	210
R2-C2	17	210
R2-C3	17	210
R3-C1	19	200
R3-C2	38	200
R3-C3	20	200

The Load variations during the day are illustrated in figure 4. The energy price of the day is extracted from (Kempton and Tomic, 2005) and are shown in Figure 5.

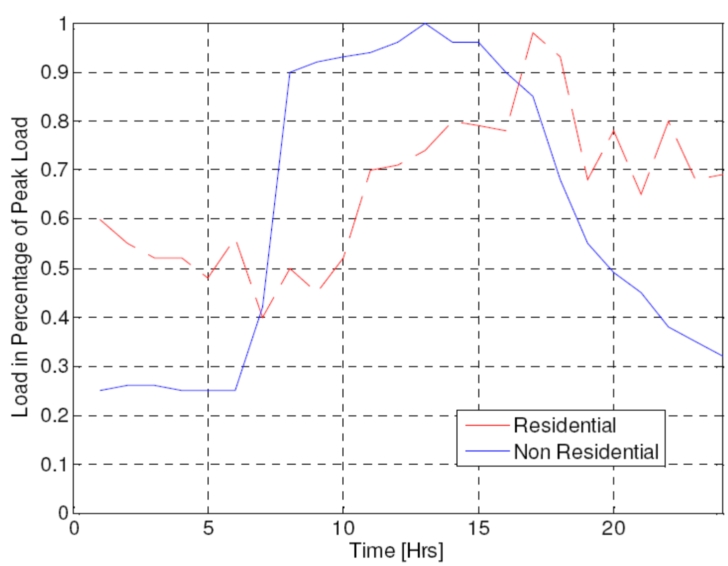

Figure 4: Load variation curve

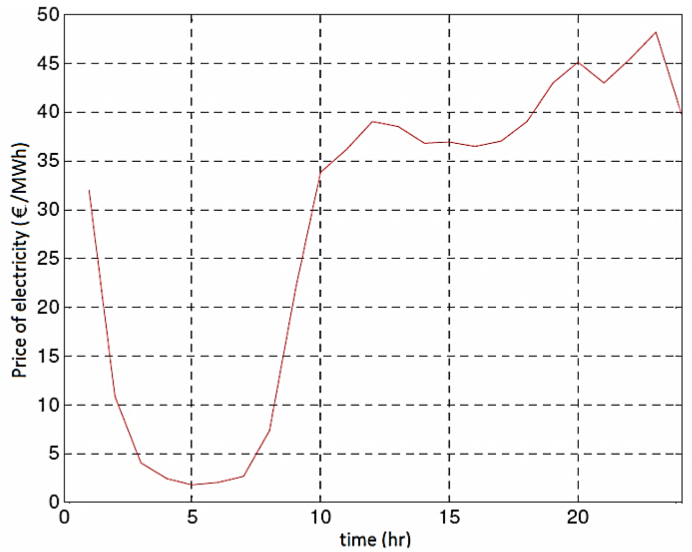

Figure 5: Daily Energy Price

Initially, the reliability is evaluated for the distribution test system without EVs. Figure 6 shows the ENS for different areas in the base case when EVs are not taken into consideration.
The total ENS of the test system whenV2G is not considered is 2885 MWh.

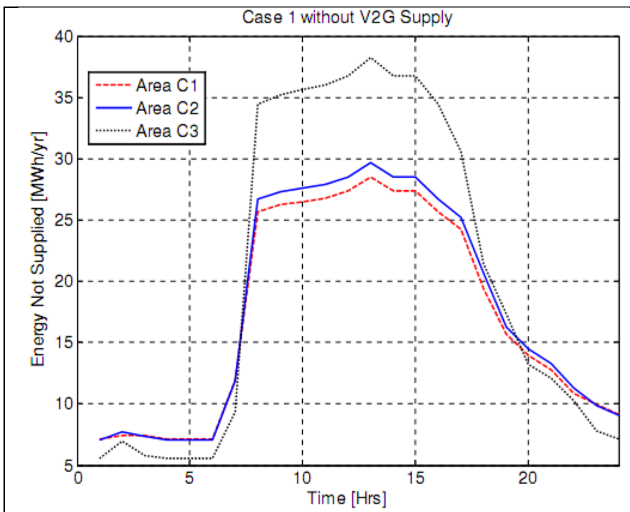

Figure 6: ENS for different areas in the base case without V2G

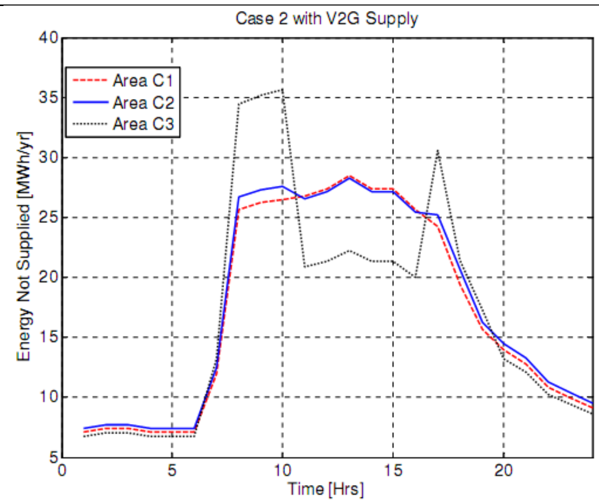

Figure 7: ENS for different areas with V2G

Now, reliability is evaluated for the distribution network in the presence of EVs.
When V2G is considered in the distribution system the reliability has improved as depicted in Fig. 7. The ENS for this case is 2745 MWh that shows 140 MWh reduction in ENS and therefore improvement in the reliability of the system.

CONCLUSIONS

In this paper, an effective approach for evaluation the reliability of the distribution system in the presence of V2G was proposed. Different factors such as daily load variation and price were taken into consideration. The ENS as one the main indices in reliability evaluation is calculated before and after

V2G deployment. The obtained results demonstrate the capability of V2G to effectively enhance the reliability of the distribution system. Moreover, comparing of the results from case 1 and case 2 showed 5% decrease in ENS.

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