EVALUATION OF THE IMPACT OF ELECTRIC VEHICLES ON DISTRIBUTION SYSTEMS COMBINING DETERMINISTIC AND PROBABILISTIC APPROACHES

Franz H. PEREYRA ZAMORA* Henrique KAGAN* Marcelo A. PELEGRINI*
*SINAPSIS Inovação em Energia – Brazil
franz.zamora@sinapsisenergia.com henrique.kagan@sinapsisenergia.com marcelo.pelegrini@sinapsisenergia.com

Vitor Luiz G. GARDIMAN** Lucca ZAMBONI** Márcio GAVAZZI**
**EDP Bandeirante – Brazil
vlgg@edpbr.com.br lucca.zamboni@edpbr.com.br gavazzi@edpbr.com.br

Marco A. P. FREDES*** Carlos A. M. GONÇALVES*** João Paulo NIGGLI Silva**
***EDP Escelsa – Brazil
marco.fredes @edpbr.com.br carlos.gonçalves@edpbr.com.br joao.niggli@edpbr.com.br

ABSTRACT

This paper presents a methodology for assessment of the impacts on the distribution network faced with the presence of electric vehicles (EV) and aims at its application in the distribution networks of two power utilities in Brazil. The impact on the electrical system is originated by the loads on the network, which are represented by particular and typical load curves associated to consumers, and theoretical models of load curves of batteries. The allocation of the load associated to EV in the network is made through deterministic and probabilistic algorithms. The assignment of the type of battery to each EV, of the state of charge of battery and time of charging, use probability distribution functions obtained in the field or curves of theoretical probability distribution functions. Regarding to the form of loading to be made by EV are analyzed the possibilities to happen uncontrolled charging at the time of the peak, loading considering a dual tariff and other approach considers the intelligent charging to have better control and use of the network. The impact on distribution networks is determined by the diagnosis of network elements, and systematic monitoring of the loading of feeders, secondary networks and distribution transformers and check the values of the voltage profile, voltage unbalance and loss. The methodological approach enables the computational implementation of a series of modules within a simulation platform.

INTRODUCTION

Electric vehicle technology is viewed by many countries as a key component to reduce greenhouse emissions and at the same time to reduce oil importation dependency for transportation activities.

As a result, many car industries emphasizes their development on many electric vehicles types, among them the pure electric vehicle (EV), that uses only energy stored in a battery and the pluggable hybrid electric vehicle (PHEV), that works through the combination of a battery and an electric motor installed in the vehicle – “on-board”- and a combustion motor. The batteries for both types can be reloaded from the electric network [1].

The introduction of the EV technology will not only has a significant effect on the transportation sector but also on the electrical energy system. A generalized implementation of EVs for particular use will cause a significant increase on the amount of electrical energy to reload vehicle batteries. As a consequence a new pattern of power demand will be created firstly for power distribution. This could cause adverse effects for the electrical distribution network mainly on areas with great concentration of EVs connected to the network at the same period of time. These effects could include excessive voltage drops and a thermic increase on circuits and a consequent energy loss increase.

A high penetration of EVs on the distribution system in a near future will influence the electrical system planning and operation decisions. Based on it, the distribution energy utilities need methodologies and computational systems to help the management of the network through the verification of loadings parameters, voltage levels, phase disequilibrium, energy losses and also on possible new investments.

METHODOLOGY

A comprehensive methodology was developed and its goal is the evaluation of the main impacts for the electrical energy distribution network of the EDP utilities in Brazil, Bandeirante and Escelsa.

Distribution Network Data

The evaluation of the electric vehicle (VE) loadings impacts on the specific network equipments end also for the entire distribution network was modeled: supply points for high voltage substations, high voltage sub transmission lines (138 kV, 88 kV), high /medium voltage substations transformers (138/13,8 kV; 88/13,8 kV), medium voltage feeders (13,8 kV), medium /low voltage distribution transformers (13,8/0,220 kV), low voltage network (240 V, 120 V, 220 V, 127, V), medium and low voltage consumers.

Typical demand curves

The use of typical demand curves is a part of a methodology used to represent network loads. Typical load demand curves information generally is available in Brazilian utilities and gives to the planning a good way to represent the diversity of all the clients load profiles. The typical load curves can represent the energy consume habits of classes of consumers grouped on energy consumption levels and also activity sector. So far, these curves are described on the percentage unit, p.u., on the basis of the median power demand of the group. These allows the construction of demand curves (in Watts) of a given consumer since we have the information of his consumption level and activity and also energy consumption in a given period of time [2]. Typical load curves are obtained in measurement samples that typify many consumption levels. Typical load demand curves associated to the consumers connected to the low voltage networks (BT), are represented by a 24 points curve. So far, given the mensal energy consumption of a consumer (energy in kWh), we can calculated an average power demand, D_{av} in kW by the expression below:

$$D_{av} = \frac{Energy}{720}$$

The demand *{D(t), t=1..24}*, can be calculated by the expression below:

$$D(t) = d(t) * D_{av}$$

Where *d(t)* representes the demand points, in p.u. values, of the typical load demand curve.

Own consumer load curves

Own load curves are available in for consumers connected to the medium voltage distribution network (MT) and are represented by 2 or 4 points or demand levels.

Demand growth taxes

These taxes model the energy market growth on a planning horizon (2011-2020). They are obtained from market forecast techniques which can consider temporal series related to the number of consumers and energy.
The growth taxes can be specific to consumer class of activity sector (residential, commercial, industrial and to public illumination).

Demand adjustment

The demand adjustment is calculated based on measurements available by the energy distribution utility. The values correspond to feeders measurements.

VE Battery Data

For simulation purposes it is important to know the capacity and state of energy available for EV and PHEV batteries.
Therefore some variables and processes depicted below are valid on the battery reload process:

i) The capacity associated to each EV (through a deterministic or probabilistic approach);
ii) The determination of the specific loading point of each VE at the electric distribution network (through a deterministic or probabilistic approach);
iii) The definition of the reload period of time of each VE battery (deterministically or through a probabilistic approach with the use of a probabilistic distribution of the state of energy of the battery).

Capacity and load curves of the batteries

Two battery capacities were considered: 16kWh e 24 kWh (Mitsubichi-Imiev and Nissan-Leaf, respectively).
For modeling the batteries load curves it will be considered initially theoretical curves [3], [4], which will be validated or modified based on laboratory measurements.
The loading is a function of voltage and current values and depends on the load circuit type used associated to each type of charging point.
For simulation and analysis purposes we considered two types of loadings as follows: Normal Charging, low voltage single phase, 220 V and 16A; and Quick Charging, low voltage, three phase, 400V and 95A.
The modeling of the VE reload process is based on the load curve associated to each battery and the possible loading point through quick or slow chargers, besides the use of residential chargers.

Level of EV Penetration scenarios (2010 – 2020)

The analysis is done through the scenario construction of the vehicle role in Brazil in the period of 2010 – 2020. The algorithms used in the impacts evaluation and distribution networks limits defines processes that consider the EV penetration level, obtained through a market research and the elaboration of large horizon scenarios, besides the verification of network elements technical limits.

EV Alocation algorithm

The modeling of the loadings associated to the EVs in the network is done through a probabilistic or a deterministic algorithm. In the deterministic procedure the goal is to find, for a certain level of EV penetration, the critical location for energy losses and to verify the voltage profile of the network for this case.

In the probabilistic approach, for a certain EV penetration level, the EVs are distributed in a random pattern in the network following a predefined probability distribution.
For the attributions of the type of battery to each EV, the state of charge (SOC) of the battery and the time of the beginning of the loading, probability distribution functions based on data from field research or from theoretical

specifications are used.

EV Loading Types

The EVs loading profiles possibilities considered and analyzed are the uncontrolled or dumb charging [5] where the charge begins predominantly in the peak load hour, the charging with the influence of a dual tariff [6] for the peak and off-peak period and an approach that considers a smart charging [5] focusing a better network usage and control.

Distribution Network Impact

A power flow calculation for each of the 24 hours of the day is made and the loadings, voltage profiles, phase imbalance and energy losses are obtained for the distribution network impacts evaluation.

The distribution network impacts is defined through systematically diagnosis of the network elements, feeders, distribution transformers and low voltage networks loading analysis, besides the evaluation of the voltage profiles, phase imbalance and energy losses. It is possible, also to get the aggregated load curves in strategically located points in the network and an impact analysis for a specific planning horizon.

Spatial Allocation of EV Charging Stations

Another aspect considered in the methodology is the EV charging stations allocation procedure. The procedure is based in cluster technique that is used to distributed public quick and slow charging stations in the utilities distribution network.

SIMULATION PLATFORM AND ANALYSIS

SinapGrid is the simulation platform used and it has a number of functions for network analysis, allowing also the inclusion and development of new modules in a transparent way.

Among the main simulation platform characteristics, for the network impact analysis support under the EV presence, we can depict the following bellow:

i) Integrated modeling of all voltage levels in the distribution network (HV, MV and LV);
ii) Friendly network editor which allows the representation of all the network components (bus bars, lines, loadings, levels of demand throughout the day, capacitors banks, voltage regulators, 2 or 3 enrolment transformers, photovoltaic generators, electric vehicles, EV charging, etc.) by schematic diagram means or through geo-referenced diagrams;
iii) Power flow calculation modulus, for balanced and unbalanced networks, capable to solve meshed networks through many algorithms (Gauss, Newton-Raphson);
iv) Deterministic and probabilistic algorithms for the EV allocation;
v) Algorithm for the modeling of the various types of EV connection, dumb, dual tariff and smart charging;
vi) Evaluation reports of loadings, voltage profile an voltage unbalance and energy losses following the PRODIST [7] recommendations;
vii) Graphical reports to compare diferent EV penetration levels and the network impacts, emphasizing the loading parameters, voltage profile and losses.

CASE STUDY

The case study to be performed involves the inclusion of electric vehicles in real networks from EDP Bandeirantes e EDP Escelsa. For this case study it was considered scenarios of penetration and EVs limits of insertion.

Simulation and Analysis Framework

The network data utilized to build the MV and LV networks correspond to the utilities georeferenced GIS system's data. The case study's simulation environment consists of the distribution network of VVE-06 (circuit of Vila Velha substation). In figure 1 are represented the slow and quick EV chargers, which were inserted in the network by the SinapGrid Editor.

Impact Evaluation in the Distribution Network

The impact in the distribution network will be evaluated according to the impact in the electric network's elements, as segments that define the topology of a distribution network and also in an aggregate way at important points of the network. The aspects to be evaluated involve: determining the network's load, voltage profile, phase imbalance and losses. Figures 2 and 3 show the simulation performed for a penetration of 10% of EVs. The demand provided (from 19:00 to 20:00 h) to the network is 4.456 MVA without EVs and 5.674 MVA with EVs on the network.

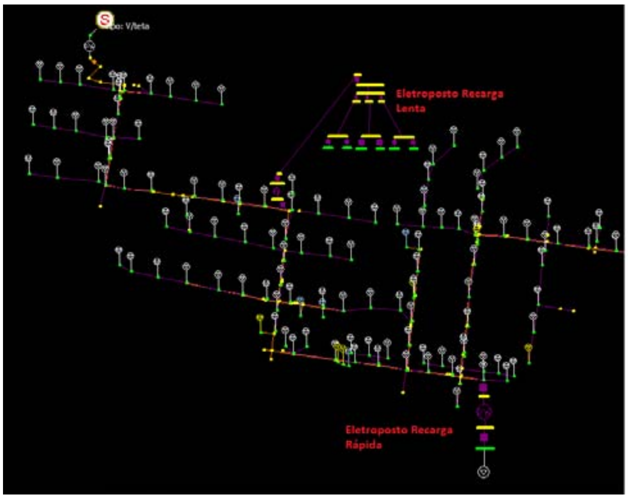

Figure 1. Slow and Quick EV Chargers inserted in the Network.

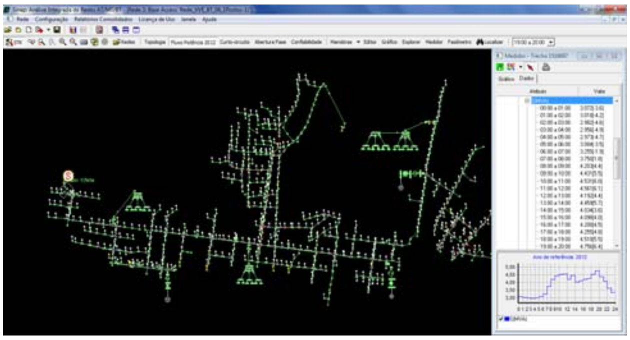

Figure 2. Demand Without Entering VE in the Network

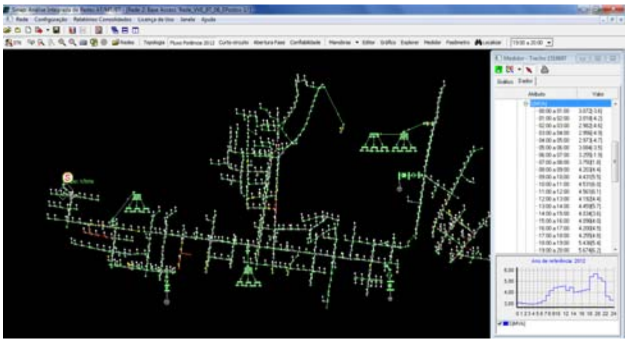

Figure 3. Demand with 10% of EVs on the network.

Figures 4 and 5 show the results of the loss for a EVs penetration of 10%. Without the insertion of EVs the network loss reach values of 194.31 MWh/month and with the 10% penetration it come to a 204.04 MWh/month loss.

CONCLUSIONS

This article presented a methodology for assessing the impact on distribution networks due to the inclusion of electric vehicles in the network. Through simulations in real networks it is possible to evaluate the impact on various components of the power grid: sub transmission lines, HV/MV SS transformers, MV primary network, MV/LV transformers and LV secondary network. Thus, issues such as diagnostics, load, voltage profile, imbalance between phases and losses were considered.

Perdas e Balanço de Energia Agregados | Perdas e Balanço de Energia da Rede

Quantidade de Equipamentos Agregados

Tipo de rede	Redes	Trafo	Cabo(km)	Regulador	Capacitor	Reator	Cons.A4	Cons.Res.	Cons.Com.	Cons.Ind
RedePri	1	0	10,191	0	3	0	14	0	0	[illegible]
RedeSec	92	92	15,877	0	0	0	0	3087	519	[illegible]

Balanço de Energia Agregado (MWh/mês (30dias))

Tipo de rede	(+) Comprada	(+) Recebida	(+) Gerada	(-) Transferida	(-) Consumida	(-) Perda	Perda (%)
RedePri	0,000	2.936,689	0,000	1.697,637	1.215,643	23,409	0,80
RedeSec	0,000	1.697,637	0,000	0,000	1.526,736	170,901	5,82

Figure 4. Losses Without the Insertion of EV's in the Network

Perdas e Balanço de Energia Agregados | Perdas e Balanço de Energia da Rede

Quantidade de Equipamentos Agregados

Tipo de rede	Redes	Trafo	Cabo(km)	Regulador	Capacitor	Reator	Cons.A4	Cons.Res.	Cons.Com.	Cons.In
RedePri	1	0	10,191	0	3	0	14	0	0	
RedeSec	92	92	15,877	0	0	0	0	3087	519	[illegible]

Balanço de Energia Agregado (MWh/mês (30dias))

Tipo de rede	(+) Comprada	(+) Recebida	(+) Gerada	(-) Transferida	(-) Consumida	(-) Perda	Perda (%)
RedePri	0,000	3.047,806	0,000	1.807,299	1.215,283	25,225	0,83
RedeSec	0,000	1.807,299	0,000	0,000	1.628,484	178,815	5,87

Figure 5. Losses Considering the 10% EV's Network Insertion

REFERENCIAS

[1] P. Richardson, J. Taylor, D. Flynn, A. Keanne. *Stochastic Analysis of The Impact of Electric Vehicles on Distribution Networks*. CIRED 21st. International Conference on Electricity Distribution. Frankfurt, 6-9 June, 2011. Paper 1158.

[2] N. Kagan, C. C. B. Oliveira, E. J. Robba. *Introdução aos Sistemas de Distribuição de Energia Elétrica*. Editora Edgar Blucher. São Paulo. 2005.

[3] J. Taylor, A. Maitra, M. Alexander, D. Brooks, M. Duvall. *Evaluation of The Impact of Plug-in Electric Vehicle Loading on Distribution System Operations*.

[4] K. Qian, C. Zhou, M. Allan, Y. Yuan. *Modeling of Load Demand Due to EV Battery Charging in Distribution Systems*. IEEE Transactions on Power Systems. Vol. 26, No. 2, 2011.

[5] J. A. P. Lopes, F. J. Soares, P. R. M. Almeida. *Integration of Electric Vehicles in the Electric Power Systems*. Proceedings of the IEEE, Vol. 99, No. 1, January 2011.

[6] ANEEL - Agencia Nacional de Energia Elétrica. *Estrutura Tarifária para o Serviço de Distribuição de Energia Elétrica. Sinal Econômico para a Baixa Tensão*. Nota Técnica N° 362/2010-SER-SRD/ANEEL. Brasília 6 de Dezembro de 2010.

[7] ANEEL - Agencia Nacional de Energia Elétrica – Procedimentos de Distribuição de Energia Elétrica no Sistema Elétrico Nacional – PRODIST – Módulo 2 – Planejamento da Expansão do Sistema de Distribuição. Resolução Normativa N° 465/2011.