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Investigation on Using Low Voltage Automatic Regulation to Minimize the Impacts of Charging Plug-in Electric Vehicles in Distribution Systems

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Abstract. This paper firstly presents the impacts of uncoordinated Plug-in Electric Vehicles (PEVs) charging in a real Brazilian Distribution System (DS). Four scenarios were elaborated with different PEVs penetration levels and the results show increased voltage unbalance, system losses, and violations of the steady-state voltage limits, even in the presence of an automatic voltage regulator installed in the Medium Voltage (MV) network. Then, as the main contribution, the potential usage of automatic voltage regulation at the Low Voltage (LV) network was investigated to minimize the negative impacts of uncontrolled PEV charging on DS steady-state operation. It is important to highlight that this is not a common practice of utilities in Brazil. The obtained results showed that regulating the voltage at the LV side could be an effective solution to keep the voltages within statutory limits.

Distribution Systems and PEV Model. The electrical system used to study the impacts of PEVs was a real Brazilian radial DS, with an MV system and 47 LV networks (i.e., systems with voltages below 1.0 kV), modeled in the OpenDSS software. Table I shows the key characteristics of these systems and Fig. 1 shows the single-phase diagram of this radial system, showing only the topology of the MV network.

Table I. – Characteristics of the test system

Name	Data
Length	4.71 km
Short-circuit level at the substation transformer	525 MVA
Voltage at the MV level	13.8 kV
Number of MV customers	159
Voltage at the LV level	0.22 kV
Peak load of LV customers[1]	4.1 MW
Number of LV customers	1,659

[1]The peak load refers exclusively to LV customers because the PEVs are allocated at the LV networks.

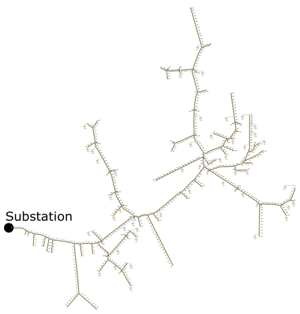

Fig. 1. Single-phase diagram of MV network

Fig. 2 shows a schematic diagram of the test system with one generic LV network of the 47 under analysis and Fig. 3 shows the residential load shape assigned to each LV customer (customer unit – CU).

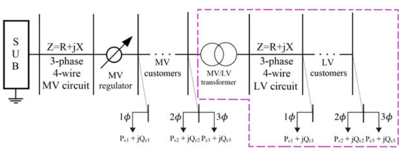

Fig. 2. Schematic diagram of the electrical power system (the purple dotted line represents one generic LV network)

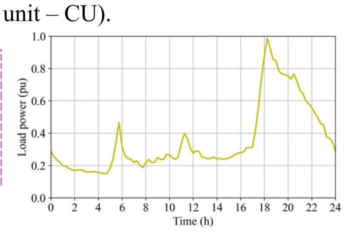

Fig. 3. Customer load shape

The main features of the PEV model are present in Table II. Fig. 4 shows an example of level 1 and level 2 charging profiles.

Table II. – Features of the PEV model

Name	Data
Battery capacity	40 kWh
Battery useable	36 kWh
Electric range	240 km
Efficiency	0.164 kWh/km
Charge power level 1	1.92 kW
Charge power level 2	6.6 kW

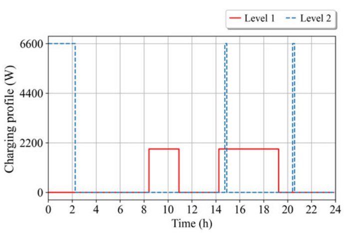

Fig. 4. Example of a level 1 and 2

Methodology. The following scenarios are considered:

1) Base scenario: there was no PEV allocated in the DS;
2) P_l 5% scenario: there were 5% of CUs with an allocated PEV;
3) P_l 15% scenario: there were 15% of CUs with an allocated PEV;
4) P_l 35% scenario: there were 35% of CUs with an allocated PEV.

P_l means here the percentage resulting from the ratio of the number of customers who have a PEV (CU_{PEV}) to the total number of customers (CU_{total}) in the entire system, as in (1). Also, the simulation algorithm applied to the test system is depicted in Fig. 5.

$$P_l\% = \frac{CU_{PEV}}{CU_{Total}}.100 \quad (1)$$

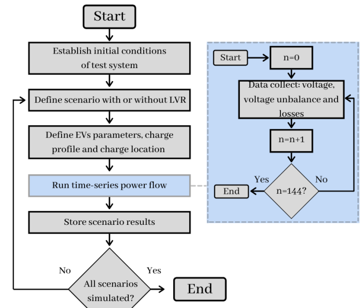

Fig. 5. Complete algorithm

Results. The limits established by regulation in Brazil for LV networks are 3% for the maximum voltage unbalance ($\%VUF_{max}$) and 0.92 pu for the minimum voltage (V_{min}).

A. Table III shows the $\%VUF_{max}$, active power losses for 24h time-series power flow, and V_{min} before low voltage regulation (LVR):

Table III. – Results before LVR

Scenarios	$\%VUF_{max}$ (%)	Losses (kWh)	V_{min} (pu)
Base scenario	2.27	413.47	0.92
P_l 5% scenario	5.51	441.23	0.91
P_l 15% scenario	4.68	509.29	0.89
P_l 35% scenario	8.95	646.56	0.79

B. Table IV shows the $\%VUF_{max}$, losses, and V_{min} after LVR:

Table IV. – Results after LVR

Scenarios	$\%VUF_{max}$ (%)	Losses (kWh)	V_{min} (pu)
Base scenario	1.83	418.20	0.94
P_l 5% scenario	3.37	448.30	0.94
P_l 15% scenario	4.54	511.78	0.91
P_l 35% scenario	6.24	637.32	0.89

Discussion and conclusion. This paper presented an investigation on using LVR to minimize the impacts of charging PEVs in DS. The voltage drop was one of the most serious impacts resulting from the connection of PEVs to the electrical grid. Furthermore, the uncontrolled charging of PEVs can result in both a decrease and increase of the *%VUF* among the scenarios, leading to severe violations. Moreover, the more unbalanced the system becomes, the higher the active losses. Also, the voltages in the LV networks exceeded the limits, but the same did not occur for the MV network. For this reason, the automatic voltage regulator has not mitigated all the violations in the LV networks. So, nine LVR devices were implemented in the system under analysis, and the results have shown that the LV networks where the LVRs were allocated experienced an improvement of the voltage profile of the system as a whole. The *%VUF* was reduced, since the LVRs were single-phase and could operate individually. Also, the magnitude of voltage violations were significantly reduced, but the LVR devices did not prevent them to occur. The LVRs prevented violations in the critical voltage range for all scenarios, which is the worst-case scenario, avoiding compulsory compensation by utilities for this range.

Therefore, in cases where controlled PEV charging strategies may not be available to PEVs owners, thus applying grid-based solutions, such as LVR, could be an interesting and feasible approach for utilities.