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Abstract. Electric vehicles (EV) offer a great potential to address the integration of renewable energy sources (RES) in the power grid, and thus reduce the dependence on oil as well as the greenhouse gases (GHG) emissions. The high share of wind energy in the Portuguese energy mix expected for 2020 can led to eventual curtailment, especially during the winter when high levels of hydro generation occur. In this paper a methodology based on a unit commitment and economic dispatch is implemented, and a hydro-thermal dispatch is performed in order to evaluate the impact of the EVs integration into the grid. Results show that the considered 10 % penetration of EVs in the Portuguese fleet would increase load in 3 % and would not integrate a significant amount of wind energy because curtailment is already reduced in the absence of EVs. According to the results, the EV is charged mostly with thermal generation and the associated emissions are much higher than if they were calculated based on the generation mix.

Keywords: CO2 emissions, Electric vehicle, Renewable integration, Power grids, Wind energy, Economic dispatch.

1 Introduction

Nowadays, worldwide a large share of mobility relies on passenger car use, and this share is expected to increase even further, especially in developing and emerging countries [1]. Transportation sector is largely dominated by internal combustion engines, relying almost entirely on oil as primary energy source (94~% of the world energy used for transportation in 2007) [2], and contributes largely to GHG emissions.

In the last years, energy and environmental concerns led to a fast growing of the renewable energies, motivated efforts for increasing energy efficiency, and promoted the search for new transportation solutions.[4] Considering the efficiency of the EV as well as their potential to address the integration of RES, the use of electricity as fuel in the electric vehicles has a great potential to reduce the dependence on oil and the GHG emissions, as well as to provide a low cost alternative to liquid carbon fuels.

Portugal is highly dependent on external energy resources (81 % in 2009) [3], however the Portuguese territory presents a large potential in terms of RES with a special focus on hydro, wind, solar and biomass. Great efforts have been made in the last years, in terms of RES installation and Portugal in one of the leading countries in the EU in terms of electricity generation from renewable sources [4].5 In Portugal, accordingly with the "EU 20-20-20 target", the strategic energy guidelines established by the Portuguese government point that in 2020, 31 % of the final energy and 60 % of the electricity produced must be from renewable sources [5]. Accordingly, targets for installed hydro, wind and solar power capacities were defined as 8600 MW, 6875 MW (revised) and 1500 MW respectively [6].

As one of the major challenges in integrating large amounts of renewable energy in the power systems, is dealing with the intermittent nature of these sources [7-8], storage is a crucial issue. Thus, the distributed storage capacity provided by the integration of the EV in the transportation sector may play a significant role to overcome renewable variability and contribute to mitigate potential unbalance between the electricity generation and demand [9], as well as contribute to reduce GHG emissions. However, when substituting ICEs by EVs, the potential gains achieved by this integration, both in terms of renewable sources integration and emissions, are highly dependent on the generation mix and time of charge. In [10] a hypothetical penetration of EVs into the present (2011) power grid was already studied. In this work the impact of the EV integration into the Portuguese power system in terms of additional power generation, CO2 emissions, renewable energy integration and thermal generation costs, will be assessed under a specific night charge scenario with a 10 % of EV penetration, for the year of 2020.

2 Relationship to Internet of Things

As the power grid integrates increasing amounts of distributed generation, the need to improve power quality, transmission efficiency and renewable energy integration increases the urge for smart grids implementation. Furthermore, in a growing renewable generation environment, the integration of the electric vehicle into the power grid will rely on networks to charge/discharge in a controlled manner (Vehicle to Grid) and thus improve renewable generation integration. In such environment the EV and the Smart Grids will be integrating and essential elements of the Internet of Things (IoT).

[4]Light-duty vehicles (LDV) account for most of the world energy use and GHG emissions in the transportation sector [2].

[5]Portuguese figures are well above the European Union objective for 2010.

3 Objectives and Methodology

In 2010, the Portuguese government estimated a 10 % penetration of EVs in the Portuguese vehicle fleet by the year of 2020 [5]. The main purpose of this work is to study the impact of those EVs on the renewable integration in the power system as well as the environmental impacts. In particular it is intended to answer the following questions: Would the integration of the EVs into the grid help to integrate wind power and reduce potential wind curtailments? What would be the benefit in terms of CO2 reduction that could be achieved from that integration?

A methodology based on a unit commitment and economic dispatch is implemented using the General Algebraic Modeling System (GAMS), in order to evaluate the impact of the EVs integration into the grid. The methodology proposed is an evolution of the model used in [11]. The optimization procedure here proposed performs the economic dispatch of the thermal, storage hydro and storage pumped-hydro technologies, in order to minimize the variable generation costs. Data concerning the run-of-the-river hydro power plants, the renewable generation and the load is given as input data, previously forecasted based on the historic 2011 time-series data. From this methodology, the thermal generation costs, the CO2 emissions and the potential need for wind generation curtailment is computed. The additional EVs load is then added to the baseline time-series and the impact on the thermal generation, CO2 emissions and renewable integration is assessed. The objective function considered for the economic dispatch includes the generation and start-up costs of the thermal units, assigns a penalty to wind curtailment, and is expressed as:

$$\min \sum_{t=1}^{T} \left\{ \left[C_{RC} . P_{RC}(t) \right] + \sum_{j=1}^{J} \left[C_G^j . P^j(t) . \delta t . u^j(t) + C_{SU}^j . y^j(t) \right] \right\} . \qquad (1)$$

where $P^j(t)$ is the power generated by the thermal unit j at moment t, in MW, $P_{RC}(t)$ is the renewable generation curtailment at moment t, in MW, $y^j(t)$ and $u^j(t)$ are a binary variables which indicate if the thermal power unit j starts-up/is running at moment $t, \delta t$ is the time interval between t and $t+1, T$ is the number of time-series periods and J is the number of thermal units. Also C_G^j is the power generation cost of the unit j, in €/MWh, C_{SU}^j is the start-up cost of the unit j, in € and C_{RC} is the renewable generation curtailment penalty, in €/MW.

Subjected to the following constraints:

3.1 Thermal Units Constraints

Thermal units are subjected to restrictions concerning maximum and minimum generation limits and maximum ramp-down and ramp-up rates [12], which are expressed by (2), (3) and (4):

$$P^j_{Min} \leq P^j(t) \leq P^j_{Max} \ . \tag{2}$$

$$P^j(t) - P^j(t-1) \leq P^j_{up} \ . \tag{3}$$

$$P^j(t-1) - P^j(t) \leq P^j_{down} \ . \tag{4}$$

In (2), (3) and (4),P^j_{up} and P^j_{down} correspond to the ramp-up and ramp-down power rates, respectively.

3.2 Reservoir Hydro Constraints

Limits to the maximum discharge, stored energy and final energy of reservoir hydro unit are imposed by (5), (6), (7) and (8), where $E_H(t)$ is the stored energy in the unit at the moment t, in MWh, $P_H(t)$ is the power of the hydro unit at the moment t, in MW and $E_{HInf}\ (t)$ corresponds to the given inflow expressed in energy units (MWh).

$$0 \leq P_H(t) \leq P_{H\,Max} \ . \tag{5}$$

$$E_H(t) = E_H(t-1) - P_H(t)\,.\,\delta t + E_{H\,Inf}(t) \ . \tag{6}$$

$$E_{H\,Min} \leq E_H(t) \leq E_{H\,Max} \ . \tag{7}$$

$$E_{H\,Fin} - E_{H\,Init} = \sum_{t=1}^{T} E_{H\,Inf}(t) - \sum_{t=1}^{T} P_H(t)\,.\delta t \ . \tag{8}$$

3.3 Pumped-Hydro Constraints

For the pumped-hydro unit the following constraints apply:

$$0 \leq P_{PH}(t) \leq P_{PH\,Max} \ . \tag{9}$$

$$-P_{PH\,Max} \leq P_{PHp}(t) \leq 0 \ . \tag{10}$$

$$E_{PH\,Min} \leq E_{PH}(t) \leq E_{PH\,Max} \ . \tag{11}$$

$$E_{PH}(t) = E_{PH}(t-1) - \left[P_{PHp}(t)\,.\,\eta_{PH} + P_{PH}(t)\right].\delta t + E_{PH\,Inf}(t) . \tag{12}$$

$$E_{PH\,Fin} - E_{PH\,Init} = \sum_{t=1}^{T} E_{PH\,Inf}(t) - \sum_{t=1}^{T} \left[P_{PHp}(t)\,.\,\eta_{PH} + P_{PH}(t)\right].\delta t \ . \tag{13}$$

$$P_{PH}(t) + P_{PHp}(t) \leq P_{PH\,Max} \ . \tag{14}$$

In (9), (10), (11), (12), (13) and (14)$E_{PH}\ (t)$ is the stored energy in the unit at the moment t, in MWh, $P_{PHp}\ (t)$ is the power of the pumped-hydro unit at the moment

t, when pumping, P_{PH} (t) is the power of the pumped-hydro unit at the moment t when generating, η_{PH} is the pumping efficiency and E_{PHInf} corresponds to the given inflow expressed in energy units (MWh).

3.4 System Constraints

There are constraints which are applied to the overall system and do not consider a specific technology. The system balance and the reserve power are expressed by (15) and (16), where $P_L(t)$ is the load at time t, $P_R(t)$ is the sum of the renewable powers (PRE) with the run-of-the river hydro and l represents the transmission losses.

$$\sum_{j=1}^{J} P^j(t) + P_H(t) + P_{PH}(t) = (1+l)\,P_L(t) - P_R(t) + P_{RC}(t) + P_{PHp}(t)\,. \qquad (15)$$

$$\sum_{j=1}^{J} P^j_{Max}\,.\,u^j(t) + P_{H\,Max}\,.\,u^j(t) + P_{PH\,Max}\,.\,u^j(t) = (1+l)\,.\,P_L(t) + P_{RES}(t)\,. \qquad (16)$$

4 EV Modeling and Charging Scenario

To evaluate the impact of the EV, both in terms of wind integration and CO_2emissions, a night charge scenario is considered. This off-peak charging scenario is assumed as the most likely to occur in the next years. In this scenario, most consumers are expected to delay the starting of EVs charge until 10 p.m. to benefit from the off-peak low electricity prices as well as due to eventual power constraints at the residential level.[6]

It is assumed that the EVs are equipped with a medium 24 kWh lithium battery, and drive 38 km a day with a fuel consumption of 0.167 kWh/km. Charging power is considered to be 3.3 kW with an 85% of charge efficiency, which includes distribution grid losses. Based on previous assumptions the EVs are modeled as electric loads and a normalized vehicle charge profile is created, according to the scenario considered. To simulate the beginning of EVs charge, a normal distribution (μ = 10 *p.m.*, σ = 1*h*) is used.

5 Case Study

5.1 Framework

In this work, the proposed methodology is applied to the Portuguese case study for the year of 2020, taking into account the main characteristics of the power system and the estimated vehicle fleet.

[6]Most of Portuguese households have a contract capacity lower than 7 kW [13].

The EV fleet is assumed to be 600 thousand vehicles which correspond to about 10 % of the Portuguese LDV fleet estimated for the year 2020, with base on 2010 registration data [14]. Considering the mean occupation of light passenger vehicles referred in [4] and [15] and passenger kilometers data [4], EVs are assumed to drive 38 km a day. Also EVs are assumed to charge according to the off-peak scenario referred previously.

Concerning the power system the values for 2020 installed capacity are considered according to the planned additions and decommissioning of power plants [5-6], [16]. By this year the overall installed capacity in the Portuguese system is expected to reach 28.8 GW, from which 9.5 GW (33 %) correspond to large hydro (4 GW of pumped-hydro), 7.2 GW (25 %) correspond to the thermal technologies (Coal and CCGT) and 12.1 GW (42 %) correspond to the RES technologies.[7] According to the estimated values, by this year the energy consumption will be 56.3 TWh.

Coal, natural gas and CO_2 prices were based on 2011 data and were considered respectively, 87.6 €/ton for coal, 22.5 €/MWh$_t$ for natural gas and 10 €/ton for the CO_2 emissions allowances. Efficiencies considered for coal and fuel-oil thermal units ranged from 37 % to 38 % and a55 % efficiency was considered for the CCGT units [17].

5.2 Simulation Results

Based on the model and previously referred assumptions, simulations were carried out for the Portuguese power system for one entire year of operation, in an hourly basis. In Fig. 1 the generation profiles corresponding to winter and summer typical periods are presented.

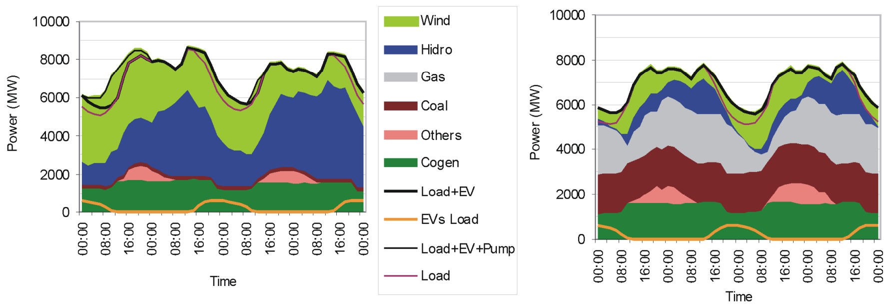

Fig. 1. Generation by technology - typical wet (left) and dry (right) periods.

Table 1 presents the simulation results obtained concerning load, power generation, curtailment, costs and emissions for the cases of the load without and with the EV charging.

The EV column of table 1 show the impact of the EV on the power system considering the marginal methodology used. The results show that the

[7] Wind power will correspond to 23.7 % of the overall installed capacity.

considered10 %penetration of electric vehicles in the Portuguese fleet would lead to an increase of 3 % in the electrical load but would not integrate a significant amount of curtailed energy. This results from the fact that the curtailment in the base case is already reduced, due the high values of hydro power installed, which comprises a significant share of pumped-hydro units.

Table 1. Simulation results

	Load	Load+EV	EV
Load (GWh)	56281	57912	1631
Generation (GWh)	57215	58783	1568
Wind Curtail. (GWh)	89.4	1.9	-87.5
Hydro Gen. (GWh)	16121	16458	337
Thermal Gen. (GWh)	10798	12028	1230
CCGT	1308	1823	515
Coal	9490	10206	716
Emissions (ton CO2)	9038	9872	834
Total Cost (M€)	474	528	55
Average Cost (€/kWh)	0.0084	0.0091	0.0334
Average Thermal Cost (€/kWh)	0.0445	0.0446	0.0450
Average Emissions (g CO2 /kWh)	160.6	170.5	511.5
Avg Thermal Emissions (g CO2 /kWh)	849.5	833.1	688.5

The additional generation required to supply the electric vehicles is mostly thermal (45.6 % coal and 32.8 % CCGT) as can be verified in table 1.

Also in table 1 one can see that the marginal generation mix has a specific emission of 511.5 gCO_2/kWh, which leads to the EV emissions of 85.3 g CO_2/km. This compares to a 33.4 g CO_2/km of emissions that would result from the total generation mix emissions of 170.5 g CO_2/kWh.

6 Conclusions

The electric vehicle, seen as a distributed storage system, has a potential to reduce eventual wind curtailments and, therefore, increase the wind integration in the power system. To evaluate this contribution, a methodology based on hydrothermal coordination, unit commitment and economic dispatch was applied to the Portuguese power system for the simulation of an entire year of operation. Results show that the considered 10 % penetration of electric vehicles in the Portuguese fleet would lead to an increase of 3 % in the electrical load and would not integrate a significant amount of wind energy. This is because curtailment is already low in the base case due to the significant pumped-hydro power installed. As a consequence, electric vehicles are charged mostly with thermal generation and the associated emissions are much higher than those that would be obtained considering the generation mix emissions.

In fact, 85 g CO_2/km were computed for the electric vehicle in the marginal approach used in this work, which compares to 33 g CO_2/km of emissions resulting from the generation mix emissions approach.

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