Modeling the Operation of Electric Vehicles in an Operation Planning Model

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Motivation

- Determine the impact of EVs charging and discharging process in the integration of RES and system operation
  - Long-term strategic studies
  - Impact of total operation cost, CO2 emissions, marginal costs
  - Wind curtailment
  - Determine EV charging strategies

Content

1. Short-term Operation Model
2. EV Representation
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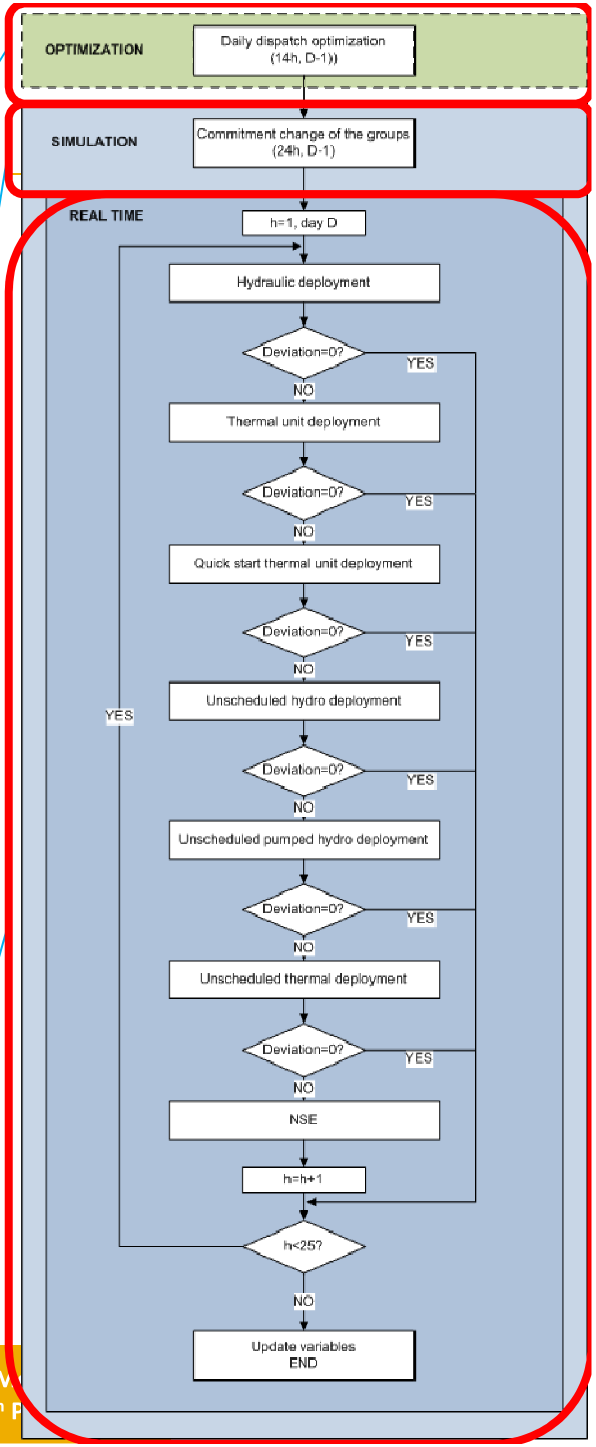
Short-term Operation Model

ROM Short-term Operation Model

Determines the scheduled daily program (**unit commitment and daily economic dispatch**) for all the generators, considering the demand and forecasted (expected) wind power generation one day in advance.

These estimations may be altered by **realizations of the uncertain parameters** (electricity demand, intermittent generation, availability of the generators) that are taken into account

Deployment of operating reserves in real-time.



Time Framework

- **Yearly scope** with a **daily time frame** and an **hourly time unit**
- **Chronological system operation** for the whole year. Initial states of the generating units, for every day, are those of the last hour of the previous day.

UC Optimization Model

- Optimization model allows determining the technical and economic impact of EVs. It is a **day-ahead perfect market model** including **EV operation**.
- Special emphasis put in RES (**wind**, **solar PV**, **CSP**) integration
- In particular, EVs are modeled as potential providers of energy and operating reserve services scheduling the charge and discharge (V2G) of their batteries.
- Include specific constraints modeling of the state-of-charge (SOC) of the batteries considering several states where EVs can be (either, connected or disconnected from the grid or moving). Besides, the provision of operating reserves by the EVs and its impact on the battery SOC.

Mathematical Formulation (i)

- Objective function
  - **Minimizes the operation costs** plus some deficit costs introduced for violating some constraints

Mathematical Formulation (ii)

- **Demand and reserve constraints**
  - **Balance of generation** (thermal units, storage hydro and pumped storage hydro plants) and demand
  - **Upward and downward reserves** provided by generating units
- **Thermal unit constraints**
  - Logical relation of **commitment, start-up and shut-down** of any unit
  - Output offered in the energy market plus the power reserve offered as operating reserve of each thermal unit is bounded by its maximum output
  - Unit variation output, **including the upward and downward power reserves**, are limited by up and down hourly ramps
  - **Minimum up time** and **minimum down time**.

Mathematical Formulation (iii)

- **Hydro plant constraints**
  - Output, including the power reserve, for each hydro plant is bounded by the maximum output
  - Balance of the hydro reservoir level includes consumption and generation of the storage hydro plant and spillage and natural inflows
- **CSP plant constraints**
  - Irradiation energy received is transformed in either CSP plant generation or charging or discharging power of the storage
  - Balance of the CSP plant storage
  - Hourly ramp constraints in the charge and discharge of the CSP plant

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EV Representation

EVs

- Provide **energy services** (allow charge and discharge (V2G) activities)
- Provide **up and down power operating reserve services**
- States in the **use of the batteries** of the EVs, depending whether the vehicle is connected, disconnected or moving:
  - The **connected** ones can be charging or discharging their batteries
  - **Disconnected** vehicles, which are stopped, do not have energy losses
  - **Moving** EVs have a pattern of distance and driving time (in fact, the energy consumed) given
- Point of view of the SO

EV Data

- **Mobility patterns**
  - Daily distance
  - SOC at the beginning of the day
  - Usage for every hour
  - Connection for every hour
- **EV fleets (type of uses)**
  - Number of EV
  - Mobility patterns used
- **Battery characteristics**
  - Maximum and minimum SOC
  - Efficiencies (GTB, BTW, BTG) (Grid-To-Battery, Battery-To-Wheel, Battery-To-Grid)
  - Maximum charging and discharging rates
  - Maximum power output

EV Modeling Characteristics. Smart charge/discharge

- **Battery energy inventory**
  - SOC at an hour + charge – discharge – transportation use = SOC at next hour
  - When EVs become disconnected or begin moving they take their battery energy out from the connected state
- **Provision of battery energy for power reserve**
  - Up and down power reserve offered implies to keep some energy at the battery
- **Use incompatibility**
  - At any hour EV has to be charging or discharging
- **Maximum charge** bounded by the remaining battery energy times the percentage of connected EV
- **Hourly charging and discharging power ramps** of the batteries
- **Bounds on the upward and downward power reserve**

EV Changes in the Mathematical Formulation

- Demand and reserve constraints
  - Balance of generation (thermal units, hydro and pumped storage hydro plants) and demand **including production and consumption of the EVs**
  - Upward and downward reserves provided by generating units **including the contribution of the EV to the reserves**

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Case Study

Main Attributes

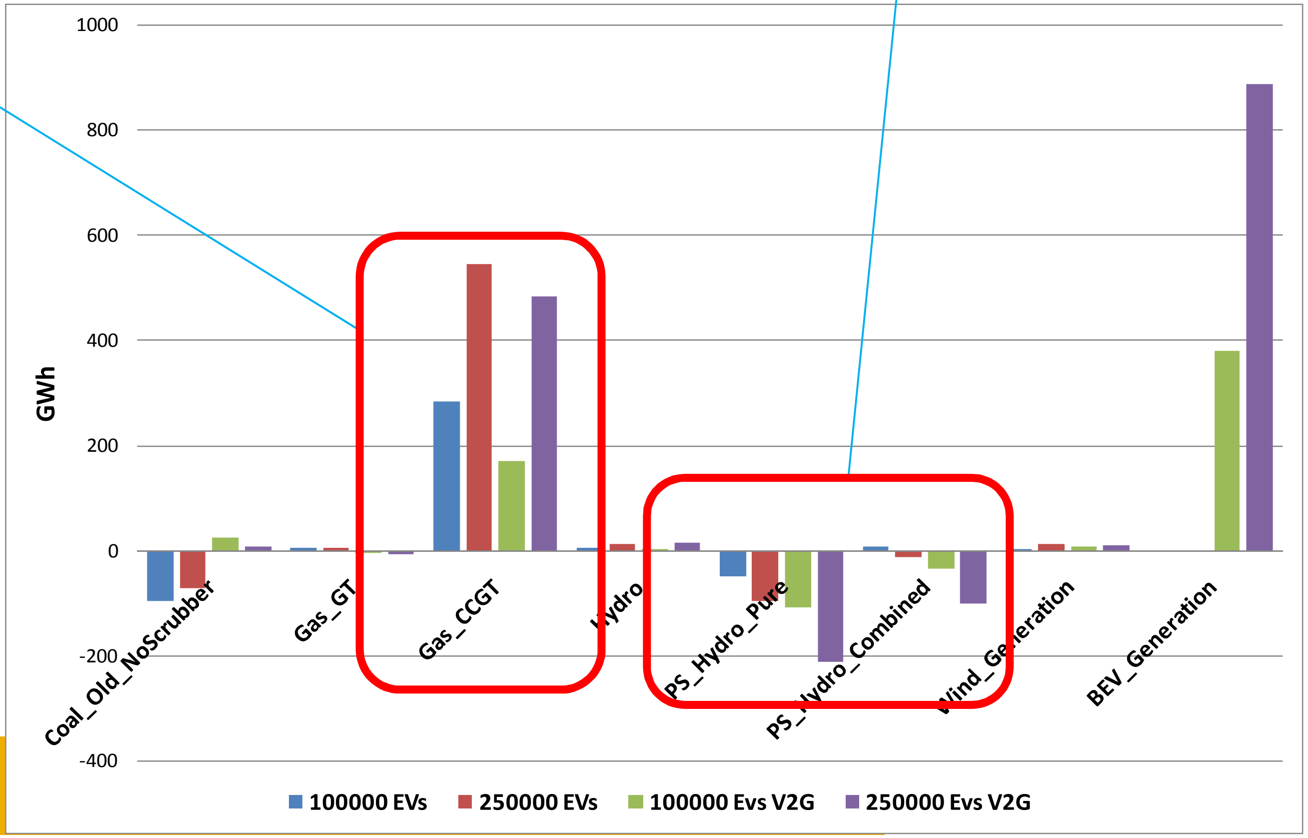
- Prospective of Ministry of Industry for 2016
- Scenarios
  - 100000 EVs (~0.5 %) of total fleet
  - 250000 EVs (~1 %) of total fleet
  - With and without V2G
- EV:
  - 0.15 kWh/km
  - 25 kWh battery capacity
  - 90 % conversion efficiencies

Demand and reserve		
Yearly Energy	323.4	TWh
Winter Peak	59135	MW
Summer Peak	44511	MW
Minimum Load	18385	MW
Peak/Off-Peak Ratio	3.2	p.u.
Max Upward Reserve Required	5974	MW
Max Downward Reserve Required	1774	MW
Net installed capacity		
Nuclear	7000	MW
Coal	6338	MW
CCGT	25026	MW
Gas Turbines	2100	MW
Hydro	16500	MW
Pure Pumped Storage Hydro	2432	MW
Combined Pumped Storage Hydro	2985	MW
Wind Generation	29778	MW
CHP	9008	MW
Other RES	10758	MW
Yearly Natural Hydro Inflows	28.5	TWh
Price		
Nuclear	0.002	€/Mcal
Coal	0.014	€/Mcal
Natural Gas	0.025	€/Mcal
CO2	30	€/t CO2

Impact on energy for the different scenarios

CCGT thermal units increase their generation due to EVs use while coal units decrease generation

Pumped storage hydro plants decrease generation in the four scenarios because EVs now play a similar storage role. Degradation is not included



Impact in costs for the different scenarios

Average cost of the energy increases with increasing number of EVs and decreases when V2G

Charging cost for each EV without V2G is less than 0.4 €/day and halves when EVs provide V2G

	0 EVs	100000 EVs	250000 EVs	100000 EVs V2G	250000 EVs V2G
Average cost of total demand [€/MWh]	26.03	26.06	26.10	26.01	26.00
Marginal cost of energy consumed by EV [€/MWh]		71.25	66.08	33.68	38.72
Yearly incremental cost per EV [€]		140	130	66	76
Value of V2G per EV [€]				74	54

Impact on WG integration for the different scenarios

Wind curtailment decreases with the EVs

Each EV is able to integrate from 38 up to 69 kWh of wind generation from a total of 2000 kWh consumed in driving every year

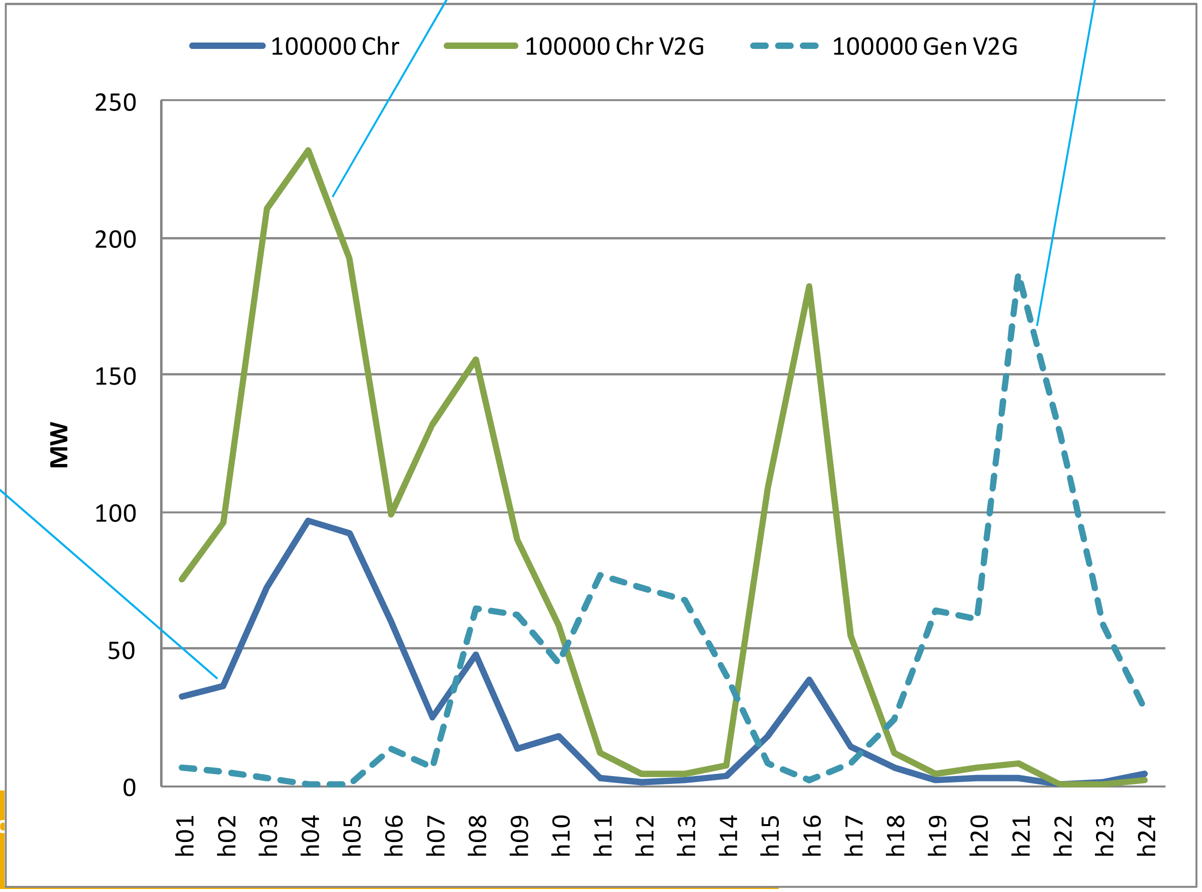
	0 EVs	100000 EVs	250000 EVs	100000 EVs V2G	250000 EVs V2G
WG curtailment [GWh]	27	23	14	20	15
WG integrated by each EV [kWh]		38	51	69	45

Average charging and discharging profiles

Charge is mainly done at off-peak hours and between peak hours in the afternoon

Charge with V2G

Discharge with V2G



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Final Remarks

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Final Remarks

- Summary
  - Short-term operation model oriented to model RES and EVs
  - Combines a unit commitment and economic dispatch, a Monte Carlo simulation of demand and generation (including RES) uncertainty and deployment of operating reserves
  - Special emphasis on modeling the impact of EV operation
  - 2016 Spanish case study presented with different EV penetration levels and V2G capability
- Comment
  - Model is being used in some European projects for evaluating the impact of EVs in the integration of RES generation in some countries

Thank you very much

Any question?

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