Impact of EV charging on electrical grids and V2G services

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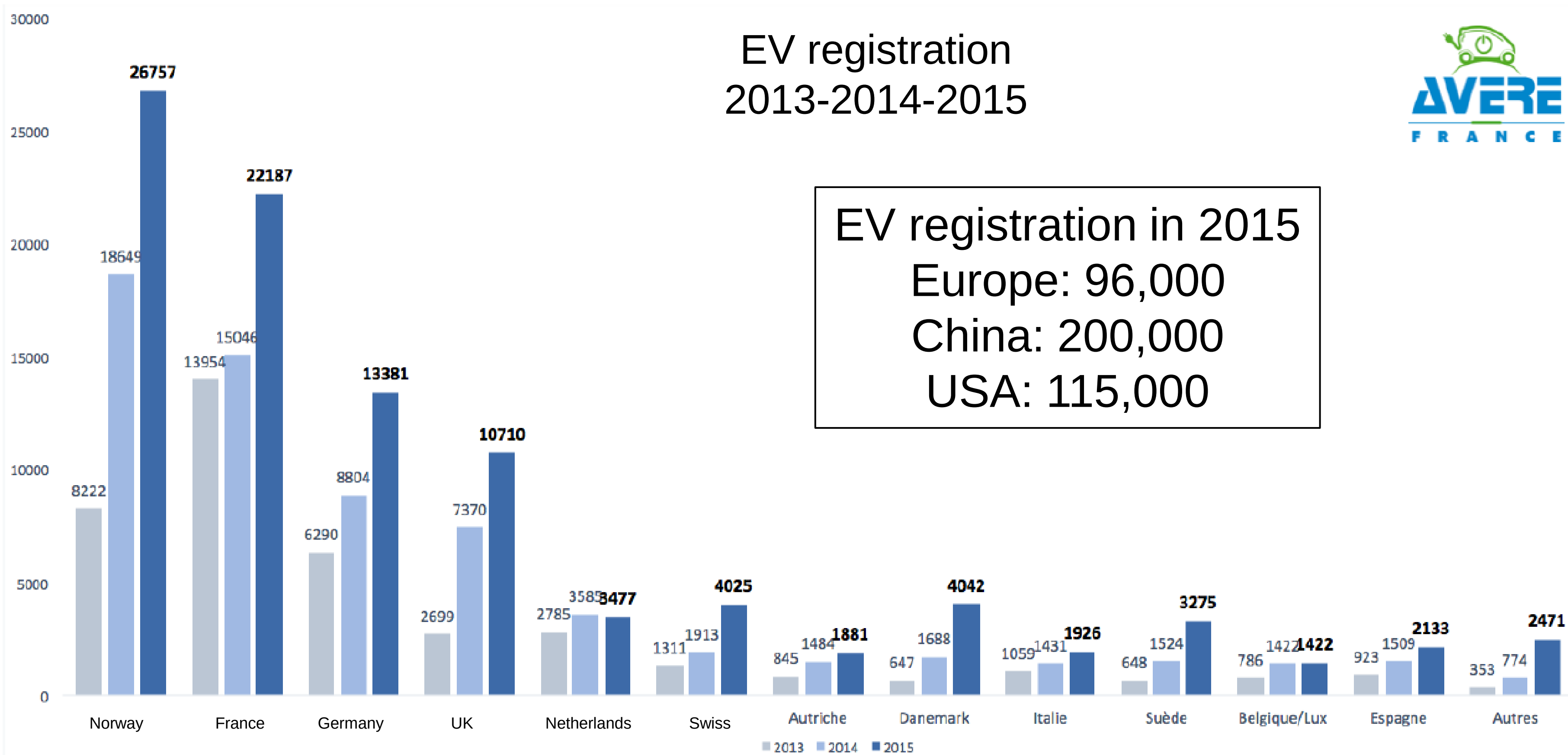
Outline

1. Energy transition: electric vehicles and renewable sources
2. Electric vehicles: roll-out
3. Electrical system:
   - operational constraints
   - Distributed resources integration
4. EV: Energy needs and charging power
5. EV: grid impact
   - Global scale
   - Local scale
6. Flexible charging and V2G: which services & value ?
   - EV → distributed storage
   - Contribution to balancing, Distribution grid (congestion, voltage, renewable sources)
7. Some case study
8. EV inside the grid → Research projects and challenges

Energy transition

- Mobility with low CO_2 emissions
  - CAFE curves (Corporate Average Fuel Economy)
    - *95g/km in 2020*
  - Reduction of urban pollution
  - Technological solutions
    - *Battery EV*
    - *Hybrid EV*
    - *Fuel cell EV (less/not mature)*
- Development of renewable energy sources
  - Photovoltaic
  - Wind
  - Biomass

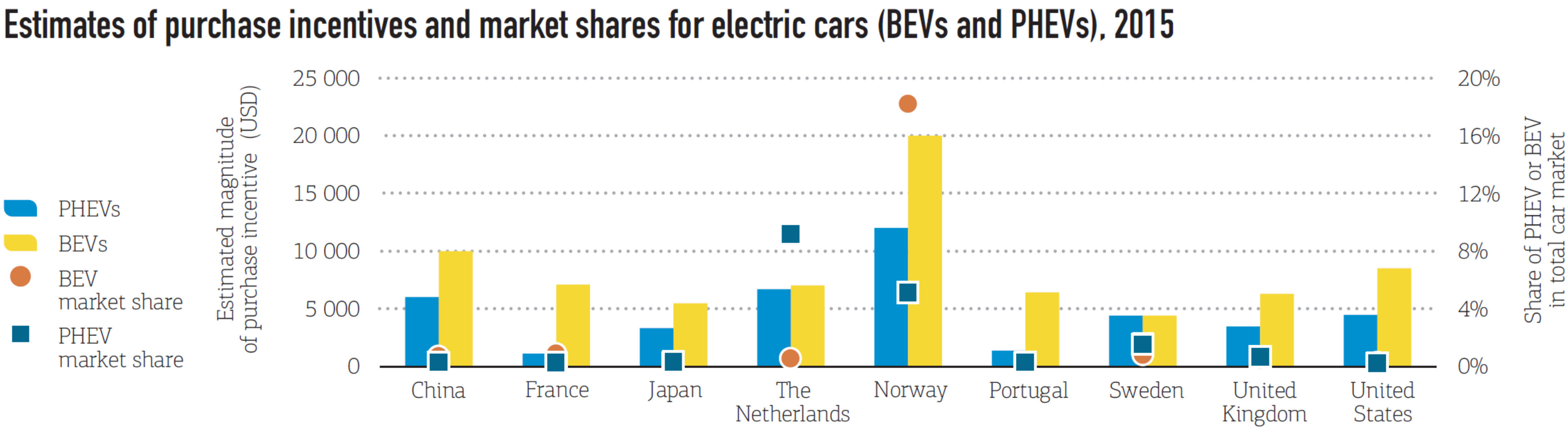
EV deployment



EV registration in 2015
Europe: 96,000
China: 200,000
USA: 115,000

End 2015: about 500,000 EV in Europe

Policy incentives



- Leading countries give the largest incentives

EVSE deployment

- Electrical grid is available everywhere
- Deployment: a solution to the limited autonomy & range anxiety
- France (public space):
  - 50 M€ program from Ademe,
  - 14000 by 2016, 30000 by 2018
- Energy transition program:
  - 7 millions EVSE in 2030

Electrical system (I)

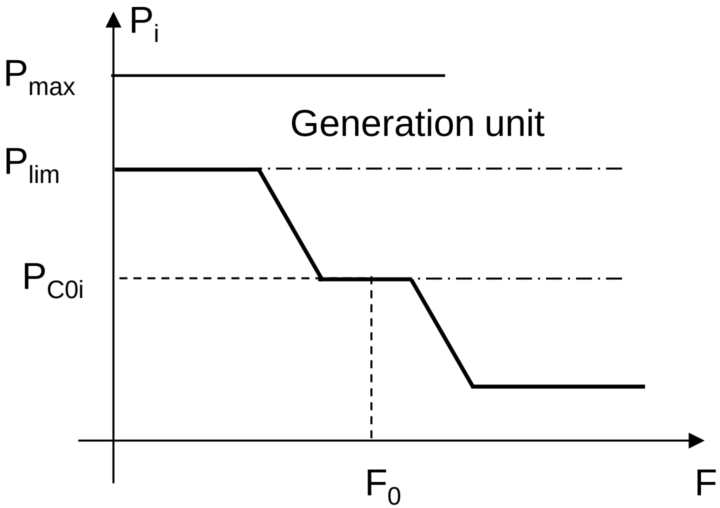
- Large generation units
  - nuclear, coal, gas, fuel, hydro
  - Flexibility (start-up, shut-down, ramping): low, moderate, high
  - Cost: investment / marginal costs
  - CO_2 emissions

	coal	Fuel	Gas	nuclear	hydro
g CO_2 / kWh	960	670	460	0	0

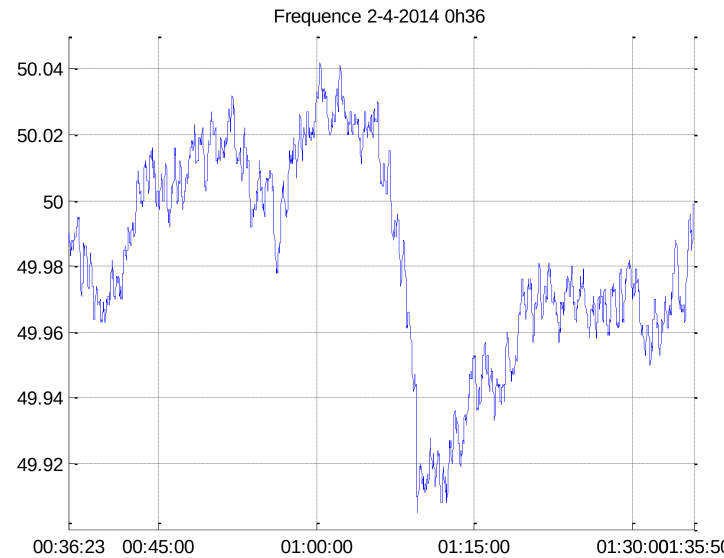
- *Emissions from EV (tank to wheel)*
  - 192 g CO_2 / km with coal turbines
  - 92 g CO_2 / km with gas
- *Generation mix*
  - France → 7.5 g/km
  - Germany → 90 g/km
  - Norway → ~0 g/km
  - Europe →~75 g/km

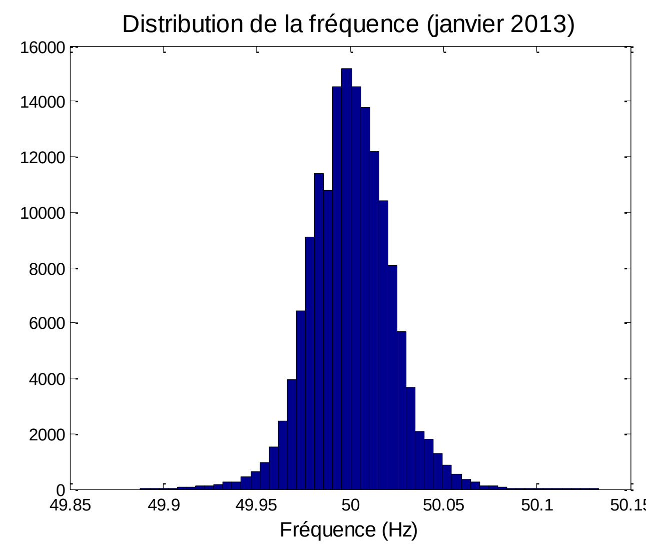
Electrical system (II)

- Transmission networks
  - Balancing ←→ frequency control
    - *Technical requirements*
    - *Market reserves*



$F > F_0$ →less generation
$F < F_0$ →more generation





Electrical system (III)

- Transmission & distribution networks
  - Voltage control ($U_{min} < U < U_{max}$)
    - *Meshed HV grids: Reactive power reserves*
    - *Radial MV & LV grids: contribution of active power control, feeder length*
  - No overloading ($I < I_{max}$)
    - *Equipment sizing, grid topology*
    - *Generation and load control*

Electrical system (IV)

- Customers
  - Industrial, commercial, residential
  - Variable demand (partially flexible)
  - Power quality requirements
- Distributed resources
  - PV, wind → variability, difficult to forecast
  - Connected to radial distribution grids
  - Constraints on distribution grids
    - *overvoltage*
    - *overloads*
  - Small storage units

The electrical system needs flexibility for a better integration of variable energy sources

EV: energy needs

- Single EV → 20-30 kWh battery
- Energy consumption : ~ 0.2 kWh/km
- Daily distance (France) : ~30-50 km → ~8 kWh
  - Urban use
  - Second car
- 1 million EV in France → 8 GWh/day
  - Global demand:

    850 GWh on 15th Aug 15; 2300 GWh on 08th Feb 12
- 300 day/y → fleet → 2.5 TWh/y
  - 0.5 % of the total energy demand
  - 10% of the wind generation
  - 30% of the PV generation

EV: charging power

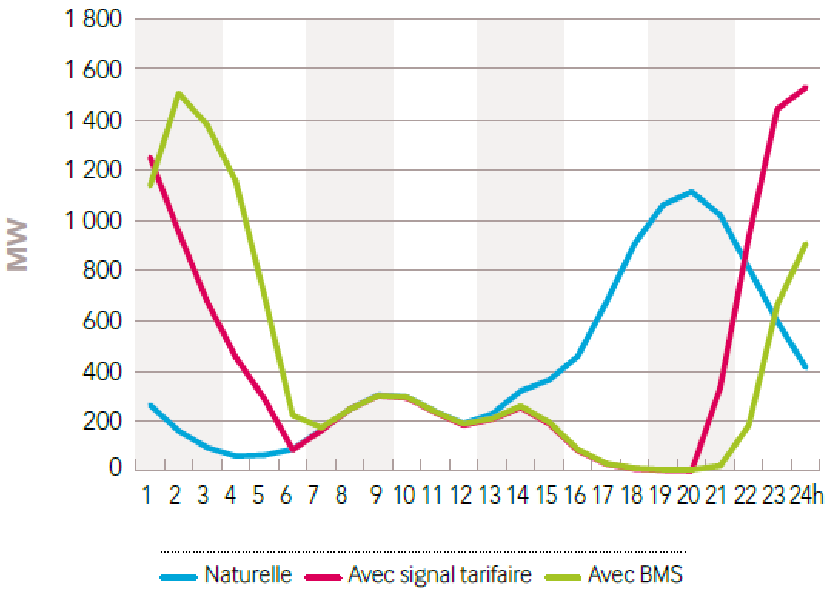
- Power depends on the EVSE current limit

EVSE power (SOC< 90%)		Duration for 8 kWh
(1φ) 230 V – 16 A	3,7 kVA	2h30
(1φ) 230 V – 32 A	7,4 kVA	1h15
(3φ) 400 V – 16 A	11 kVA	50 min
(3φ) 400 V – 32 A	22 kVA	25 min
(3φ) 400 V – 63 A	43 kVA	12 min
(DC) 500 V – 100 A	50 kW	10 min
Tesla charger	120 kW	

- Standard IEC 61851 allows the control of the current limit (1 A step)

EV fleet and electrical system (I)

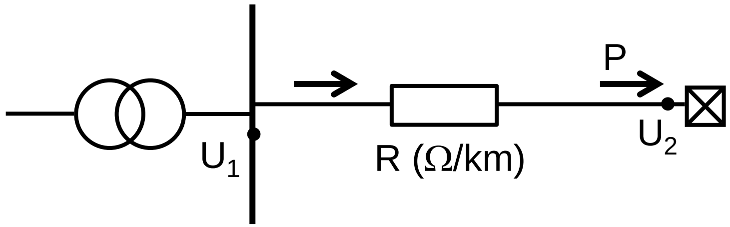
- Impact at the global level → transmission grid (balancing)
  - Risk of peak power
    - *Analysis by RTE ➔*
      - 1 million EV & PHEV
      - 1 GW peak at 8 pm
  - Shift the EV peak to off-peak period



  - Which generation units to charge EV ?
    - *Economic optimisation under technical contraints*

EV fleet and electrical system (II)

- Impact at the local scale → distribution grid
  - Additional transformer peak load → thermal constraints, aging
    - *Rated power : 1MVA,   630 – 400 – 250 – 160 kVA*
  - Voltage drops
    - *Low power charging is prefered*



$$\frac{\Delta U}{U}(\%) \approx \frac{R.P}{U^2}$$

U = 400 V
R = 0.4 Ω/km

$\frac{\Delta U}{U} = 0.25\%$ */ km.kW*

  - Connection of fast chargers (> 43 kW)
    - *Grid reinforcement: transformer, line,*
    - *Creation of new substations*
  - Power quality → harmonics

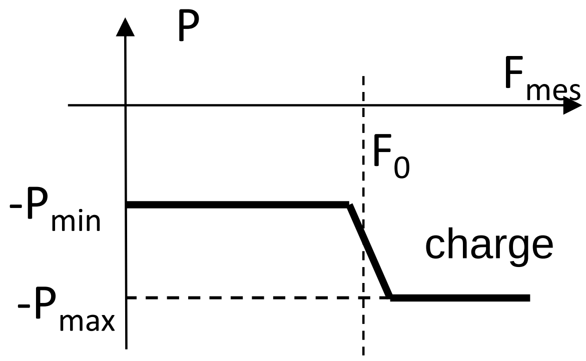
EV fleet: flexible storage units

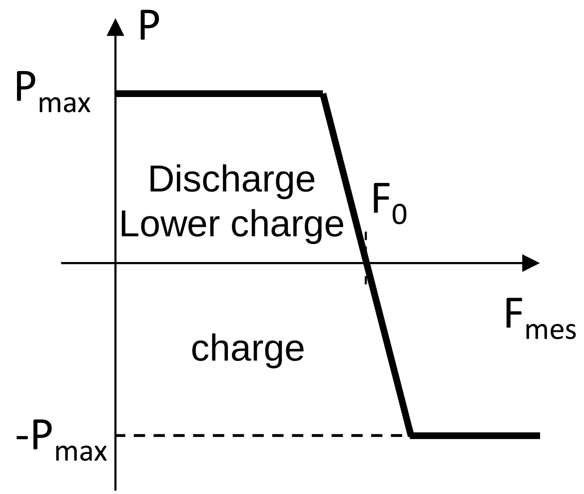
- Small storage units connected to LV or MV grids
- Short usage for mobility < 2h/day
  - easy to shift

- Can these batteries help the grid operation?
  - Characteristics:
    - *High response time*
    - *Low energy capacity*
  - To mitigate balancing contraints
  - To mitigate voltage & congestion constraints
  - Mobility needs must be satisfied
  - Impact on battery aging

Grid services (I)

- Frequency control for balancing
  - power capabilities
  - Primary frequency control (seconds)
    - *3000 MW in Europe*
    - *10% by EV fleets → 300 MW → 10^4 - 10^5 EV*

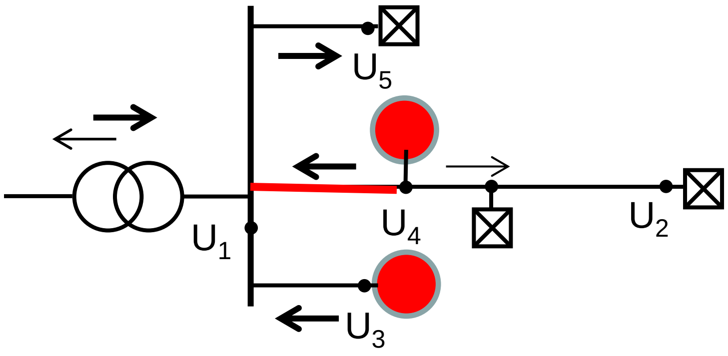


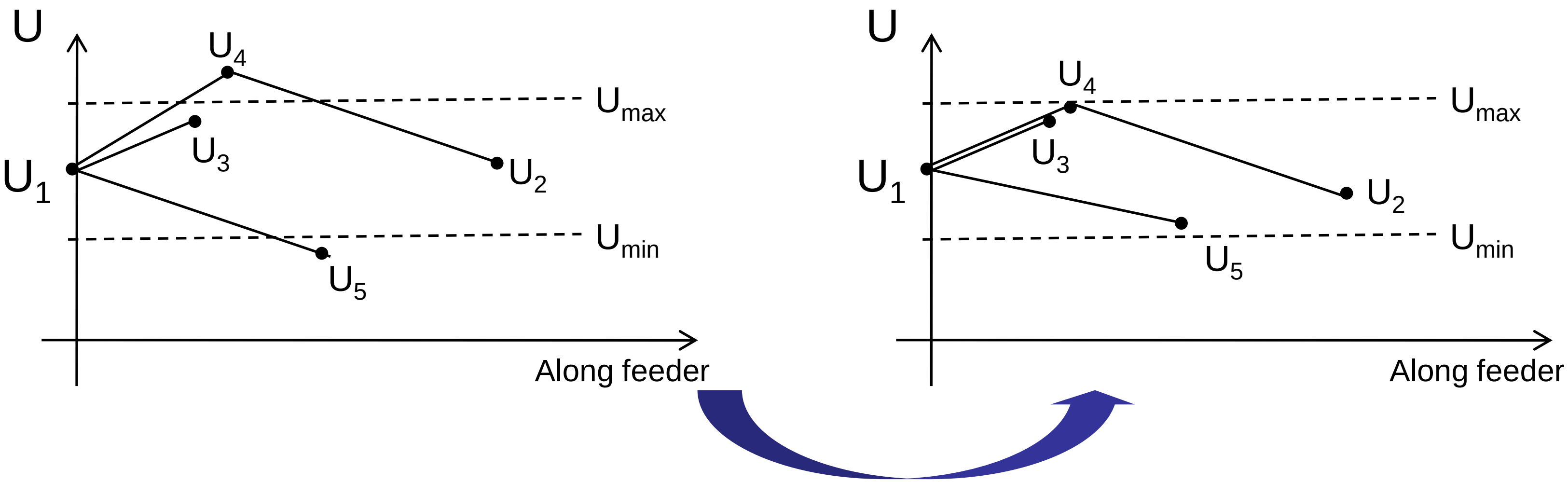


$F > F_0$ → less generation or more demand
$F < F_0$ → more generation or less demand

Grid services (II)

- Renewable sources integration

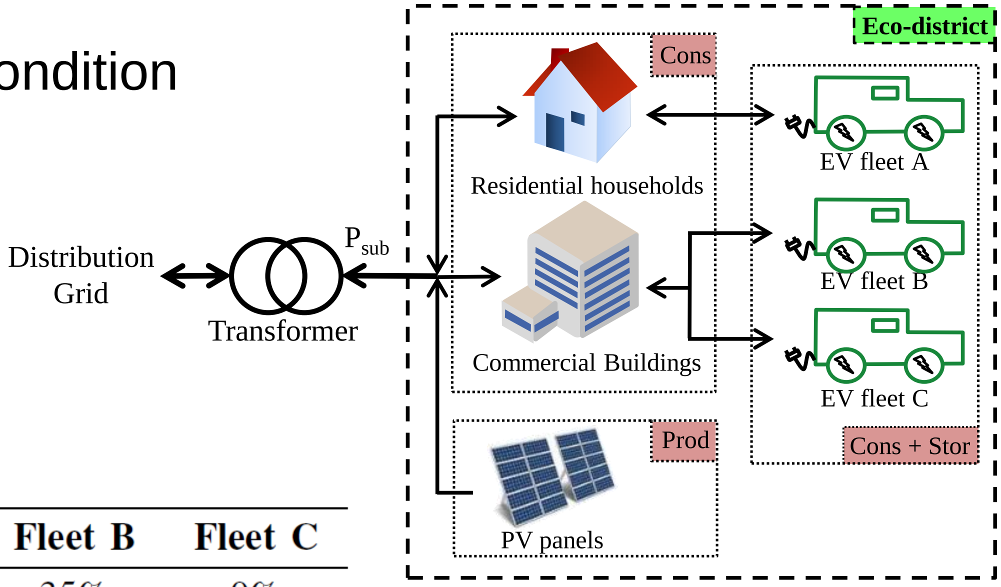




Increase the charging power downstream U_4
Reduction of the charging power in U_5

Case study (I)

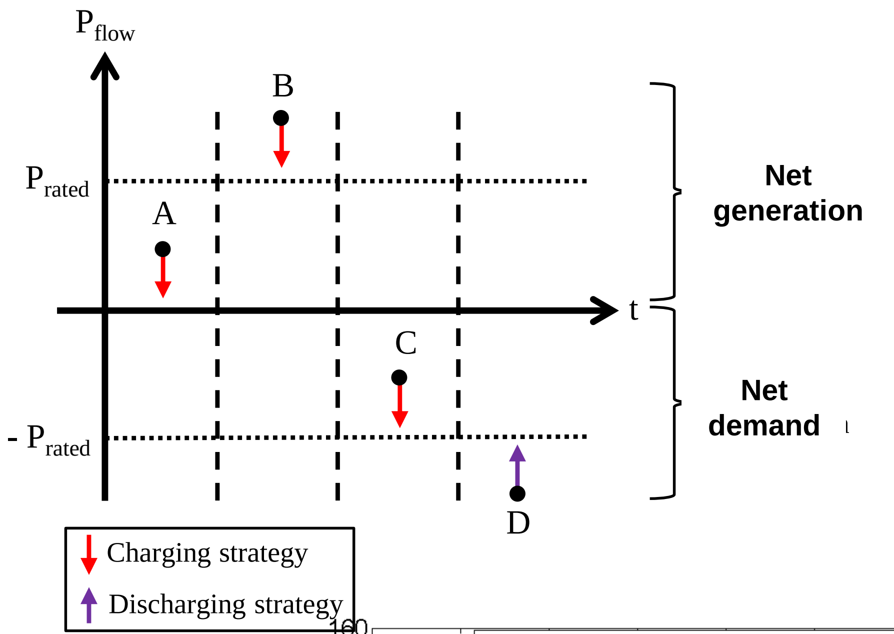
- Eco-district
  - Transformer loading condition

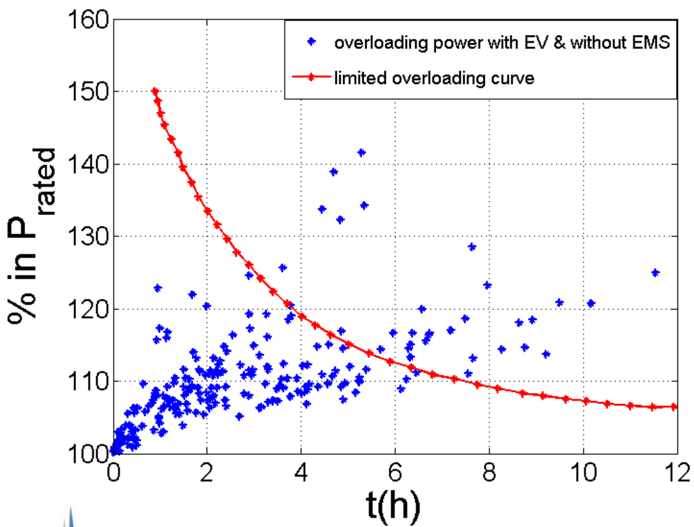


EVSE power plug	Fleet A	Fleet B	Fleet C
Slow (a) - 3kW	93%	35%	0%
Slow (b) - 7kW	7%	34%	0%
Intermediate charging - 22kW	0%	29%	100%
Fast charging - 43kW	0%	2%	0%

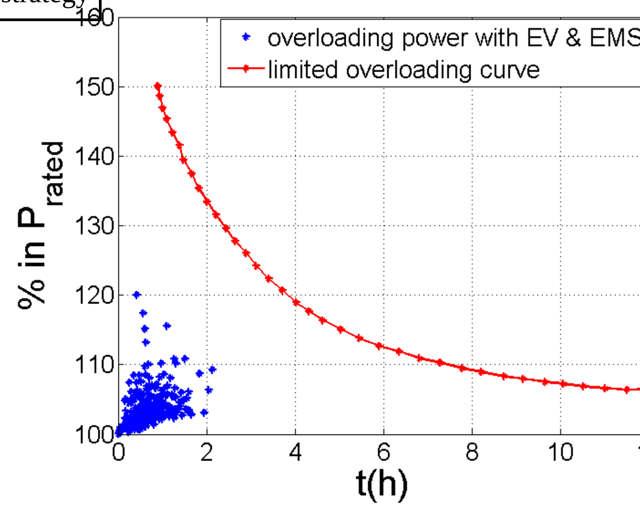
Case study (I)

- Eco-district
  - Transformer loading condition





EV control charging



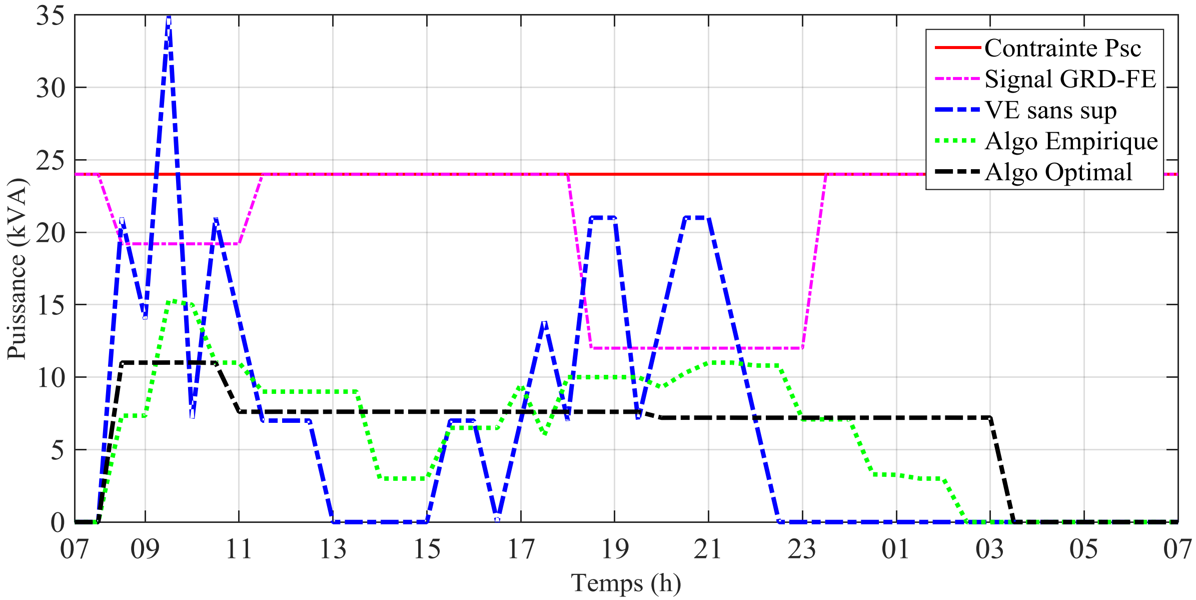
Case study (II)

- BienVEnu project
  - Residential buildings
  - EVSE connection solution
  - Car-sharing operator
    - *EV sharing*
    - *EVSE sharing*
  - EMS - Smart charging
    - *Optimal contracted power*
    - *Constraint from the DSO*
    - *Level services*
  - 7 kW EVSE

Service level	Type de client	Max need (km)	Max delivery (h)
Priority	Car sharing, P2P	40	2
Standard	P2P, Résidential	50	4
Economic	P2P, Résidential	80	8

Case study (II)

- BienVEnu project

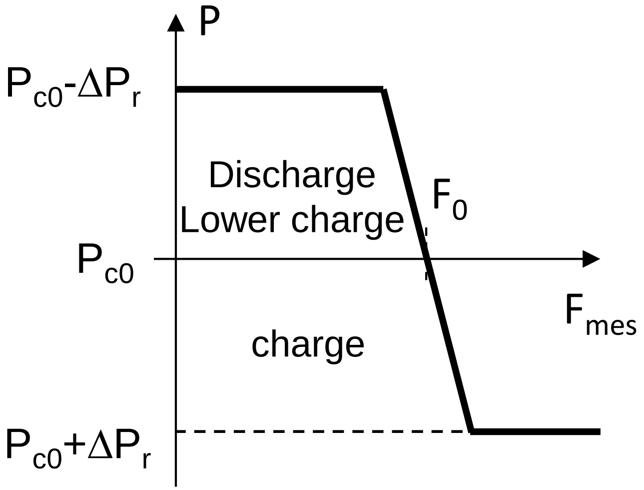


	Satisfaction rate at the end of charging period (%)	
	Without constraints	With constraints
18 kVA	90,1	87,3
24 kVA	**99,4**	96,7
30 kVA	**99,7**	**99,2**
36 kVA	99,9	99,7

Case study (III)

- Power reserve for frequency control
  - Valorization
  - Symetrical or asymetrical markets
  - Hourly markets
  - Uni or bi-directional power flow

Scenarios	Ratio of EVs having an EVSE at work
Scenario 1	0%
Scenario 2	25%
Scenario 3	50%
Scenario 4	75%



Codani et al, Int. J. of Electric and Hybrid Vehicles Vol. 7, No. 2, 2015

Charging level	Primary EVSE	Secondary EVSE
Slow charging A (3kW)	95%	35%
Slow charging B (7kW)	5%	34%
Intermediate charging (22kW)	0%	29%
Fast charging (43kW)	0%	2%

Average earnings (per EV, per year), EnerginetDk market prices

Scenario	Unidirectional control	Bidirectional control
Scenario 1	25€	149€
Scenario 2	28€	251€
Scenario 3	29€	353€
Scenario 4	31€	456€

Research projects in Europe

- Grid for vehicles (G4V), (2010-2014)
  - Modeling of the EV demand
  - Impact on grid reinforcement
  - Load shifting is prefered
- Edison, (2010-2014)
  - EV fleet into the grid
  - Fleet operator (aggregator), standards (IEC 61851)
  - Fast chargers(>50 kW)
- Merge, (2010-2014)
  - Impact of EV charging: grid planification
  - Uncontrolled charging, smart charging, price based
  - Participation to power reserve
- Green-emotion, (2011-2015)
  - Impact of EVSE on grid (harmonics, reinforcement)
  - Load curve

Research topics

- Grid services
  - Reliability of the service
- Which value?
  - Balancing → accessibility to distributed resources
  - Distribution → which market designs?
- Social issues
- Batteries aging with grid services
  - Impact
  - Better use of batteries

Conclusion

CentraleSupélec

- Weak energy impact
- Power is more critical
- EV → distributed storage
- EV could help the grid
  - Base case: charge in off-peak
  - Advanced case:
    - *Charging power controlled by aggregator*
    - *Contribution to power reserve*
    - *Following the local generation*
- Business models must be found
- Social acceptance of services to smart grids

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