Soirée des doctorants

Thèmes : Flexibilité des réseaux de distribution, réseaux à courant continu et intégration des véhicules électriques

Le bureau français de l'IEEE PES vous convie à la soirée annuelle des doctorants, au cours de laquelle les trois lauréats du prix de l'année, viendront présenter leurs travaux. Nous leur donnerons la parole sur trois thèmes différents. Les exposés seront introduits par les responsables industriels concernés qui viendront expliciter les enjeux des travaux présentés.

Emmanuelle Vanet présentera ses travaux sur la gestion opérationnelle des ressources de flexibilité dans les réseaux de distribution, incluant les générateurs d'énergie décentralisés.

Julian Freytes développera ensuite son approche de l'analyse de l'interopérabilité des stations de conversion AC-DC de différents constructeurs installés sur un même réseau en courant continu.

Paul Codani exposera son approche de l'intégration des véhicules électriques au réseau, partant des contraintes techniques jusqu'au modèle d'affaire.

Organisation et Parrainage

- Chapitre français de l'IEEE PES (Power & Energy Society)
- Avec l'appui de la SEE (Société de l'Electricité, de l'Electronique et des Technologies de l'Information et de la Communication) – Club technique « Systèmes électriques »

Lieu

RTE - Tour Initiale
1, terrasse Bellini, Paris - La Défense
Métro ligne 1– Station : Esplanade de la Défense
Plan : http://bit.ly/1iZ39Jy

Mardi 16 Mai 2017
de 17h30 à 19h30
RTE - Tour Initiale – 1, terrasse Bellini Paris - La Défense

17h30	***Accueil et introduction*** Sébastien Henry, *Président du bureau français de l'IEEE PES, Directeur SI & Télécommunications, RTE*
17h40	***Distribution de l'intelligence et approche hétérarchique des marchés de l'énergie distribués dans les Smart Grids*** Emmanuelle Vanet *(G2Elab, Grenoble-INP), introduction par Mathieu Gabel (Electricité de Strasbourg Réseaux) et Romain Gigault (GE Grid Solutions)*
18h15	***Interoperability between different Modular Multilevel Converters connected to a MTDC grid*** Julian Freytes *(L2EP, Ecole Centrale de Lille), introduction par RTE (A confirmer)*
18h50	***Grid Integrated Vehicles: business models and technical constraints for car manufacturers*** Paul Codani *(Centrale Supelec), introduction par Damien-Pierre Sainflou (PSA)*
19h30	***Pot de l'amitié***

Inscription et Renseignements

Après la soirée, les présentations sont disponibles sur http://ewh.ieee.org/r8/france/pes/

Flexibility of Distribution Grid used in Transport Grid

IEEE Power & Energy Society : Soirée des doctorants
Introduction de la présentation d’Emmanuelle VANET

Romain GIGAULT
June 9, 2017

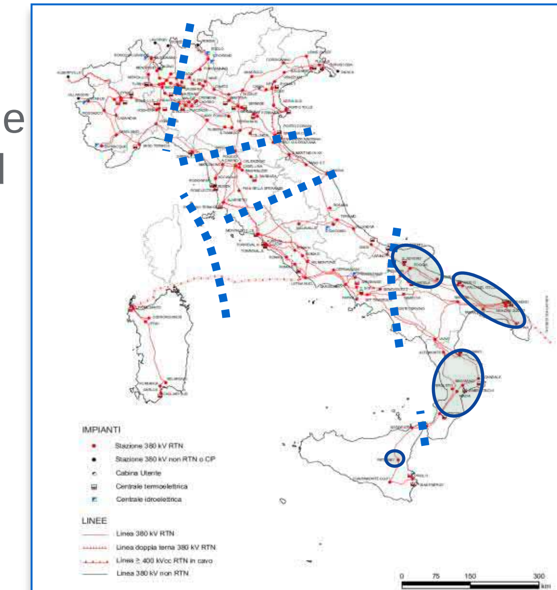
Ancillary Services Market – Case of Italy

Ancillary Services Market products: aFRR, mFRR and RR

Unit commitment/re-dispatch coupling the market clearing engine with a contingency analysis to generate network security-related constraints

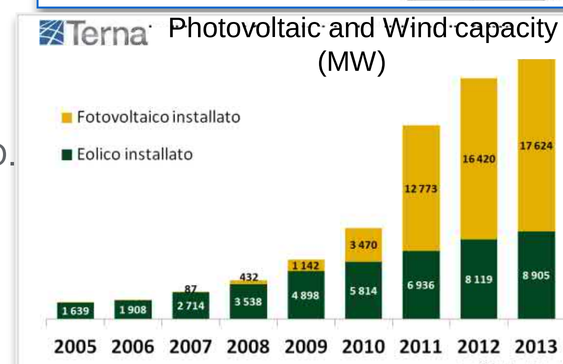
Heavily constrained network due to its topology:

- Necessary commitment of specific production units needed in service for particular conditions.
  - Voltage control support during low-load conditions.
  - Congestion control in lower kV grids.



Large renewable capacity…

18,610 MW solar power installed and 9,080 MW wind power installed [2015].



… integrated in the ancillary services market

- RES connected to high, medium and low kV grid provide system services to TSO.
- RES submit offers directly to TSO or alternatively traders aggregate RES offers.
- Small RES and aggregator flexibility offers (< 1 MW) are available to the market.

Nice Grid > Microgrid Demonstrator.

NICE GRID
A SMART SOLAR DISTRICT
ENEDIS
L'ELECTRICITE EN RESEAU

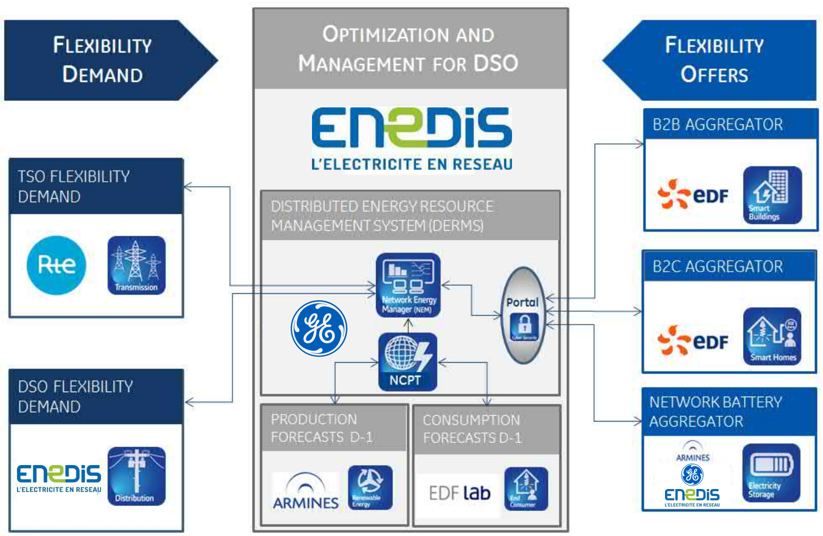
Challenges addressed

Integration of renewables (**PV**) in the distribution grid, leading to **backfeed and voltage issues**.

Congestion or voltage issues **in the transmission grid**; Overload during outages in distribution grid

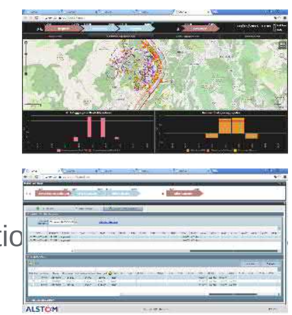
Islanding of a LV grid using batteries and PV

Solutions to these challenges



DERMS for DSO

- Network Energy Manager
  Local flexibility market
  DSO situation awareness
  TSO call for flexibility
- Microgrid Control Unit
  Local SCADA system over BPL communicatio
- Battery aggregator
  Scheduling and storage dispatch optimization



Value proposition

Solution to **provide flexibility to the TSO**, use it internally for **MV grid constraints** and a process to **facilitate market integration of DERs**. Integrated utilities can **valorize their own flexibility** (heat grids, water grids, …).

Classification du document
☐Confidentiel
☐Restreint
☐Interne
✓ Public

STRASBOURG ELECTRICITE RESEAUX

VERS UNE EXPLOITATION OPTIMALE DES RÉSEAUX DE DISTRIBUTION

IEEE Power & Energy Society : Soirée des doctorants
Introduction de la présentation d’Emmanuelle VANET

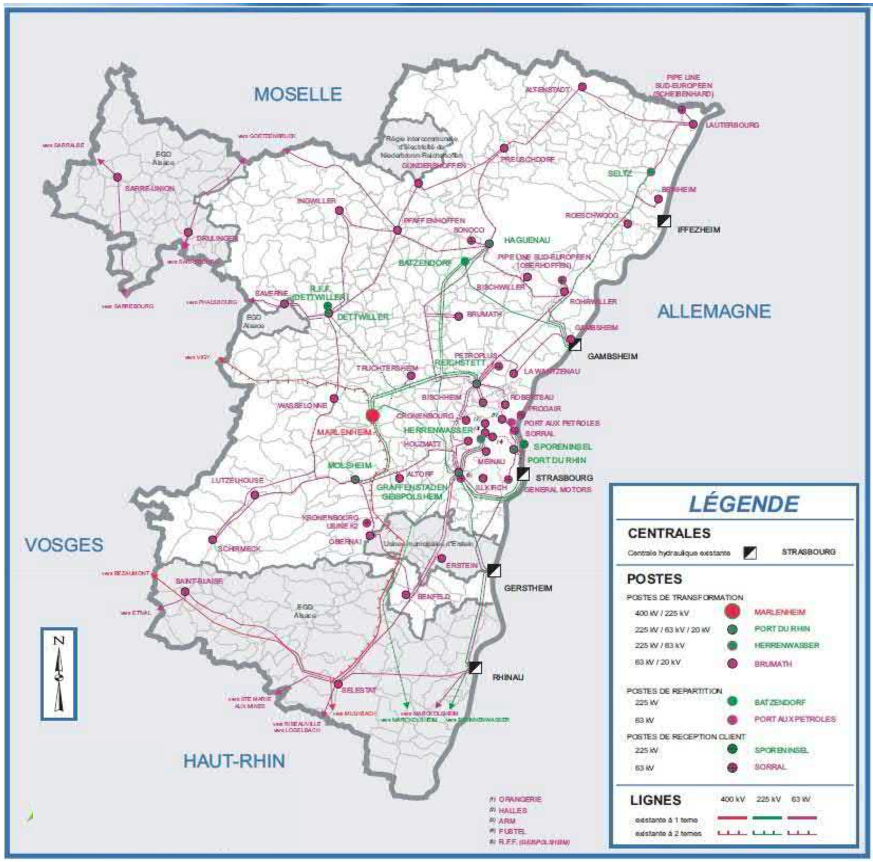
Mathieu GABEL, Responsable du centre de conduite de STRASBOURG ELECTRICITE RESEAUX
16/05/2017

DES RÉSEAUX EN MUTATION

2e distributeur en France

Opérateur de réseaux HTB, HTA et BT

- 530 000 clients dans le Bas-Rhin
- 45 postes sources HTB/HTA
- Pointe à 1540 MW



EnR dans les réseaux HTA et BT

Augmentation significative en 10 ans

- 50 MW de production raccordée en 2006
- 100 MW de production raccordée en 2016

De nouveaux challenges à relever

- De nouveaux acteurs
- Des contraintes qui émergent
- Une réglementation qui évolue
- Une complexification de la planification
- Des coûts et des délais pour les raccordements

STRASBOURG ELECTRICITE RESEAUX

VERS UNE EXPLOITATION OPTIMALE DES RESEAUX

<u>La modification des principes classiques</u>

- La fin des réseaux exclusivement amont-aval
- La fin du « fit, connect and forget »

<u>Le développement des possibilités de flexibilité</u>

- Le Dispositif d'Echange d'Informations d'Exploitation est une réalité
- Les expérimentations smart grids « Flexibilité » se multiplient
- Le cadre réglementaire est à compléter

Un objectif : L'exploitation optimale des réseaux

→ En temps réel et de manière prévisionnelle

- Meilleure connaissance des réseaux, de la météo, des consommations, des marges disponibles
- Capacités dynamiques des lignes, plan de tension dynamique, …

→ Exploitation des flexibilités du réseau BT par le réseau HTA, une piste explorée par Emmanuelle VANET dans le projet DREAM

STRASBOURG ELECTRICITE RESEAUX

Distributed intelligence and heterarchical approach of distributed balancing markets in Smart Grids

Emmanuelle Vanet

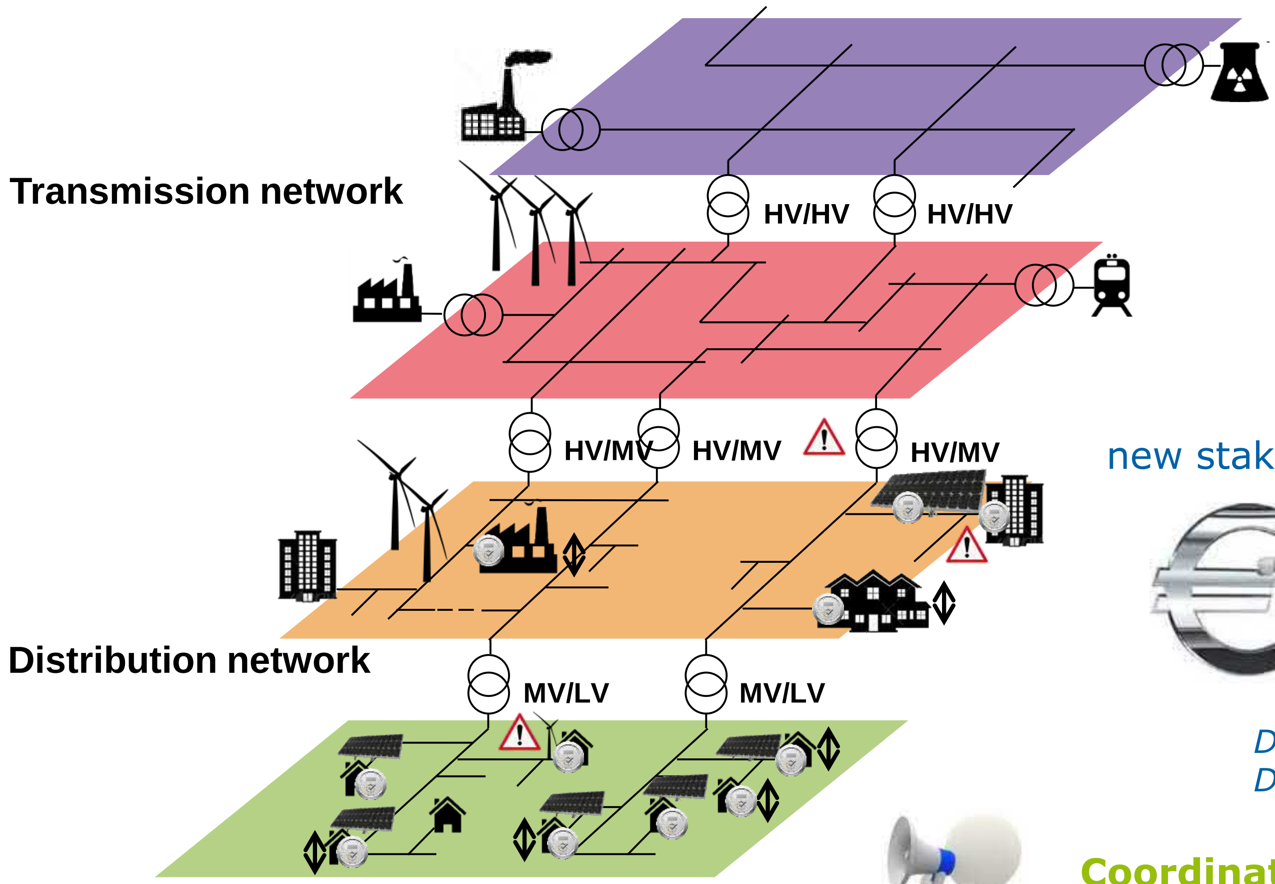
Defended the 27th September, 2016

Supervisors: Raphaël Caire & Nouredine Hadjsaid
Jury: Hans Akkermans, Marc Petit & Abdellatif Miraoui

IEEE Power & Energy Society : Soirée des doctorants
16 mai 2017

UMR CNRS 5269 - Grenoble-INP – Université Grenoble Alpes

From actual networks to Smart Grids



New challenges

leading to…

new stakeholders

new sustainable energy producers

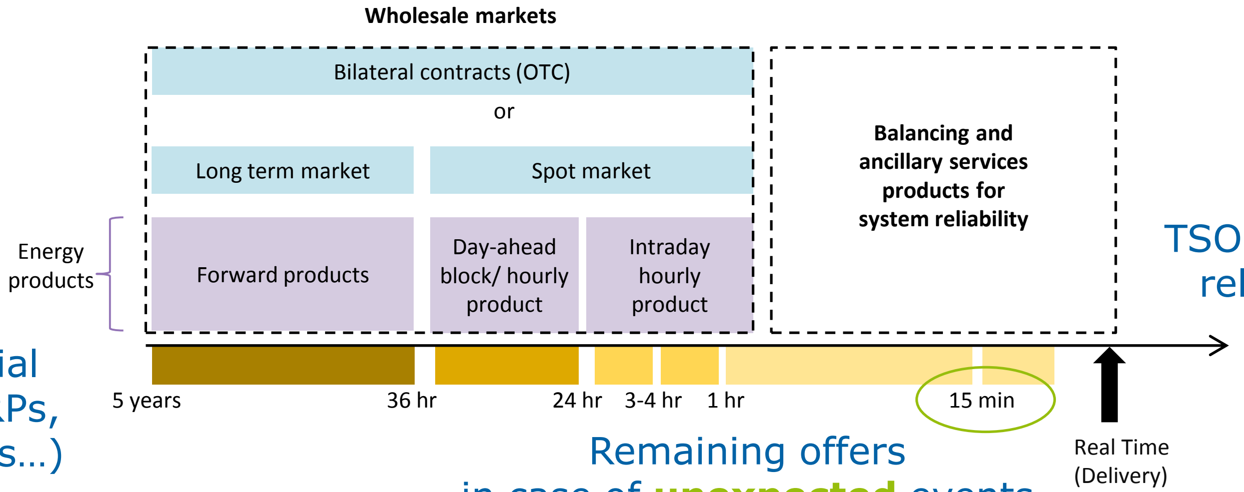
DG: Distributed Generation
DER: Distributed Energy Resource

Coordinated use of measurements and flexibility resources is a possible **solution**, possible thanks to **communication**

→ How these **flexibility resources** can be **exchanged** on the existing markets ?

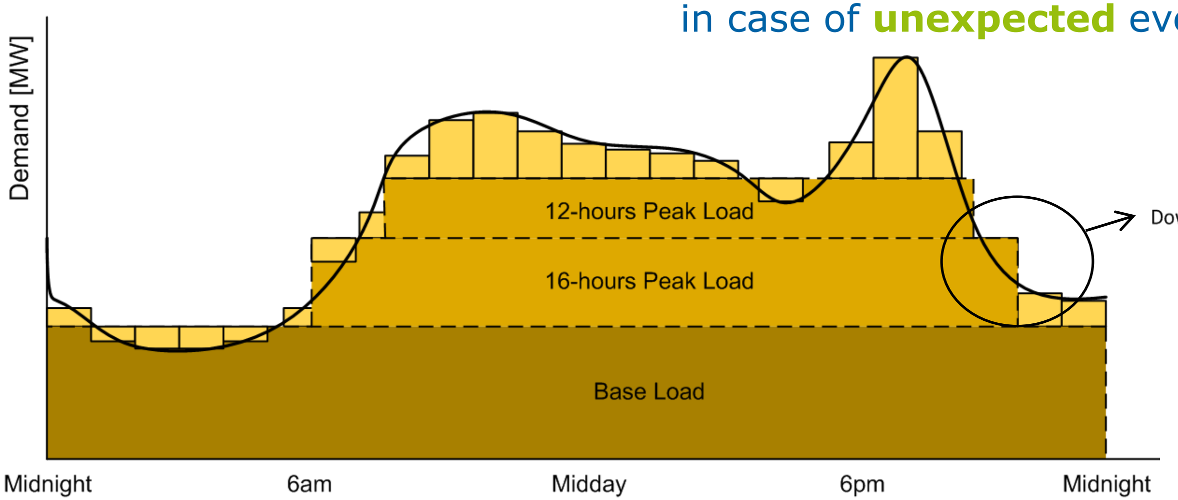
European energy markets overview

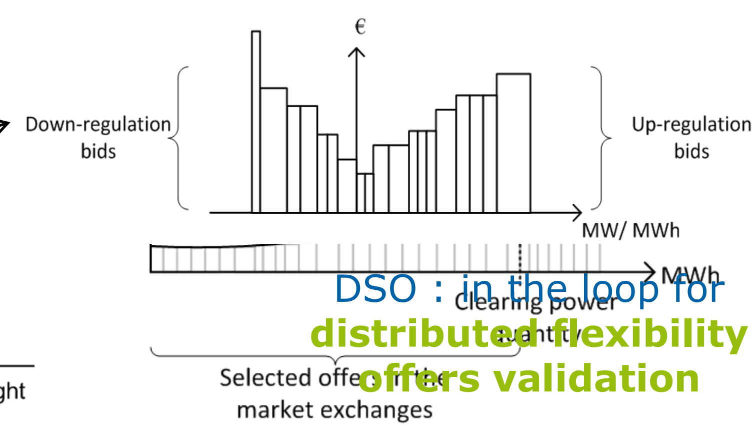
Commercial parties (BRPs, aggregators…)



TSO : system stability and reliability **responsible**

Remaining offers in case of **unexpected** events





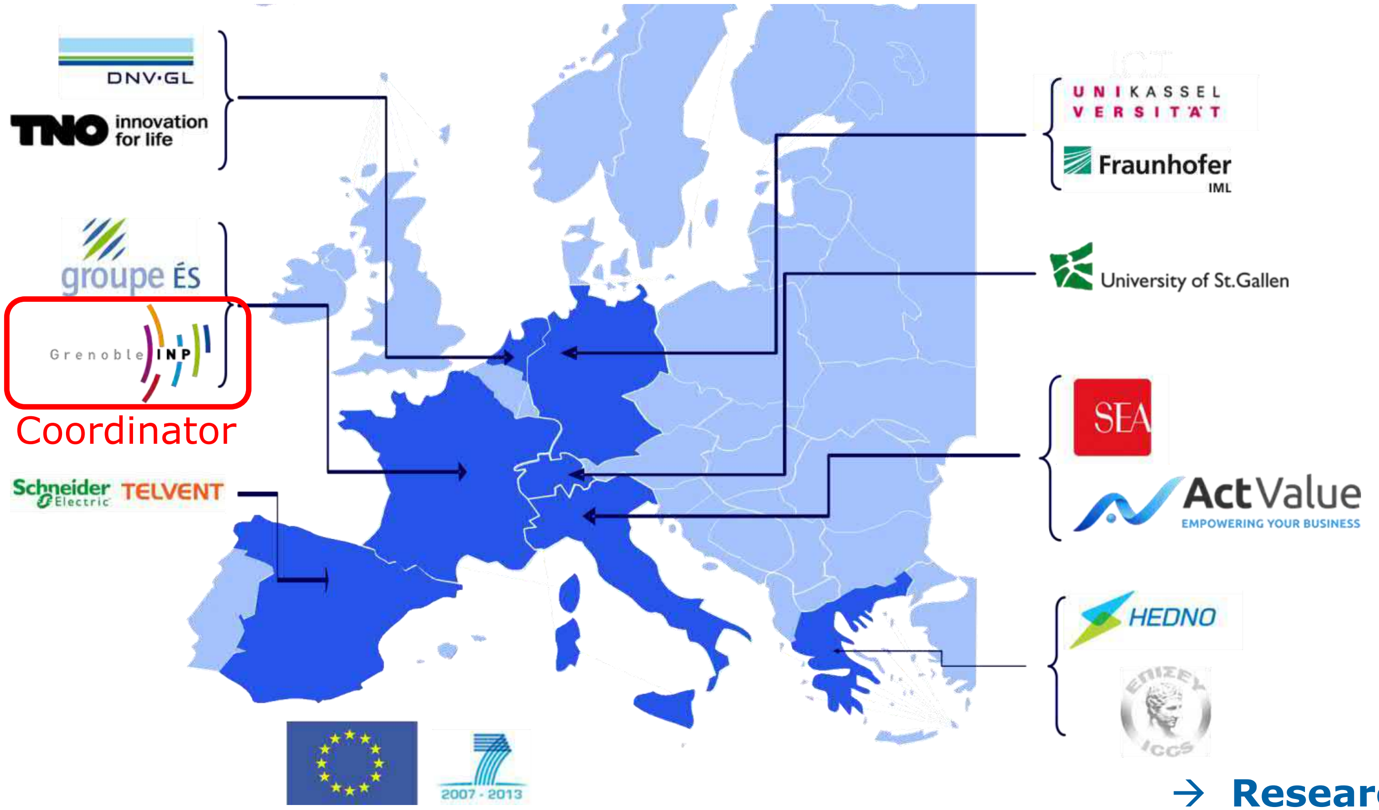
DSO : in the loop for **distributed flexibility offers validation**

→ How to **coordinate** the use of **local flexible resources** in distribution systems ?

The DREAM project

Distributed **R**enewable resources
Exploitation in electric grids through
Advanced heterarchical **M**anagement

www.dream-smartgrid.eu



12 partners

7 countries

40 months

5 trial sites

→ **Research & development**
→ **Implementation & tests**
→ **Demonstrations & validation**

Outline

Part I. Creation of a new distributed architecture

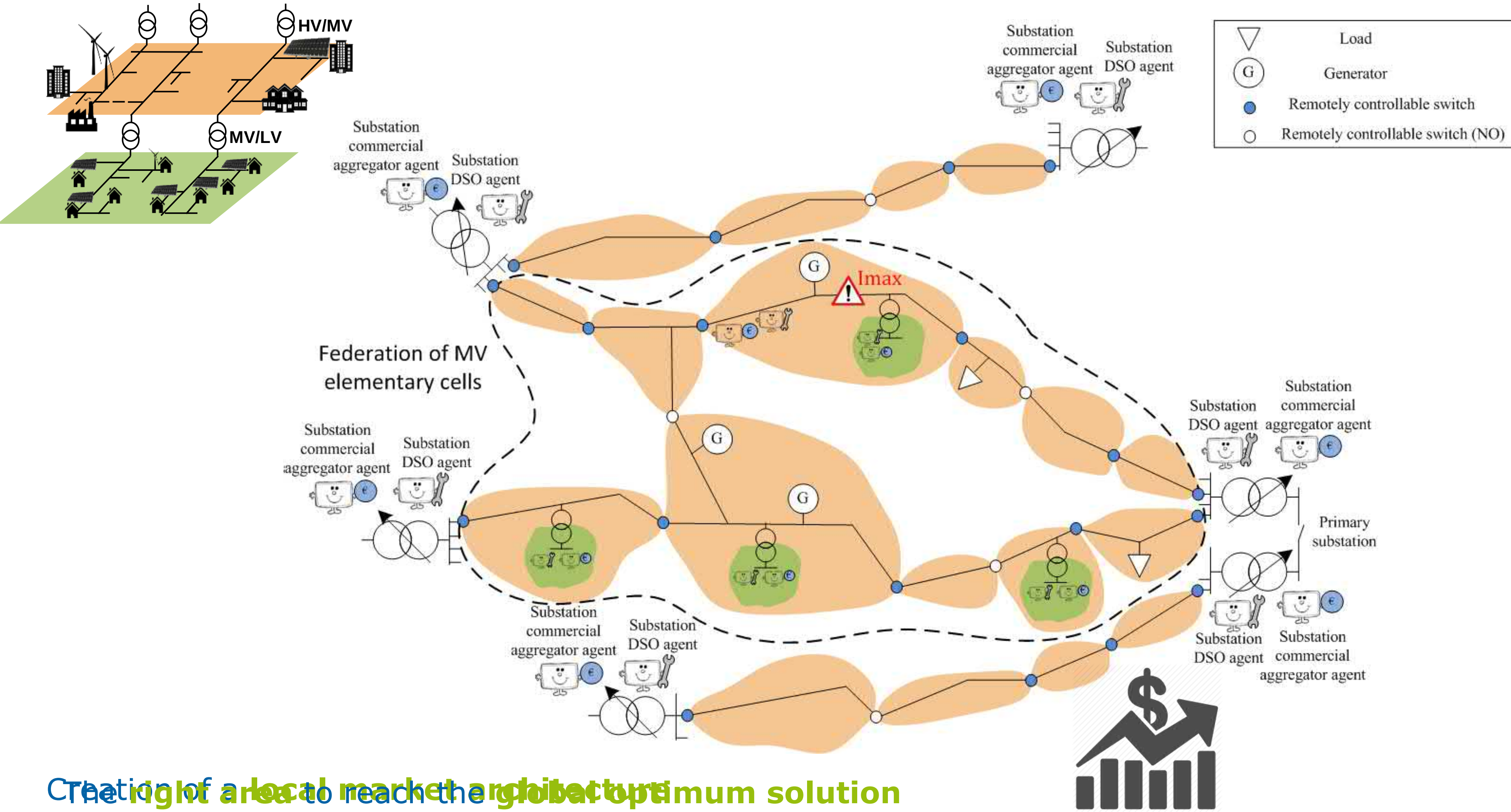
- Coordination of local resources and grid components
- Instauration of local market places

Part II. Short-term local risk management and contingency analysis for the DSOs

Part III. Increasing network performance thanks to the available remaining flexibility resources

Autonomous coordination of local resources and grid components

Global optimal coordination of local flexible resources



Creation of a **local market architecture**

The **right area** to reach the **global optimum solution**

✓ *R. Baerenfaenger, E. Drayer, D. Daniluk, B. Otto, E. Vanet, R. Caire, T. Shamsi Abbas and B. Lisanti, "Classifying flexibility types in smart electric distribution grids: a taxonomy," in CIRED Workshop 2016, 2016.*

Outline

Part I. Creation of a new distributed architecture

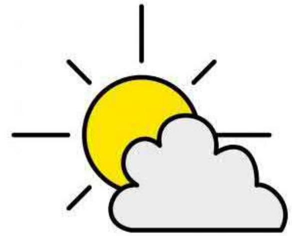
Part II. Short-term local risk management and contingency analysis for the DSOs

- DSO risk management and contingency analysis
- Distributed provision mechanisms of MV and LV flexibility resources

Part III. Increasing network performance thanks to the available remaining flexibility resources

Short-term local DSO risk management

Why system operators are performing contingency analysis?

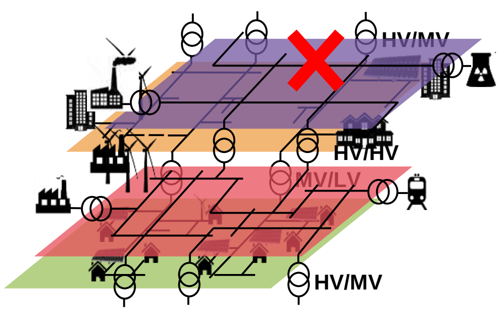

Any unexpected unbalance due to weather uncertainties, any failure or maintenance work…

Existing contingency analysis and operational planning methodologies

Transmission systems

Distribution systems

N-1 rule



Real need of a distributed balancing market

Existing mechanisms are also needed for operational planning

Some mechanisms for operational planning

→ N-k rules

→ Grid reinforcements

→ European margins (FCR + spinning reserves)

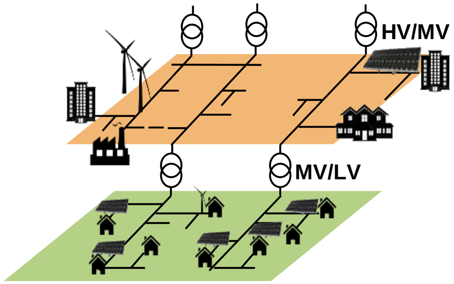
→ Interconnection capacity reserves

→ Local flexibility resources

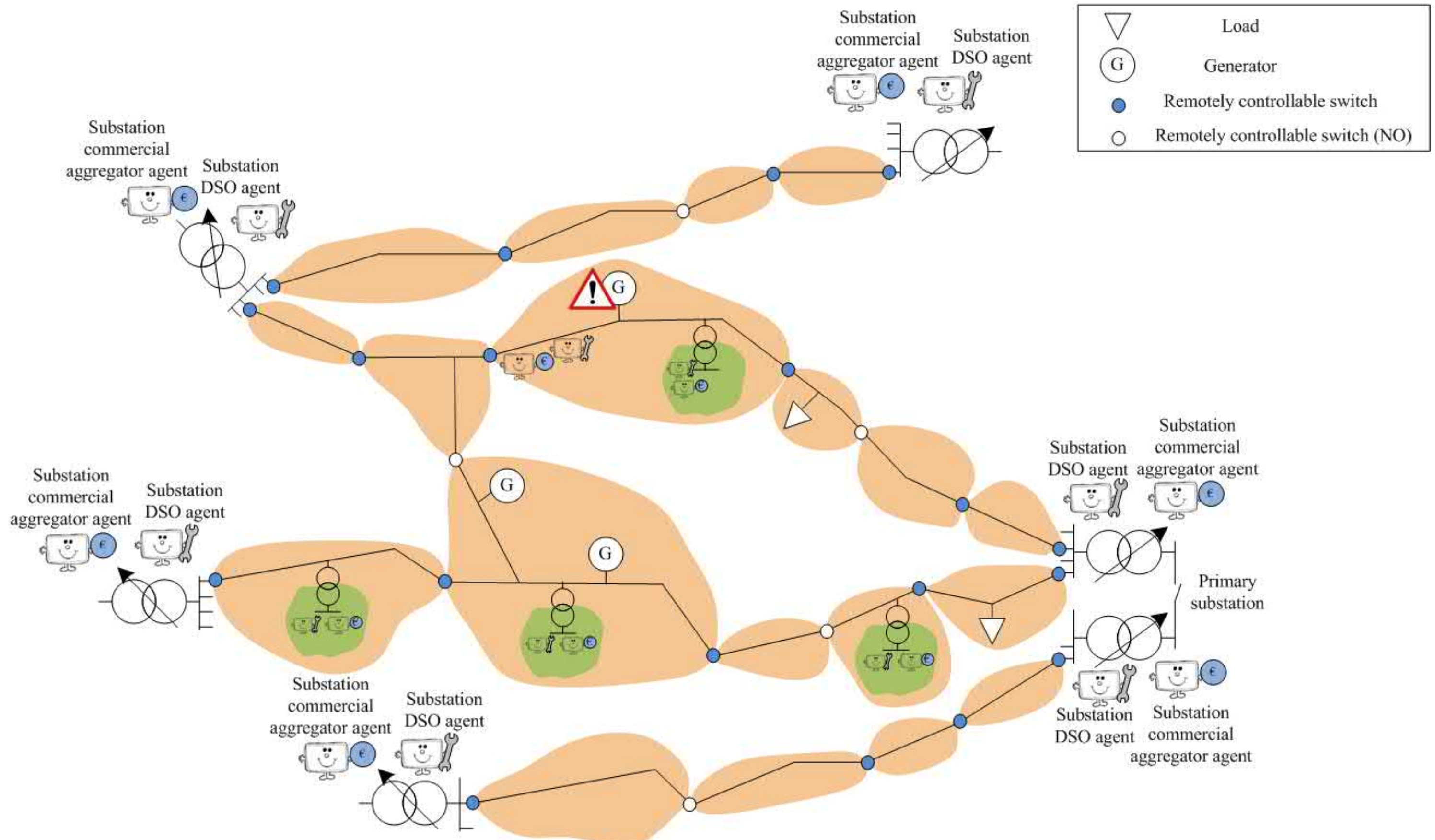
FCR : Frequency Containment Reserve

Evaluation of the available capacity

How **local flexibility offers** could help DSOs for **operational planning**?

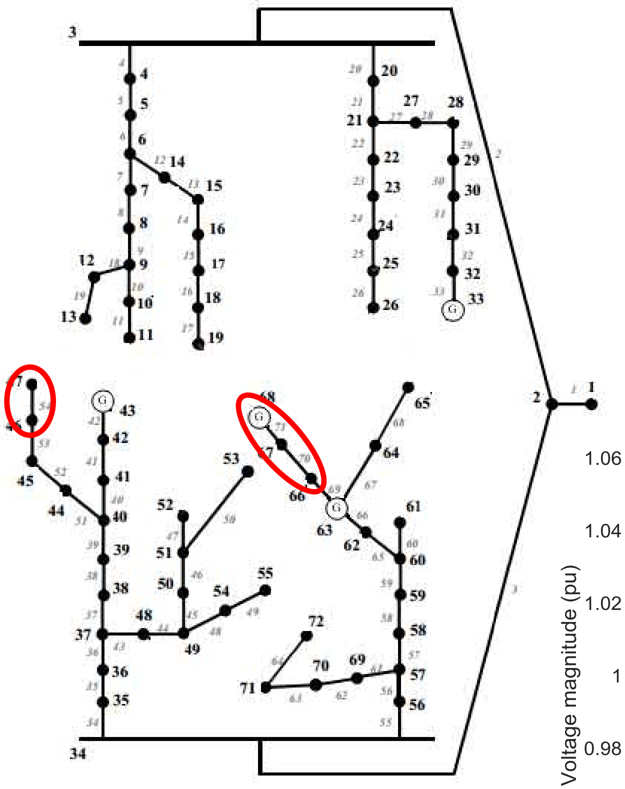


Optimal use of local flexibility offers that are remaining after markets gate closure

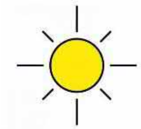


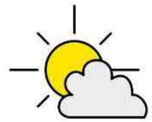
Development of optimisation methods

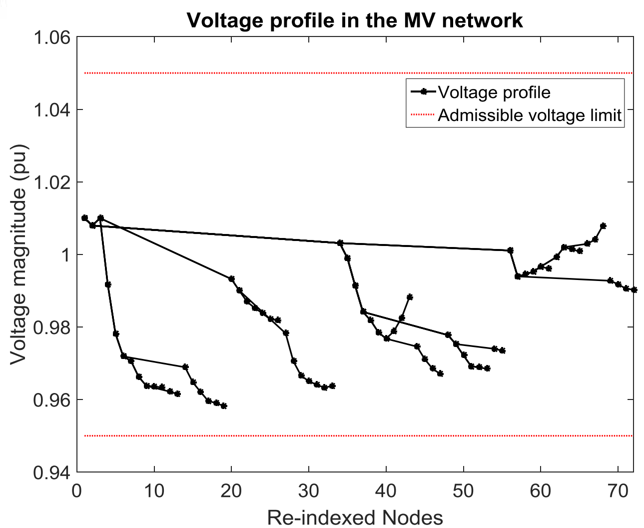
Example on a particular test case



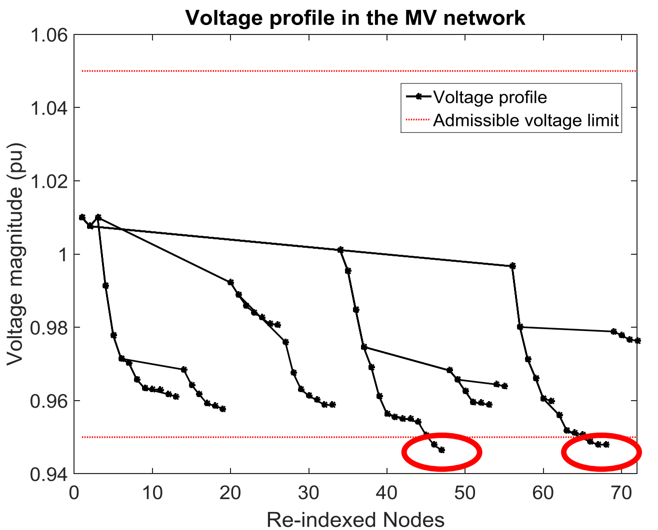
IEEE network
72 nodes
4500 kW of subscribed active power
1200 kWc of peak power (4DGs – PV production)







(a) Expected voltage profile with the forecasted weather conditions (4p.m)



(b) Voltage profile in case of sudden changes in the weather conditions (4p.m)

Results comparison on a given test case

How to guarantee the security and the quality of supply **at the minimum cost**?

Algorithm	Fobj (€)	Execution time (s) *	Number of function evaluations
Heuristic (cost)	4,67	0,65	9
Heuristic (efficiency)	3,51	0,51	7
Branch-and-cut	2,85	4,67	46
Exhaustive	2,85	1438,29	65536

* Run on a Intel® computer Core™2 Duo CPU E8400 @3.00GHz with 4,00 Go of RAM

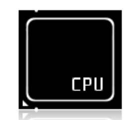
Algorithm	Advantages	Drawbacks
Heuristic methods	• **Few** computational requirements • **Straightforward** • Always converging to a solution	• Greedy algorithm • Global optimal solution **not guaranteed**
Branch-and-cut method	• **Guaranteed** convergence to the **global optimal** solution	• **More** computational requirements • Need of an **embedded** branch-and-cut solver • **Commercialized** for industrialization
Exhaustive method	• **Guaranteed** convergence to the **global optimal** solution	• **High** computational requirements

Short-term local DSO risk management

Contributions

- Instauration of a distributed mechanism for **short-term local DSO risk management**

- Development of several methods with **different computational requirements**



- Use of **local MV flexibility resources** that have a real **impact** on the potential constraints

- Creation of a mechanism to **consider LV downstream networks** and their **inherent flexibility resources** for MV level operation

  ✓ E. Vanet, G. Lebel, et Al., “LV4MV : a concept for optimal power flow management in distribution grids, using DER flexibility,” in *CIRED 23rd International Conference on Electricity Distribution*, 2015.

  ✓ E. Vanet, S. Toure, N. Kechagia, R. Caire, and N. Hadjsaid, “Sensitivity analysis of local flexibilities for voltage regulation in unbalanced LV distribution system,” in *2015 IEEE Eindhoven PowerTech,* 2015.

  ✓ E. Vanet, G. Lebel, et Al., “Flexibility activation optimization for constraints management in distribution grids, using DER flexibility through LV4MV,” in *CIRED Workshop - Helsinki 14-15 June 2016*, 2016.

Outline

Part I. Creation of a new distributed architecture

Part II. Short-term local risk management and contingency analysis for the DSOs

Part III. Increasing network performance thanks to the available remaining flexibility resources

- Minimisation of the network losses
- Addition of flexibility procurement cost

Increasing network performance

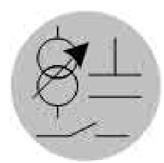
French **technical losses** estimations (2015)

- Transmission : around **10 TWh**
- Distribution : around **23 TWh**

Existing methodologies to improve technical losses reduction

Different mathematical approaches…

…and different considered flexibility resources



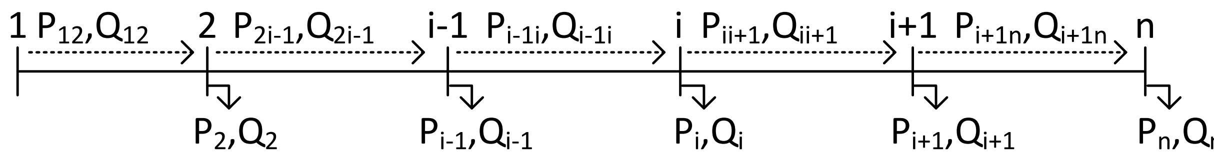
→ MV flexible grid components
  OLTC transformers
  Capacitor banks
  Reconfiguration

→ Flexibility from MV end users
  DGs reactive power output control
  DR and DGs active power management

Discrete, binary and continuous decision variables

- **MINLP problem**
- **NP hard**

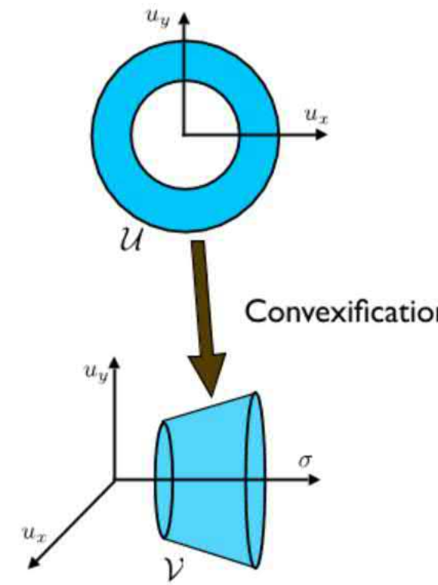
Problem formulation (Branch Flow model)

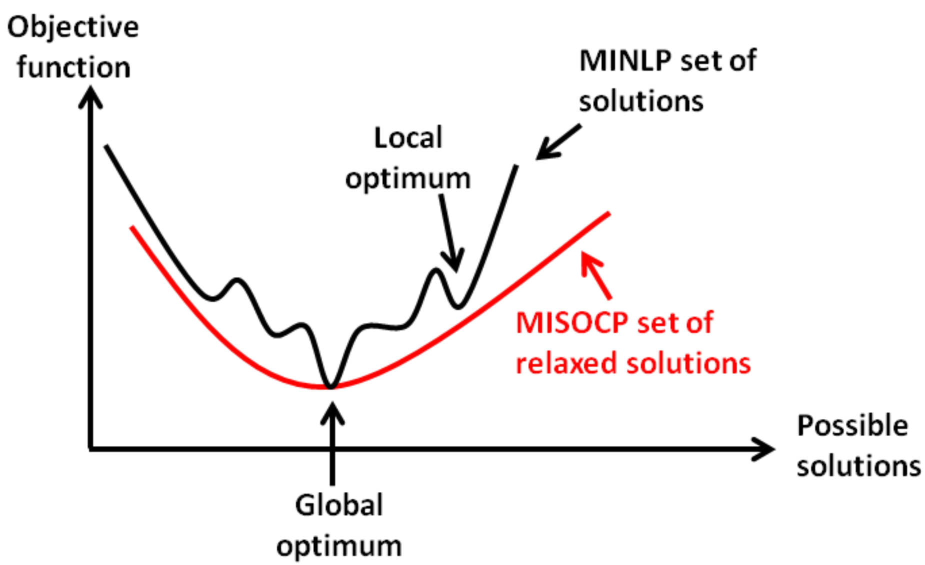


$$l_{ij} = \frac{P_{ij}^2 + Q_{ij}^2}{v_i}$$

Non convex

$$l_{ij} \geq \frac{P_{ij}^2 + Q_{ij}^2}{v_i} \Leftrightarrow \left\| \begin{matrix} 2.P_{ij} \\ 2.Q_{ij} \\ l_{ij} - v_i \end{matrix} \right\|_2 \leq l_{ij} + v_i$$





Addition of the flexibility procurement cost

1st objective function

$$min \sum_{(i,j)\in\Omega} r_{ij}.l_{ij}$$

Minimisation of the network losses at a given time

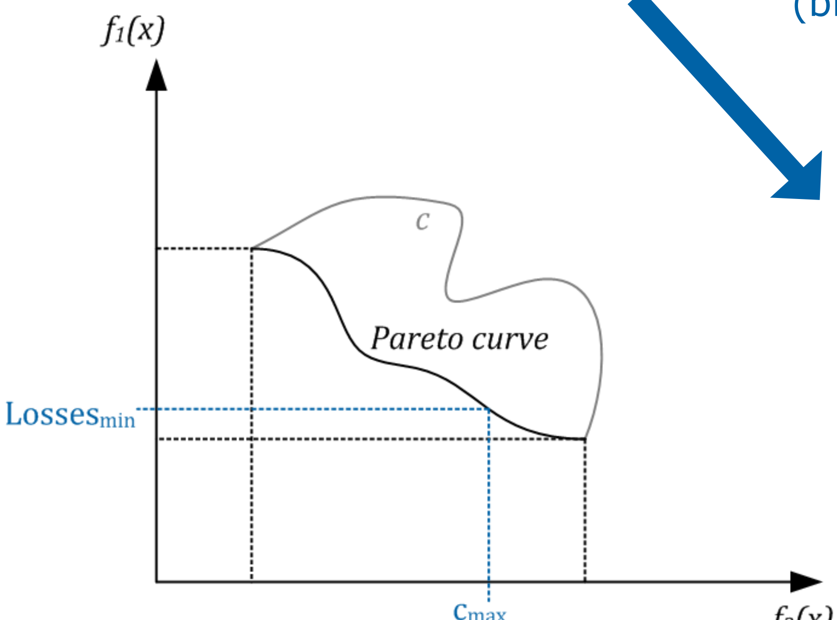
Minimisation of the flexibility procurement cost

2nd objective function

$$min \sum_{i\in\Gamma} \sum_{l\,\in\,L(i)} x\_act_{il}.c_{il}$$

Cost of offer activation

State of offer activation (binary variable)

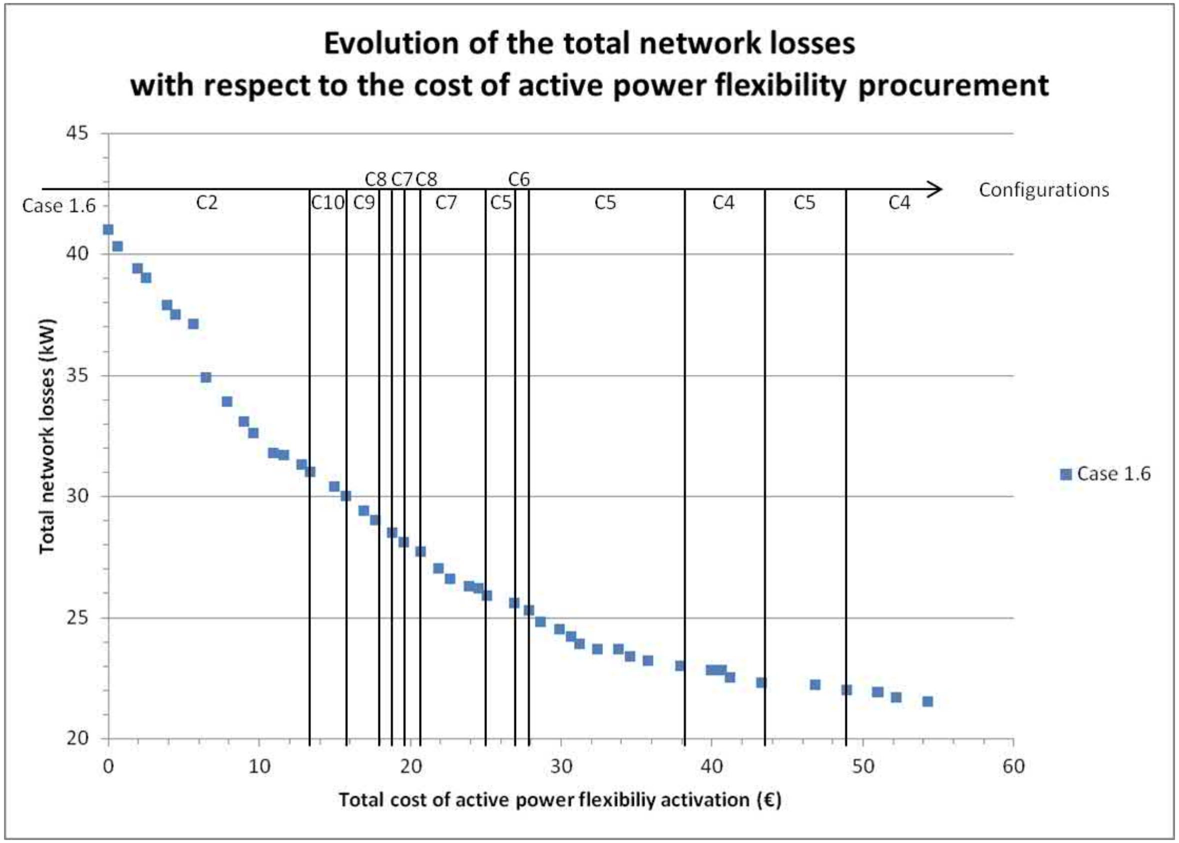


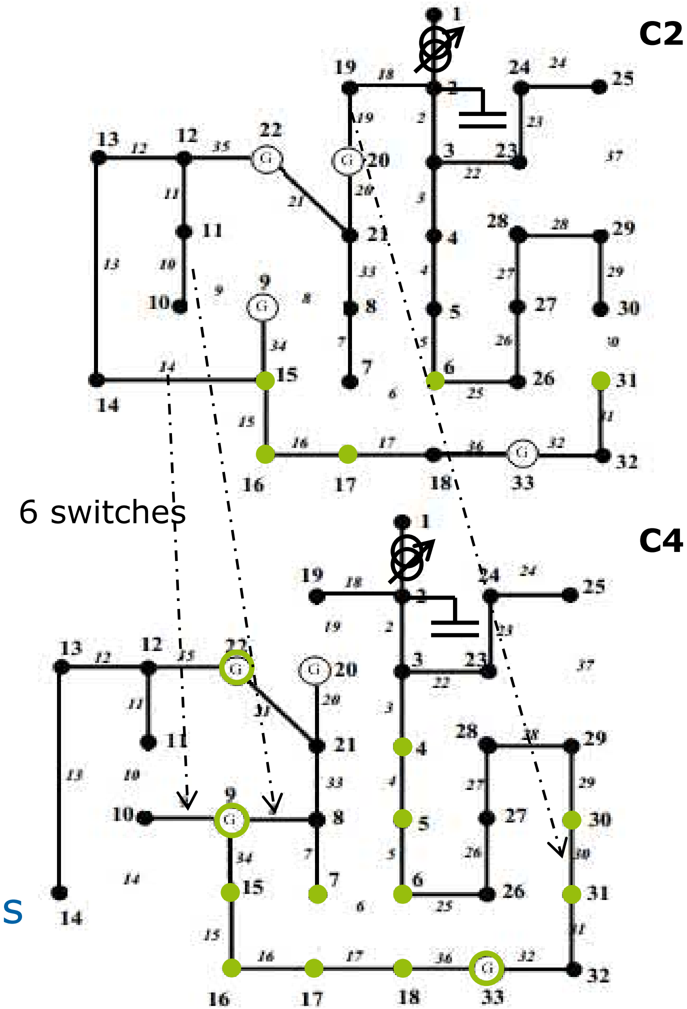
Constraint on the flexibility procurement cost

$$\sum_{i\in\Gamma} \sum_{l\,\in\,L(i)} x\_act_{il}.c_{il} \le c_{max}$$

Addition of the flexibility procurement cost

Pareto curve for a particular test case





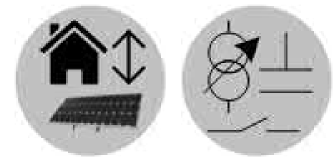
Decrease load consumption → decrease network losses

Warning ! The **load consumption** have to be **shifted**

Increasing network performance

Contributions

- **Distributed** advanced function for **increasing network performance** while considering **the available flexibility resources**



- **Optimality** of the solution found **guaranteed**

- Any procurement of flexibility resources should be **associated with a cost** for the DSO

€

→ Addition of a constraint on the total cost of DR activated offers

→ Give a clear vision on the Pareto front/ Trade-off between losses and flexibility activation on a long time frame

Conclusions

- New **dynamic coordination and control** infrastructure to consider the **optimal part** of the MV network with respect to its current **operational needs**

- New methodologies for **short-term DSO operational planning**

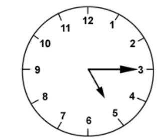
  → **Compatible** with the existing market processes
  → Several methods requiring **different mathematical needs**

- New methodologies for **local constraints management** and **optimal network efficiency improvement**
  → Guaranteed optimality conservation
  → Multi-objective methodology

- **Implementation** of these tools on a **real industrial case**
  → Reduce the risk of not respecting dispatching orders in ancillary services market by using flexibility resources
  → Reduce grid reinforcements during airport load growth

Further works

- **Extend** these methodologies on a **more adequate time frame**
  - → Rebound and report effects
  - → Availability of the flexibility offers
  - → Dynamic constraints on flexibility resources



✓ *B. Swaminathan, "Optimal Operational Planning of Distribution Networks", thèse en cours au g2elab, 2017.*

- Determine the **most problematic flexibility offers**
  - → One potential solution is the use of the fuzzy logic

- Assess the potential end users **flexibility acquisition**
  - → Real challenge
  - → Uncertainties on their availability

✓ *J. Sayritupac, R. Caire, E. Vanet, C. Larios, "Behaviour Analysis of an Operational Planning Tool facing Activation Probabilities, for Near Optimal Operation of Smart Grids" accepted in CIRED 2017 Glasgow, 2017.*

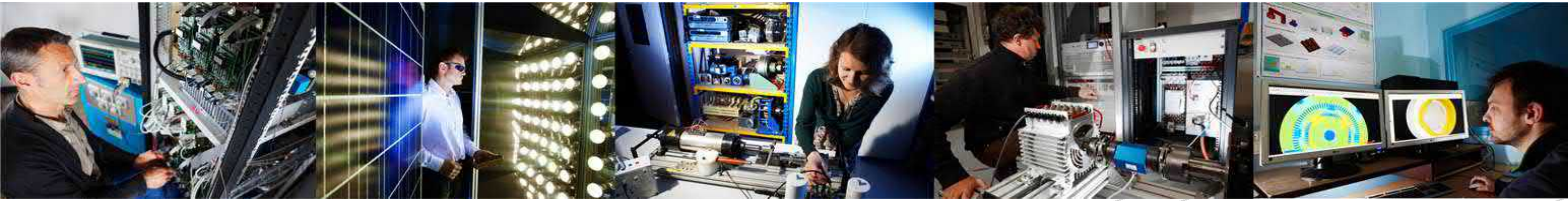
- Imagine other types of **local flexibility exchanges**
  - → OTC contracts instead of local market places
  - → New transactions schemes with blockchain
  - → Impact on the DSO business model

Thank you for your attention !

Romain Gigault
GE Grid Solutions

Mathieu GABEL
Strasbourg Electricité Réseaux

Emmanuelle Vanet
G2Elab



16/06/2017

Interoperability between Modular Multilevel Converters connected to a Multi-Terminal DC grid

Student: **Julián Freytes**

Director: Xavier Guillaud (L2EP - Centrale Lille)

Co-supervisors: Frederic Colas, François Gruson (L2EP – ENSAM)

Industrial supervisors: Olivier Despouys, Samuel Nguefeu, **Pierre Rault**, Hani Saad (RTE)

IEEE PES Power & Energy Society

see

L2EP Laboratoire d'électrotechnique et d'électronique de puissance de Lille

Rte Le réseau de transport d'électricité

- Context – Why MTDC grids?
- HVDC system description
- On dynamics of DC power systems: Challenges
- Multivendor schemes: Interoperability
- How to study the IOP ?
- Conclusions

- **Context – Why MTDC grids?**
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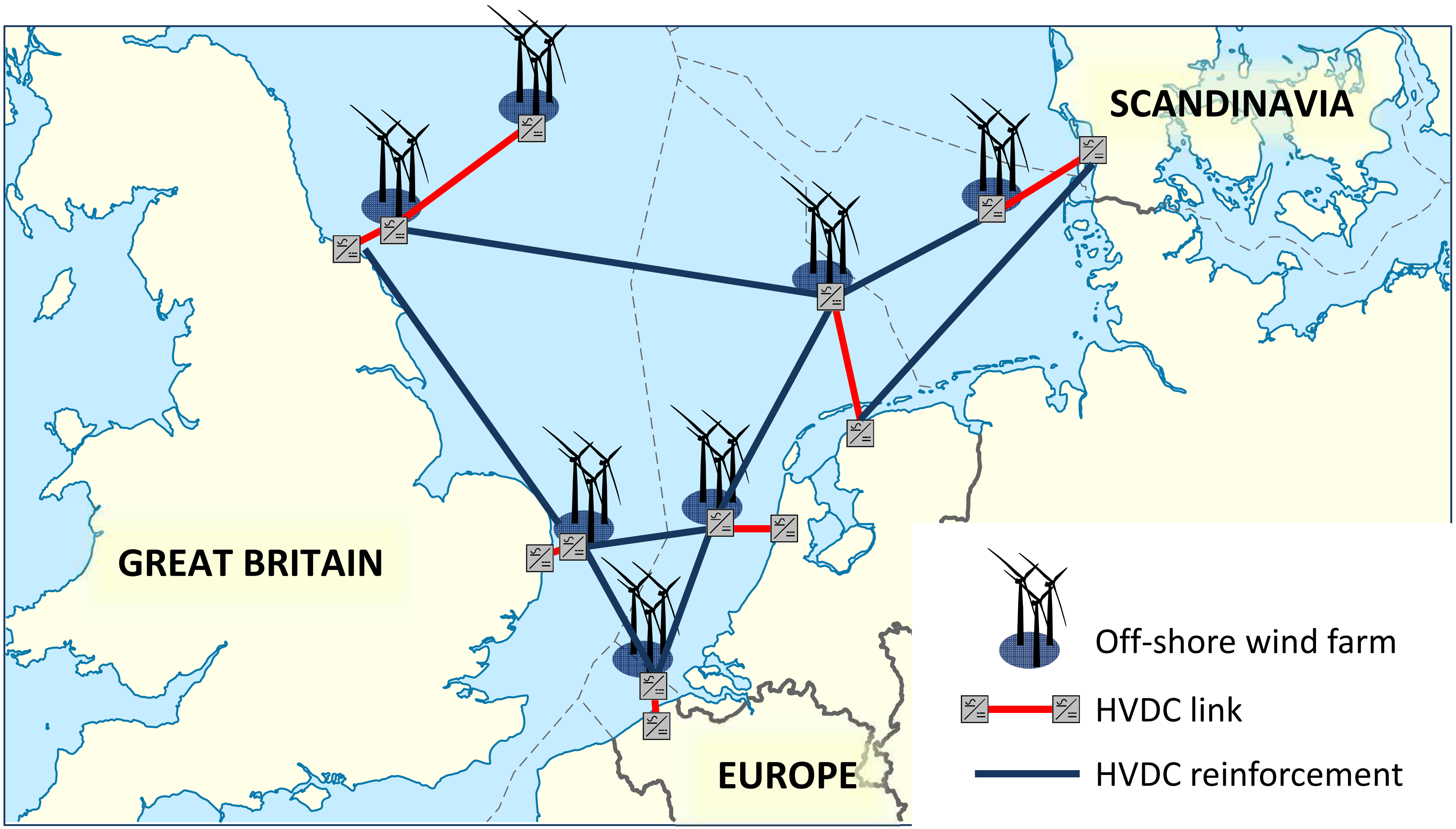
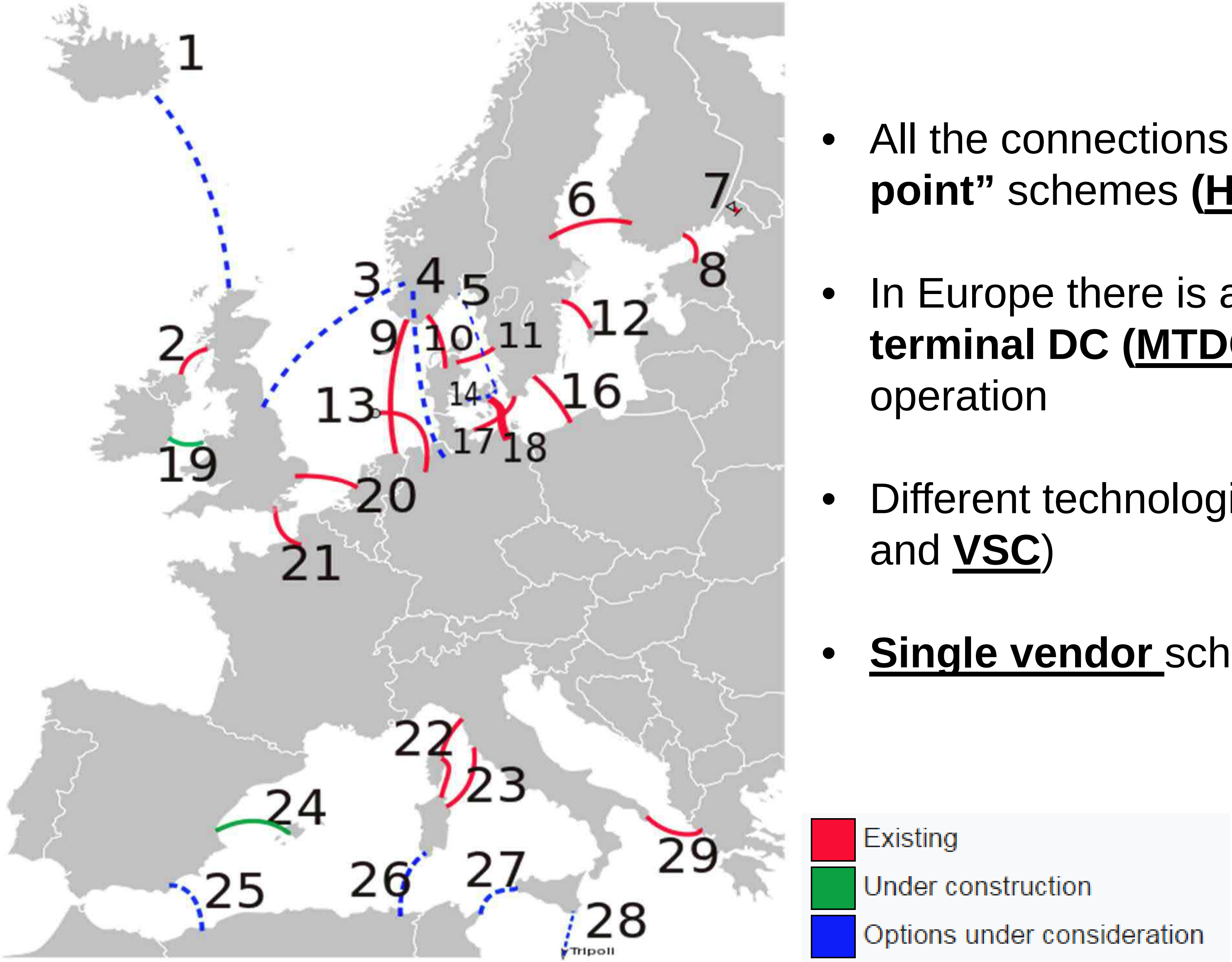
- Multivendor schemes: Interoperability
- How to study the IOP ?
- Conclusions

Offshore wind power development

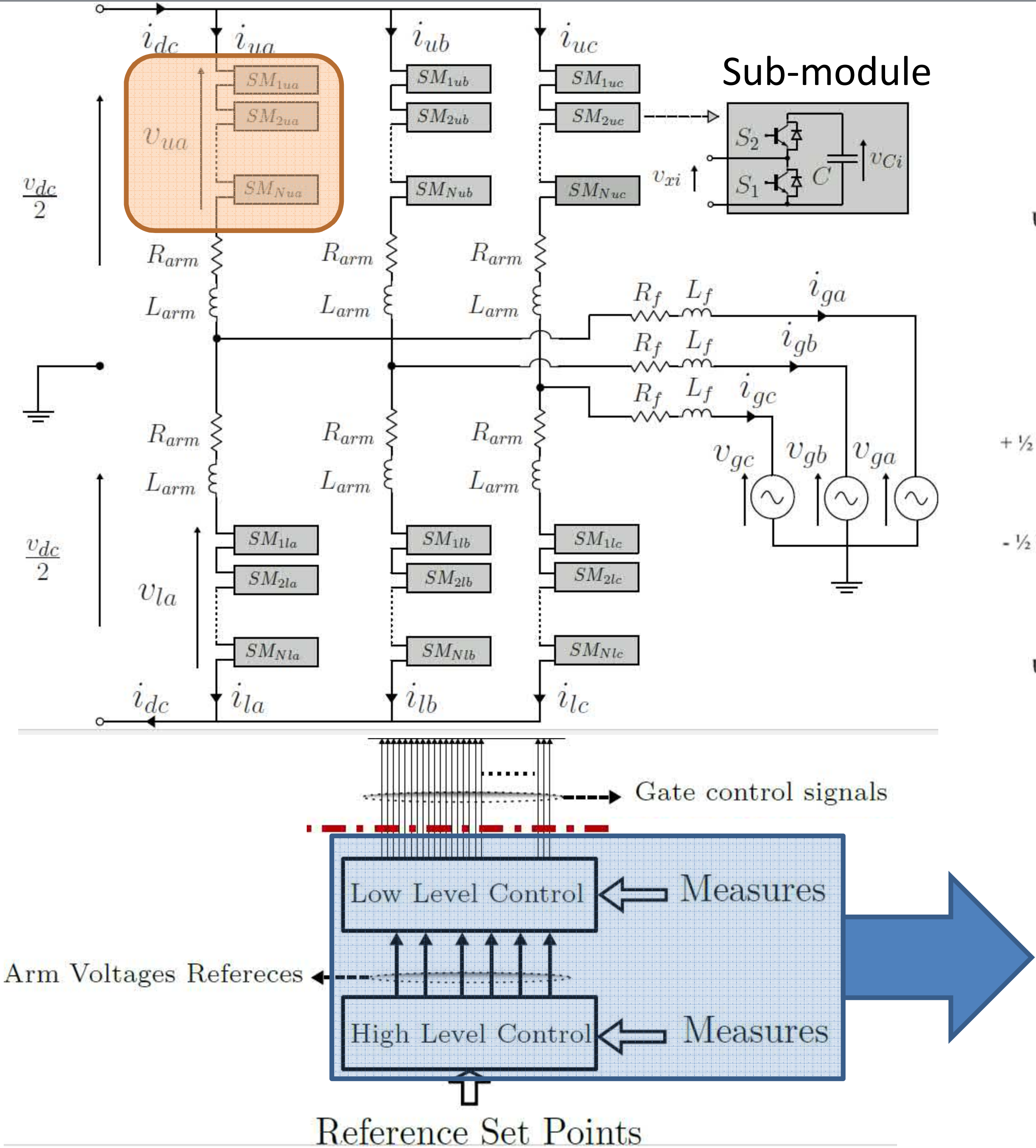


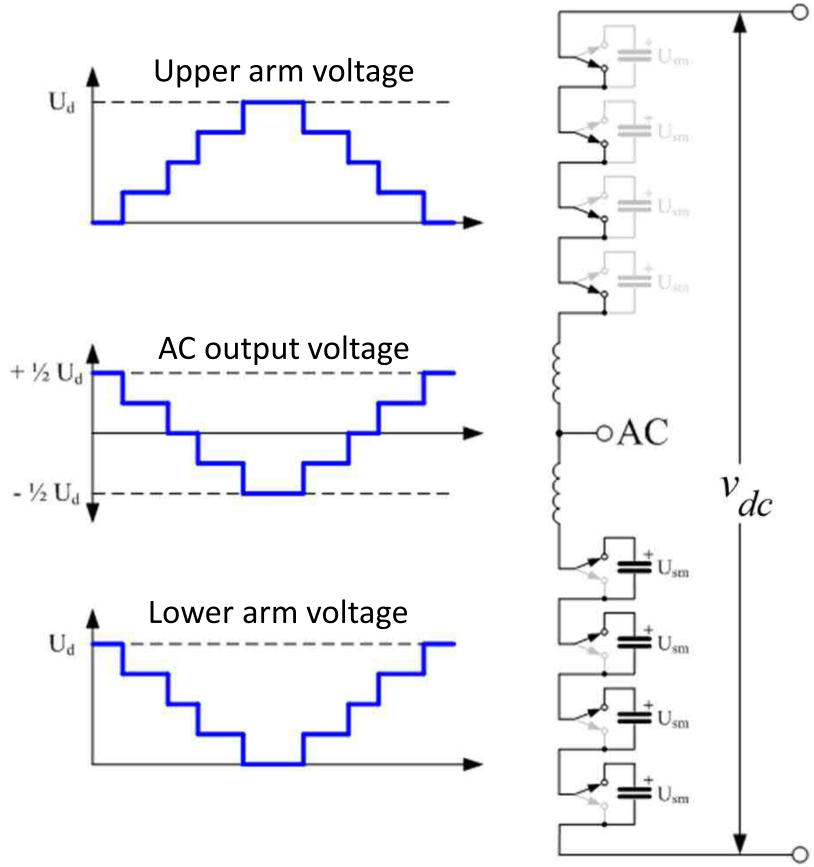


https://en.wikipedia.org/wiki/List_of_HVDC_projects

- All the connections are **"Point-to-point"** schemes **(<u>HVDC Link</u>)**
- In Europe there is actually no **multi-terminal DC (<u>MTDC</u>)** system in operation
- Different technologies are used (LCC and **<u>VSC</u>**)
- **<u>Single vendor</u>** schemes !

- Context – Why MTDC grids?
- **HVDC system description**
- On dynamics of DC power systems: Challenges
- Multivendor schemes: Interoperability
- How to study the IOP ?
- Conclusions

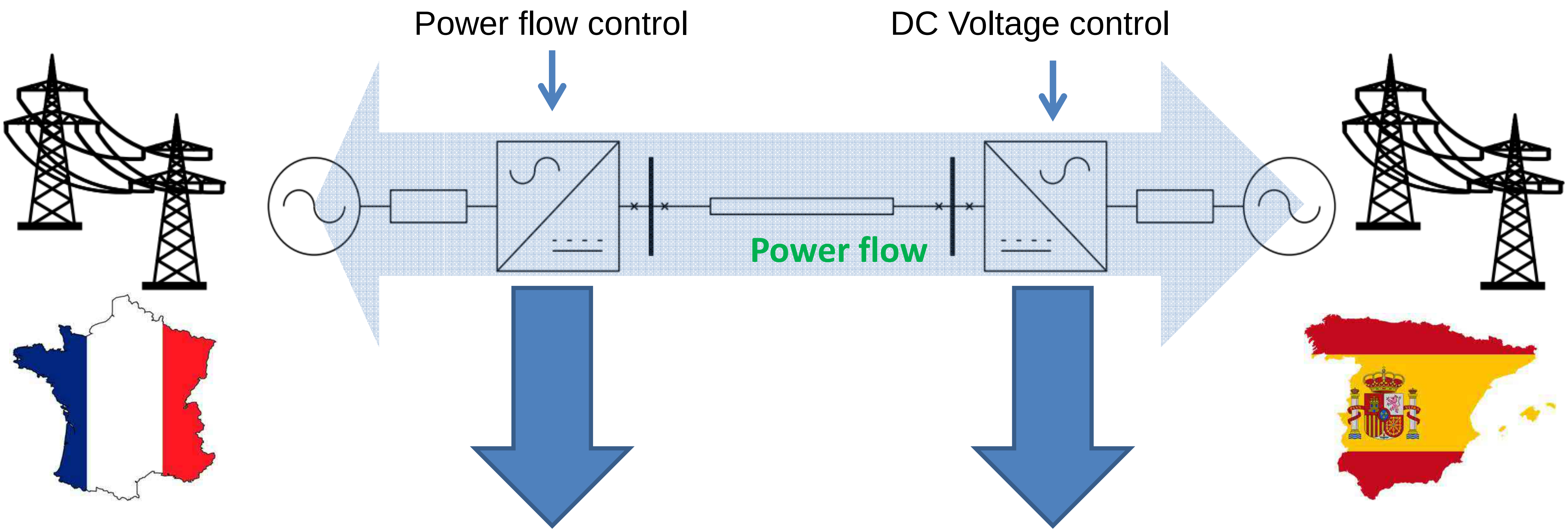


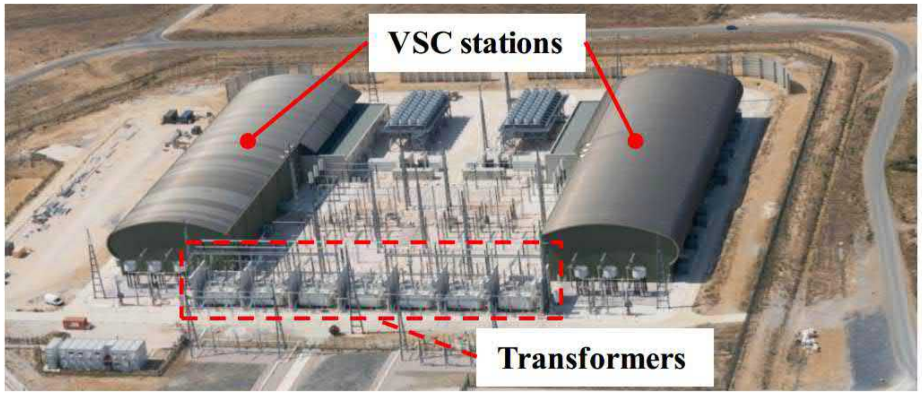


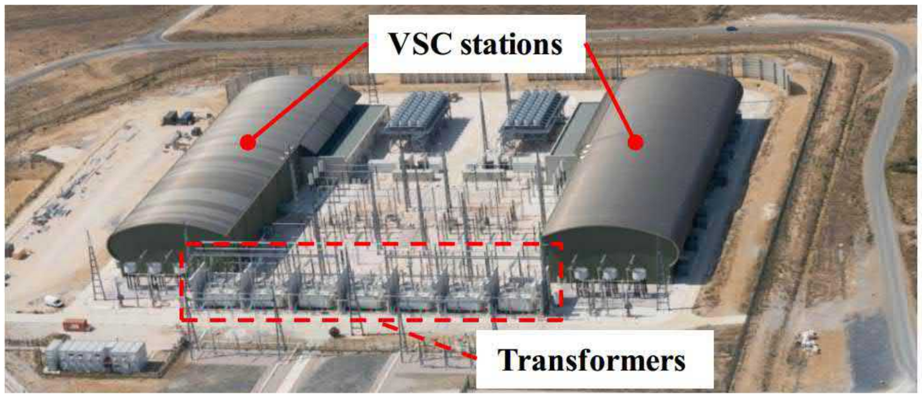
All the "intelligence" of the system is comprised in the control

HVDC system description – HVDC Link

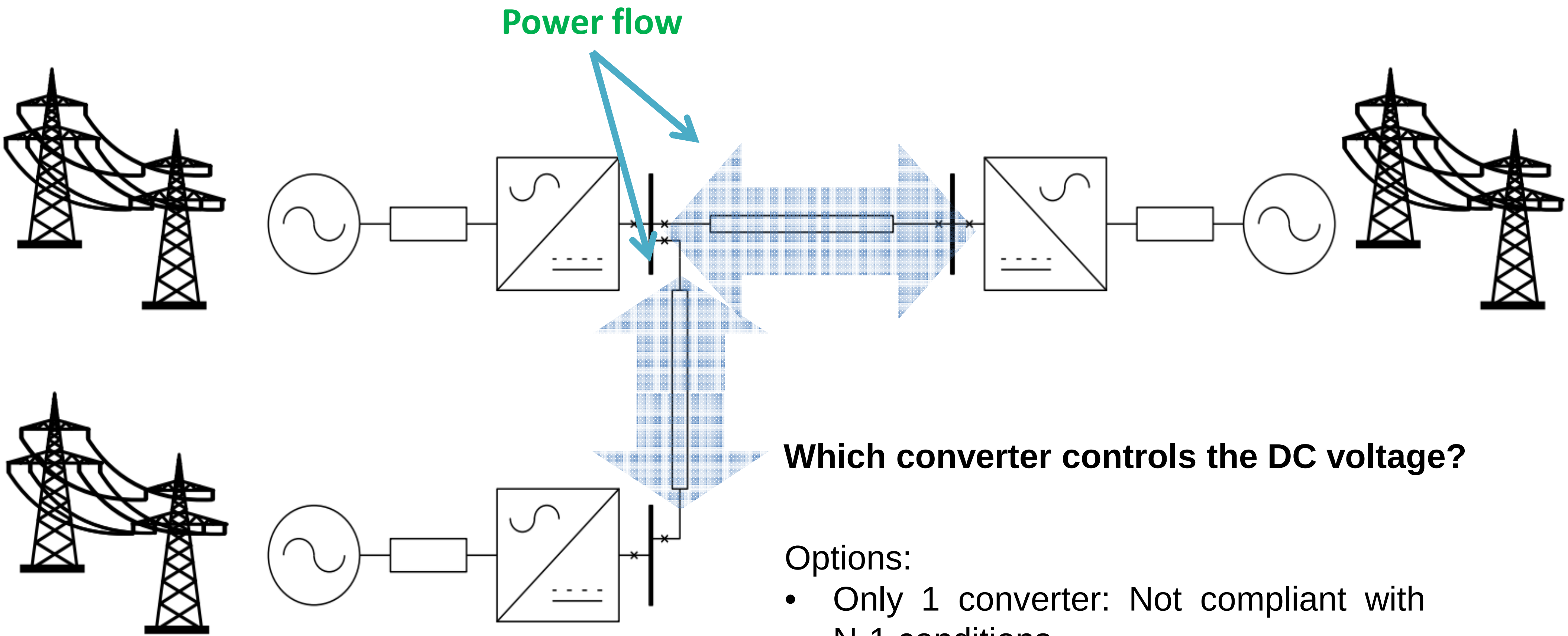
INELFE project – Connection between ***France & Spain*** – **Vendor**: Siemens







H. Saad, Modélisation et simulation d'un liason HVDC de type VSC-MMC, **2015**

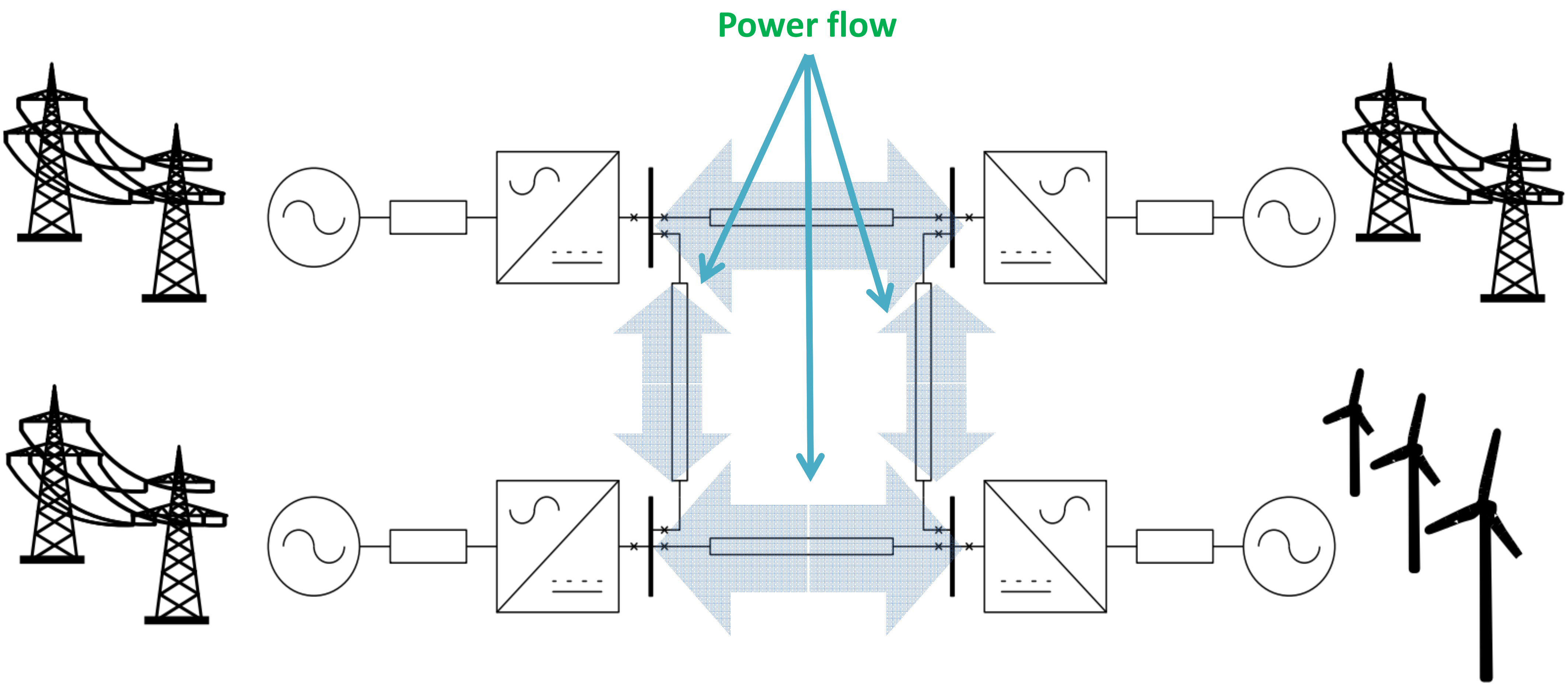


Which converter controls the DC voltage?

Options:

- Only 1 converter: Not compliant with N-1 conditions
- More than 1:

Droop control: Analog to the AC frequency controller of the synchronous machines.

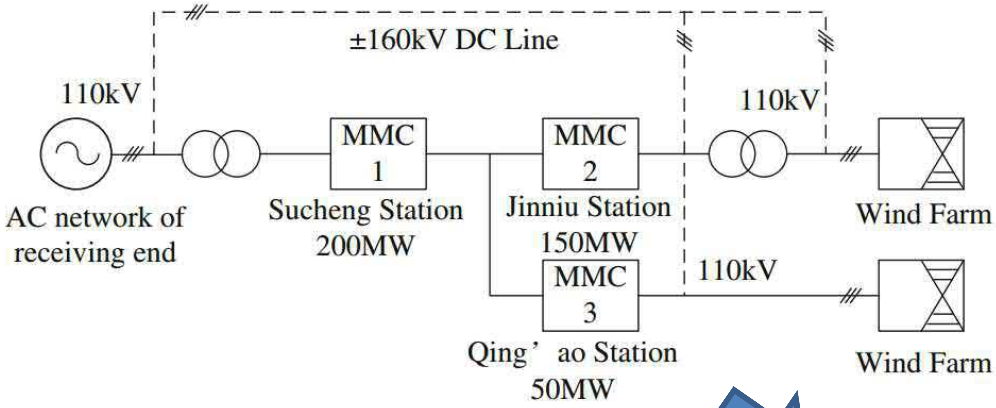


Challenges:

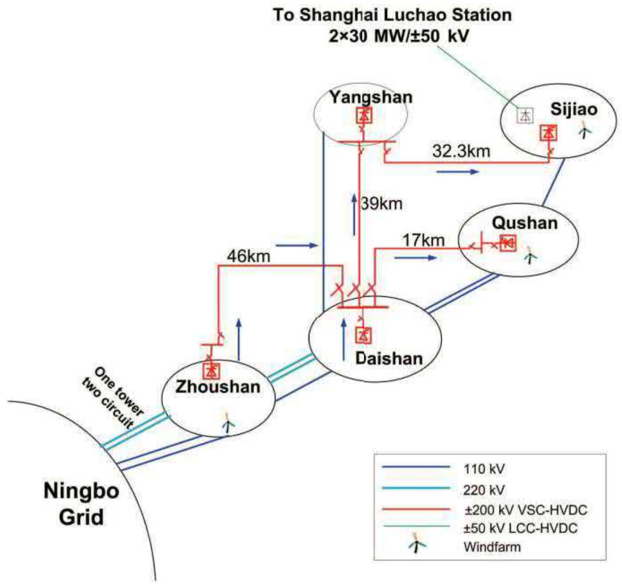
- Fast fault clearance?
- Grid protection coordination?
- Communication requirements?
- Voltage level?

Nan’ao (3 terminals)

…Multivendor scheme



Zhoushan (5 terminals)



Main vendor

Constructor 1 **Constructor 2** **Constructor 3**

- Context – Why MTDC grids?
- HVDC system description
- **On dynamics of DC power systems: Challenges**
- Multivendor schemes: Interoperability
- How to study the IOP ?
- Conclusions

AC	DC
Frequency ω	DC voltage level u_s
Impedance of connection X	Resistance of connection R
Active power transfer $\frac{V^2 \sin(\delta)}{X}$	Power transfer $u_s \frac{\Delta u_s}{R}$
Constant of mechanical inertia $H = \frac{1}{2} J \frac{\omega_{base}^2}{S_{base}}$	Electrostatic Constant $H_c = \frac{1}{2} C_s \frac{U_{s\,base}^2}{P_{base}}$

From 3s to more than 10s for a power plant

Around 40ms (or less) for 1 VSC

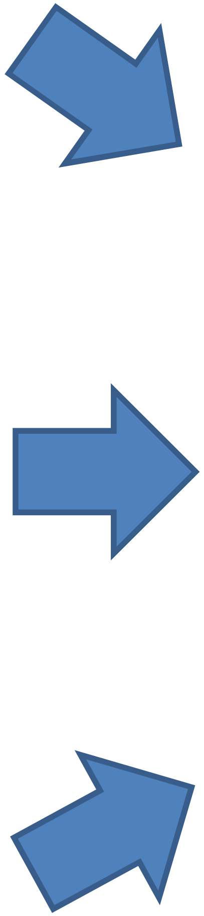
VERY FAST DYNAMICS !!!!

Simple models are usually used

Electromechanical models

Decoupled

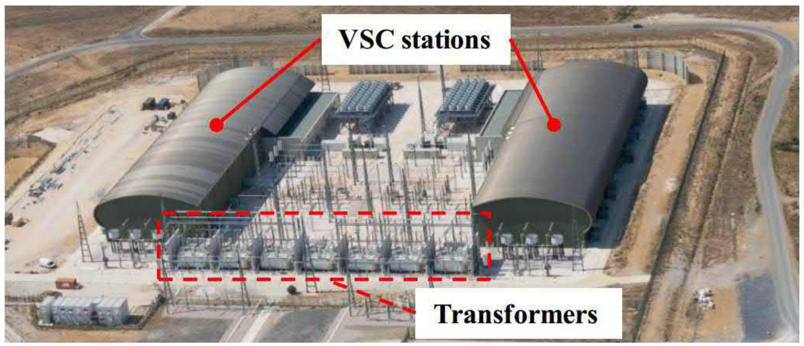
Electromagnetic models



The **decoupling** between the **electrical** and **mechanical** phenomena* in classical **AC systems** allows to use **simple models** and still be able to study **large grids**

* …also the experience !

How to model the DC components???



???

???

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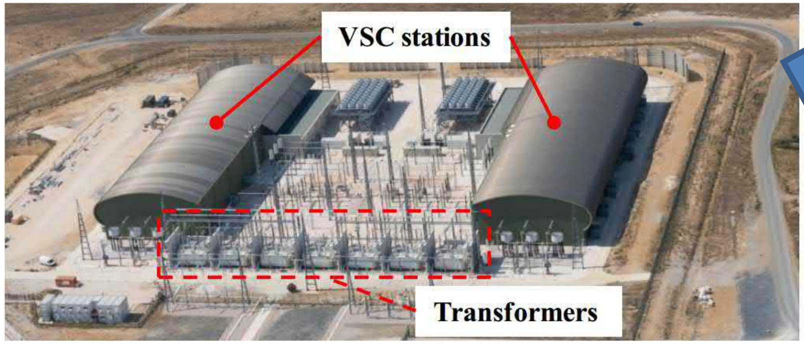

Ongoing works are trying to **model** the **components** of the **DC systems*** for different studies:

Hard task since the **fast dynamics** force to consider **detailed models**

* …with uncertainties due to the lack of experience !

- Context – Why MTDC grids?
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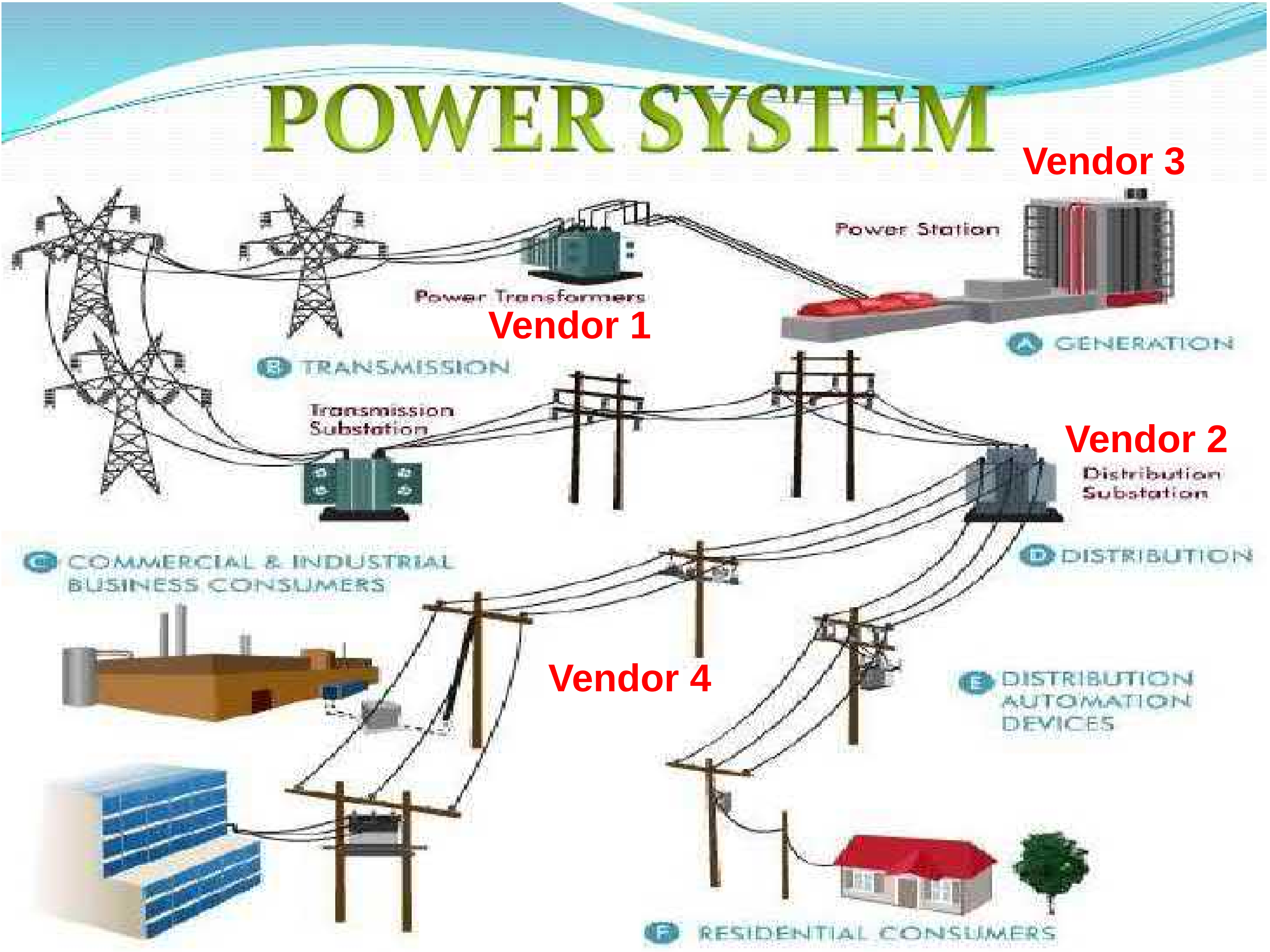
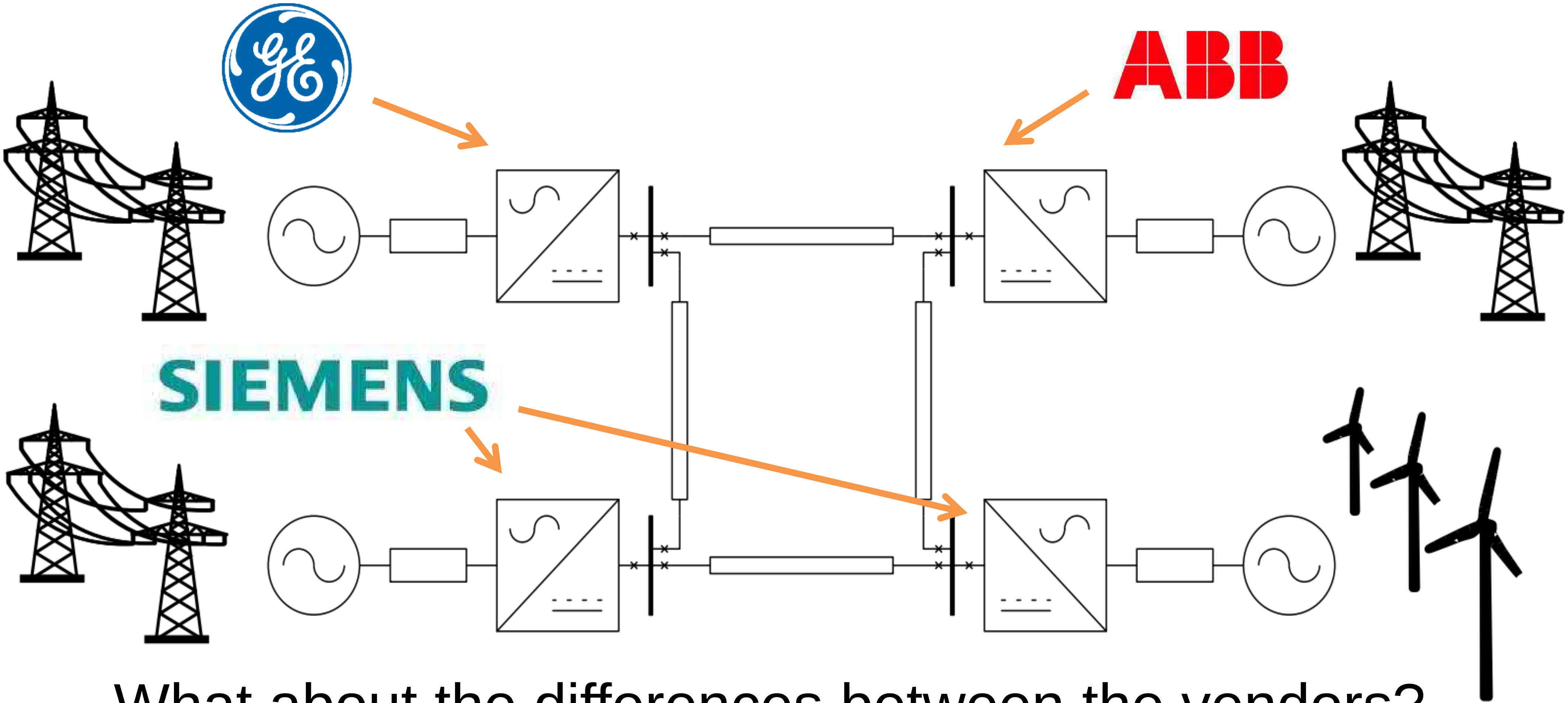


- Physical **knowledge** of the system
- **Interoperability** studies were performed
- **Standards** were created
- Technology evolving **not so fast**
- More than 100 years of experience worldwide !

Let us **assume** that we **DO** have **representative models** of the DC components …

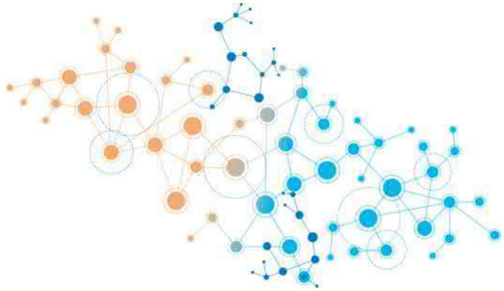


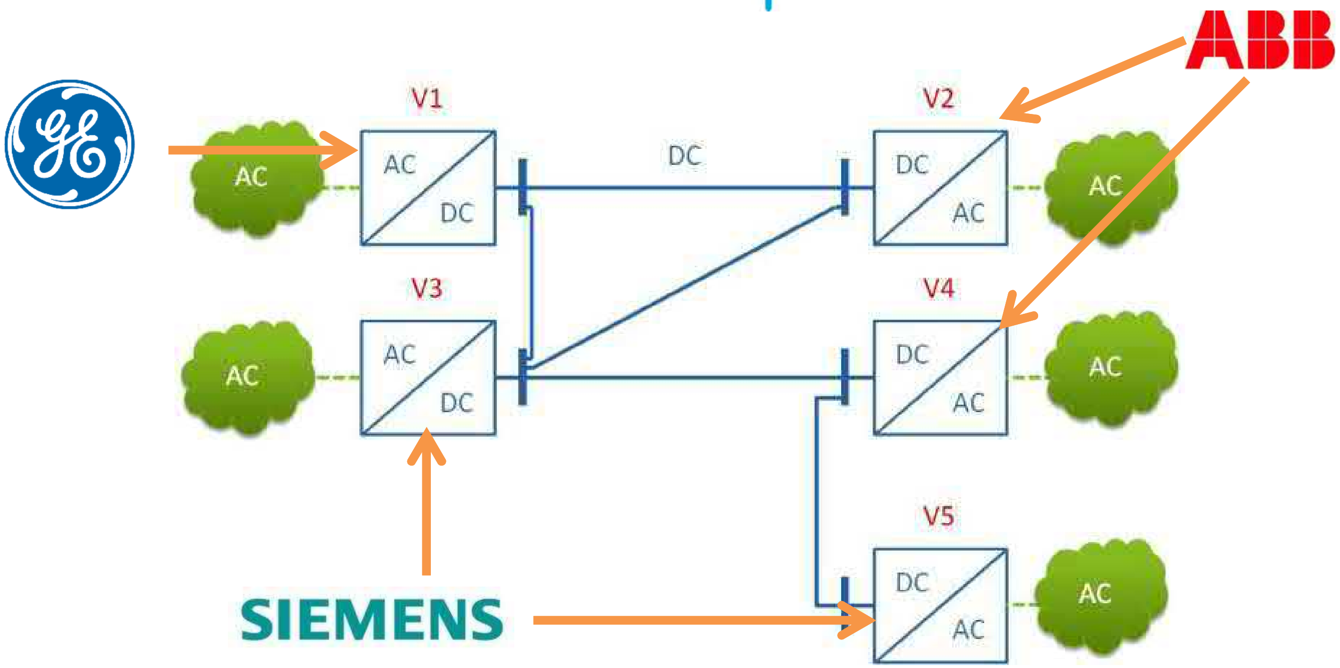
What about the differences between the vendors?

INTEROPERABILITY (**IOP**)

Multivendor schemes: Interoperability

- What are the conditions to ensure **maximum interoperability** for multivendor **MTDC-MMC** based grids?





Multivendor schemes: Interoperability

Best Paths PROJECT

Objective: Highlight the conditions necessary to ensure maximum interoperability, for all parties involved at different project stages ,for a wide range of HVDC arrangements based on recent VSC technology (in particular: MMC or Modular Multi-level Converters).

Demo #2 Partners:

- ABB
- Siemens
- GE
- RTE
- REE
- Elia
- Ecole Centrale de Lille
- University of Strathclyde

Manufacturers (ABB, Siemens, GE)

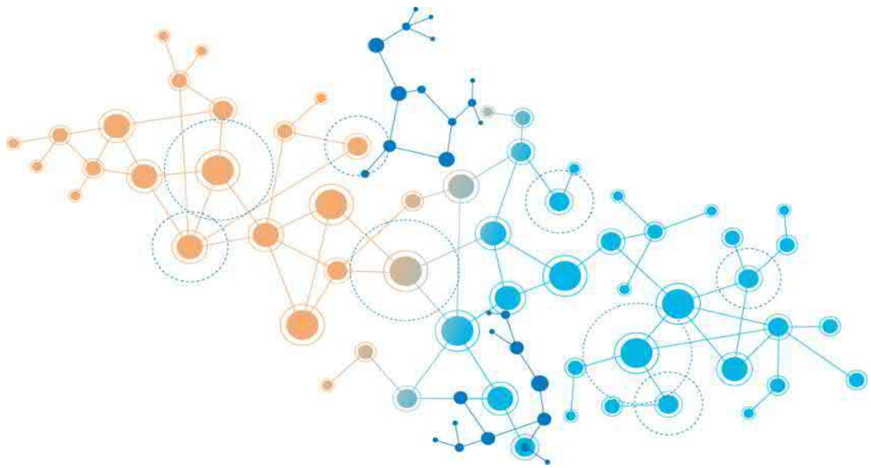
TSOs (RTE, REE, Elia)

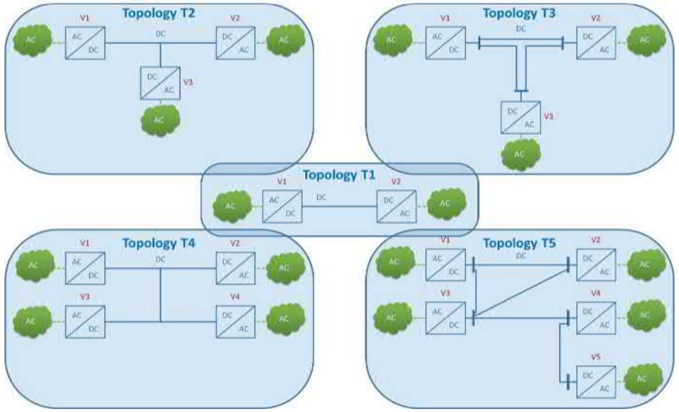
Universities (Ecole Centrale de Lille, University of Strathclyde)

Simulation tool:

EMTP-RV

The reference for power systems transients





Different DC grid topologies were studied

More than 1000 simulations were performed and evaluated

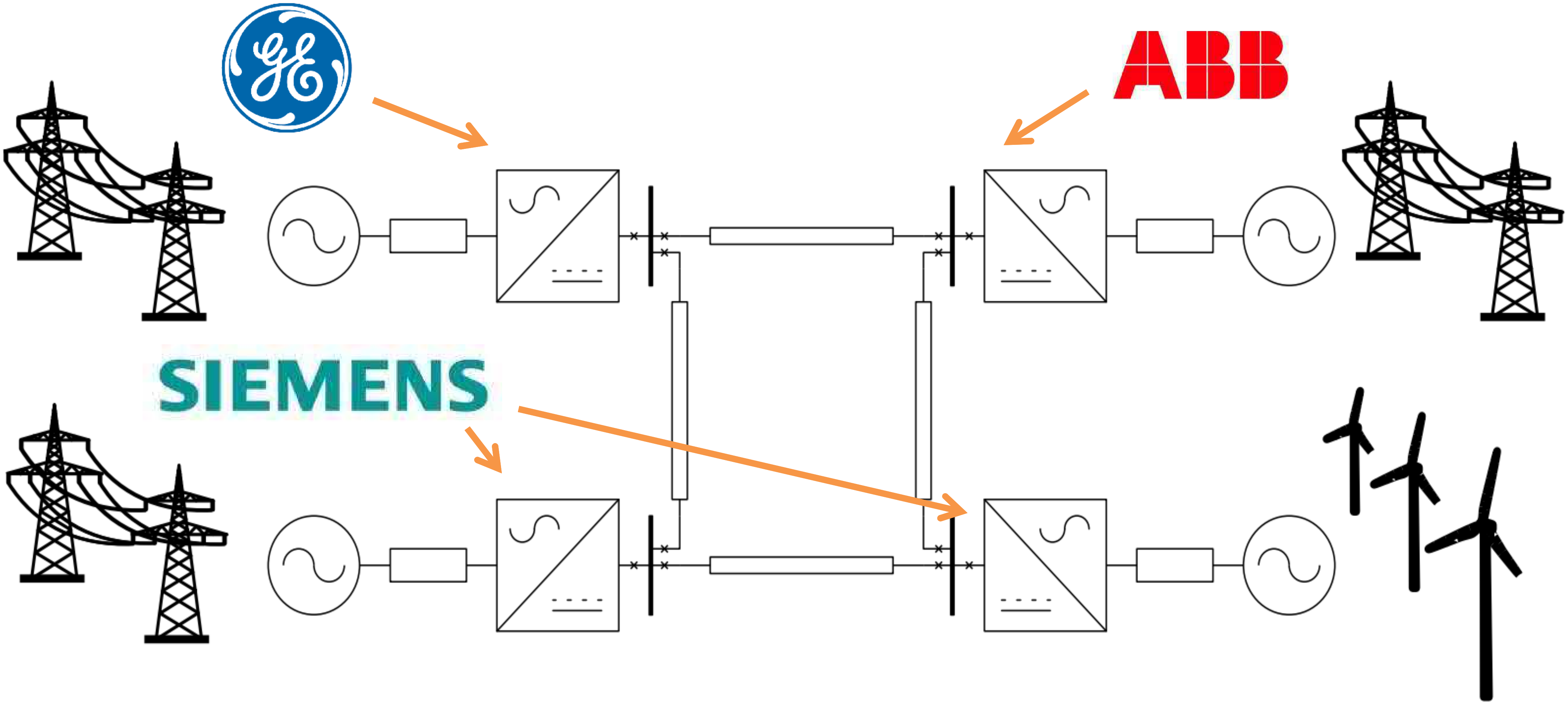
A simulation test reveals an **IOP** issue if and only if the following **two conditions** are met:

1) The same simulation works fine when considering a single vendor scheme (for all converters); and

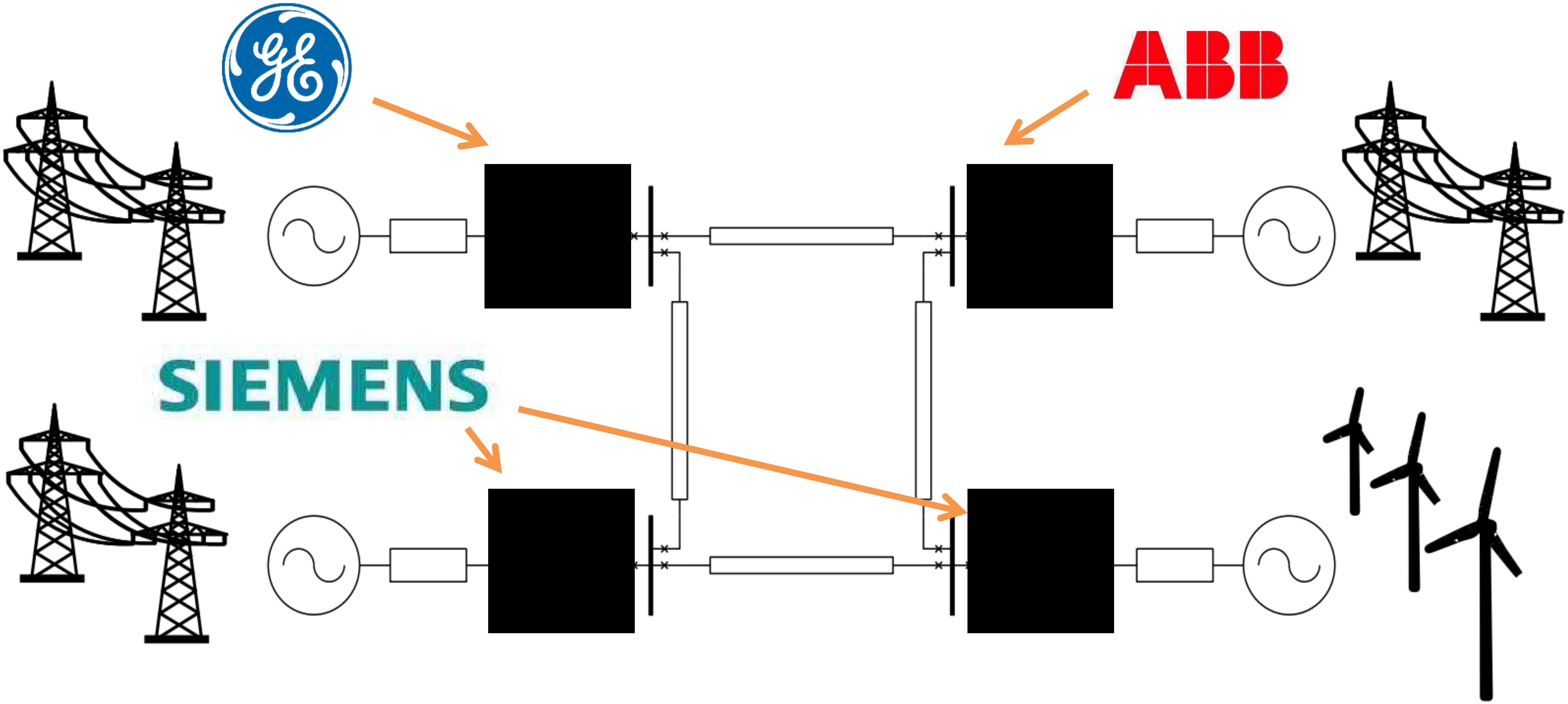
2) The same simulation DOESN'T works fine when considering a multivendor scheme

Definition of IOP in the BestPaths project

In BestPaths projects it was evaluated by simulation different scenarios to study the interoperability



DO we have **models** of the VSC?



- Context – Why MTDC grids?
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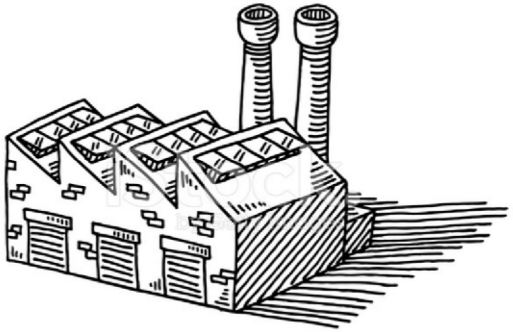
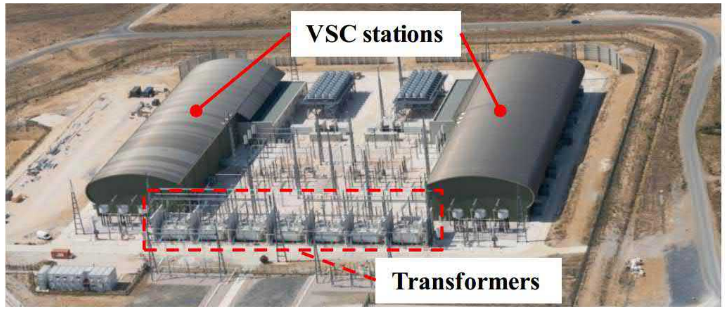
- Multivendor schemes: Interoperability
- **How to study the IOP ?**
- Conclusions



Black Box Model (VSC and Control)



Real system

Heuristic Approach

- **Simulations**
- **Simulations**
- **Simulations**
- **...**
- **Simulations**

Analysis of sim. results

Conclusions

What if an IOP is encountered ????
How to explain it and/or solve it???

Open Models (VSC and Control)

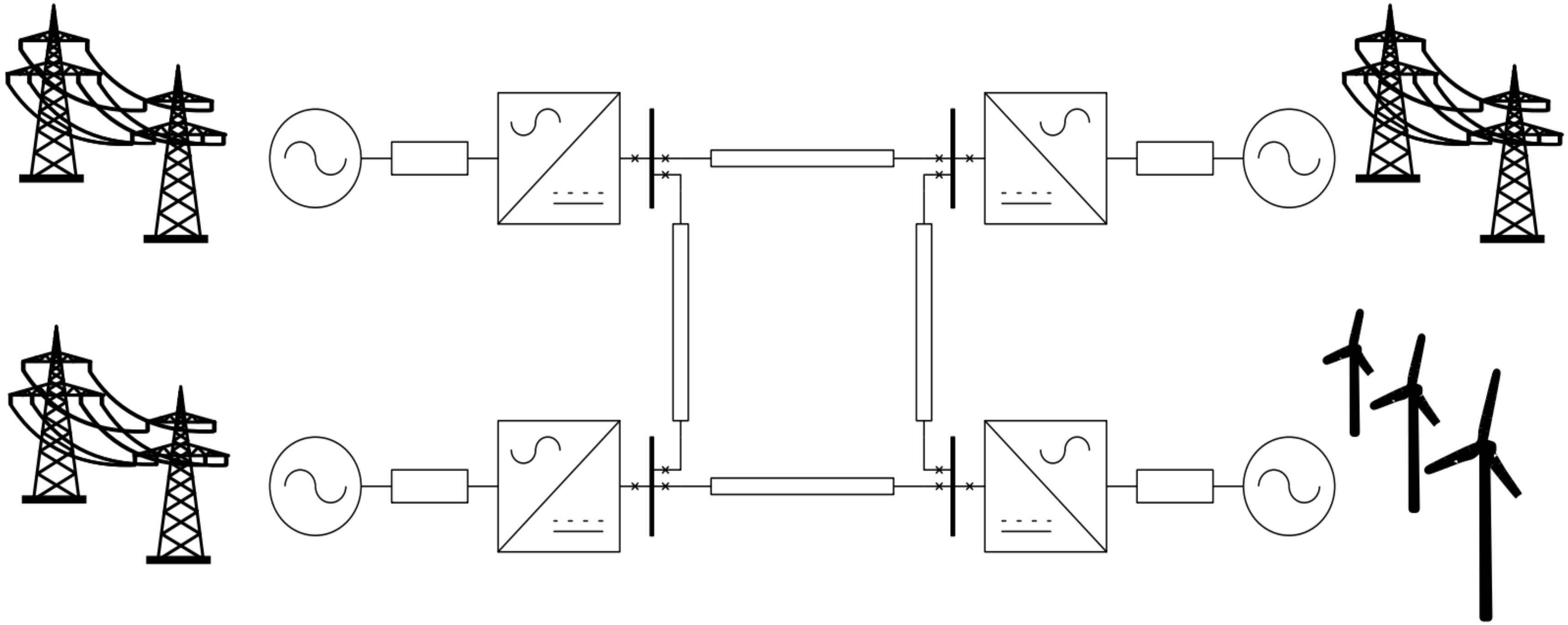
Schematics and physical relations

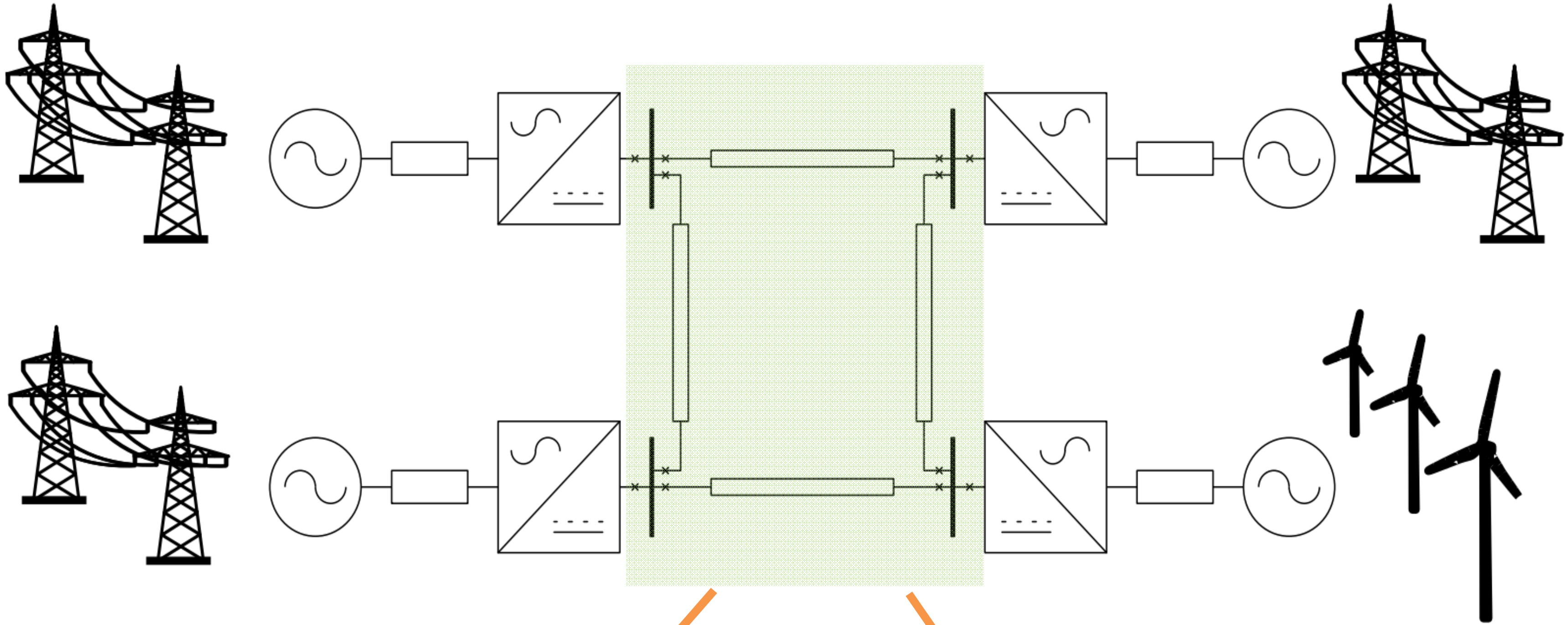
Used Methodology

Modelling → **Control** → **Analytical tools** → **Simulations**

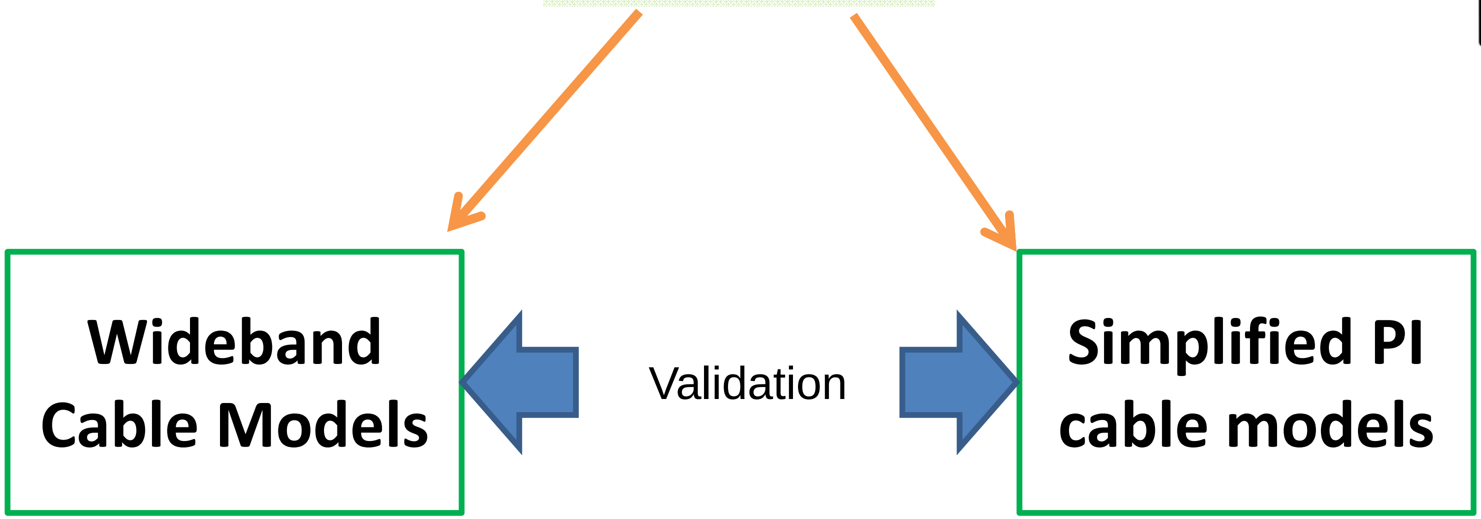
Conclusions

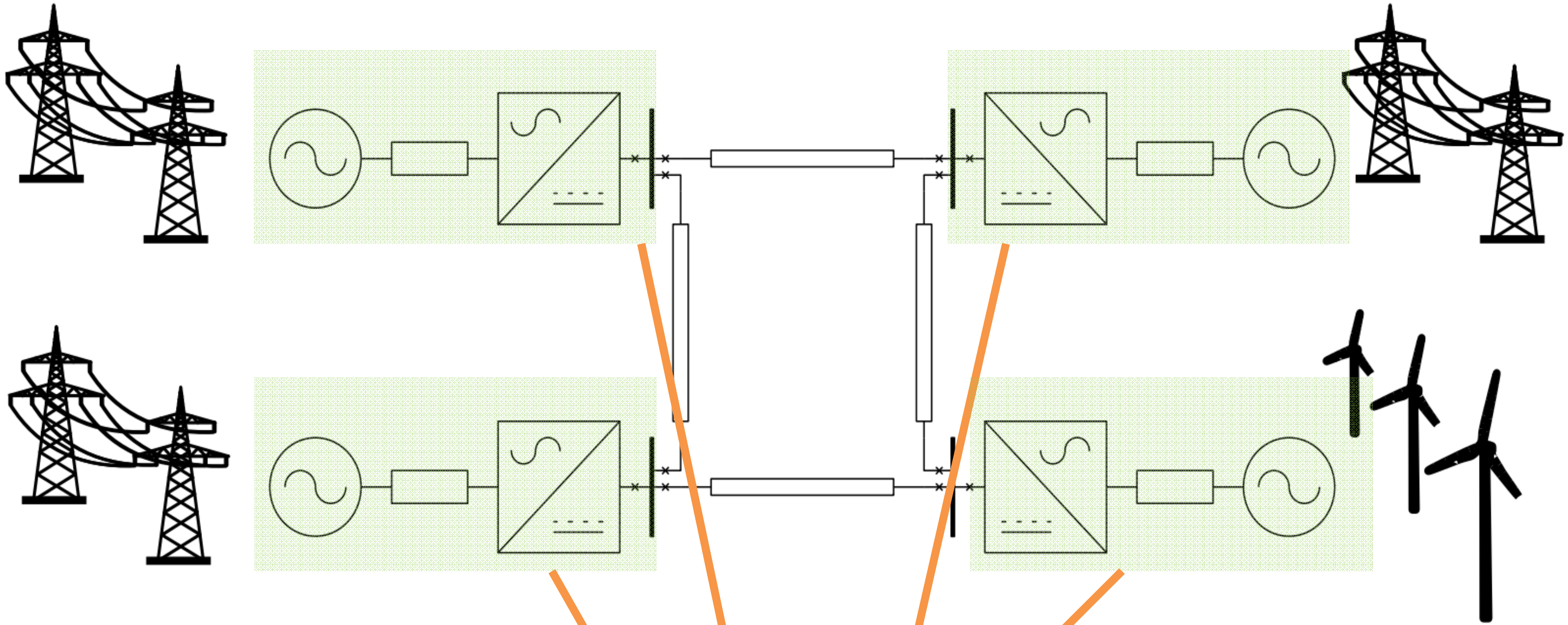
** Not only universities: TSOs, Research Centres and even vendors….*





DC Cables


Wideband Cable Models
Validation
Simplified PI cable models



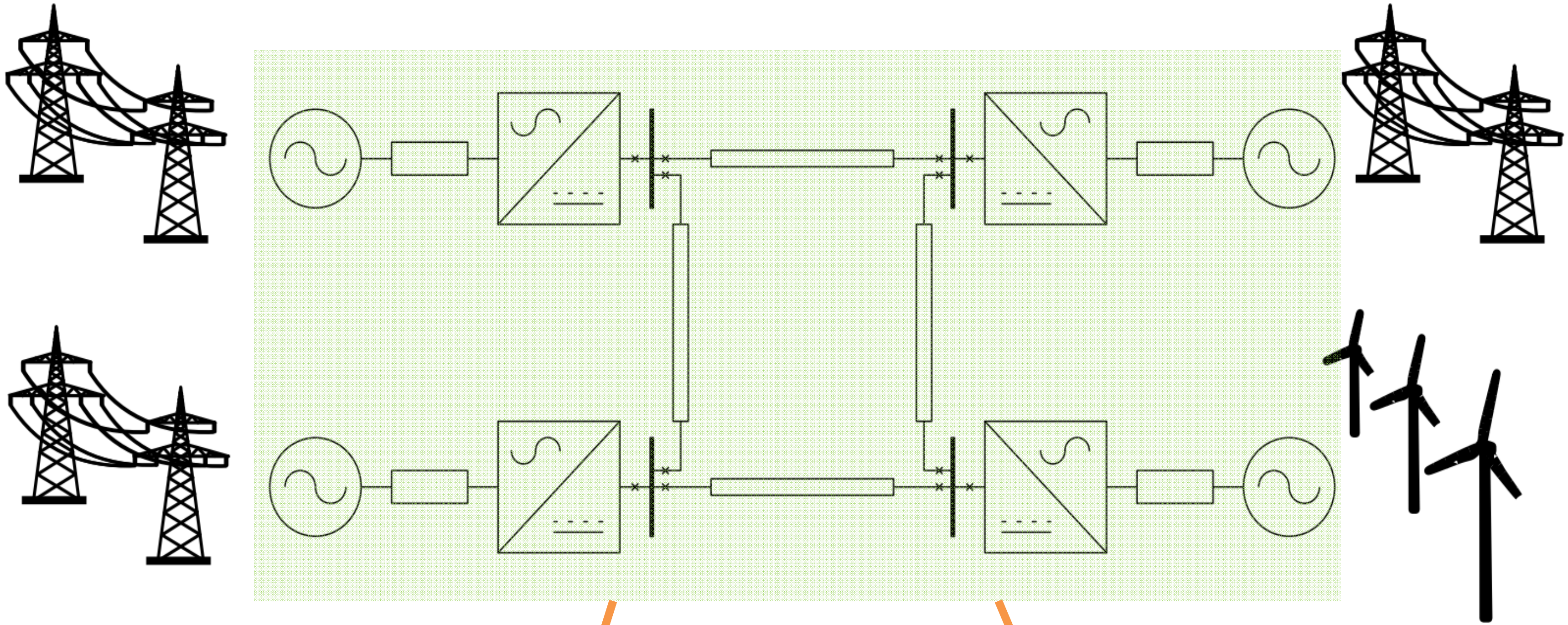
MMC + Control

Different models

Detailed models (with switching)

Validation

Simplified models (continous)



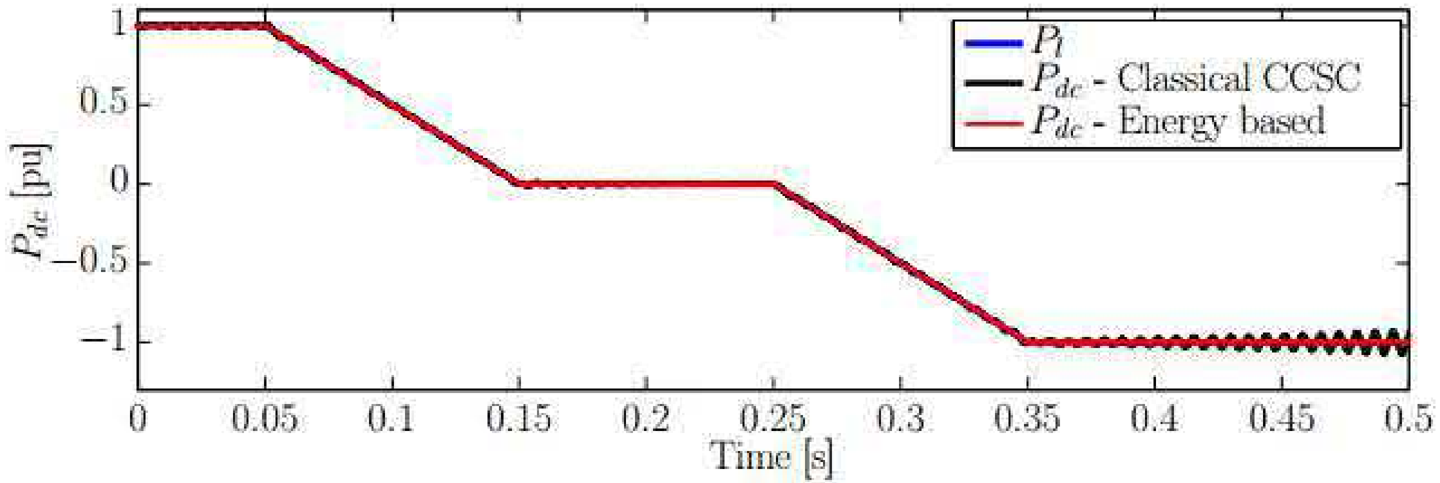
Complete system

Complete EMT model (Detailed)

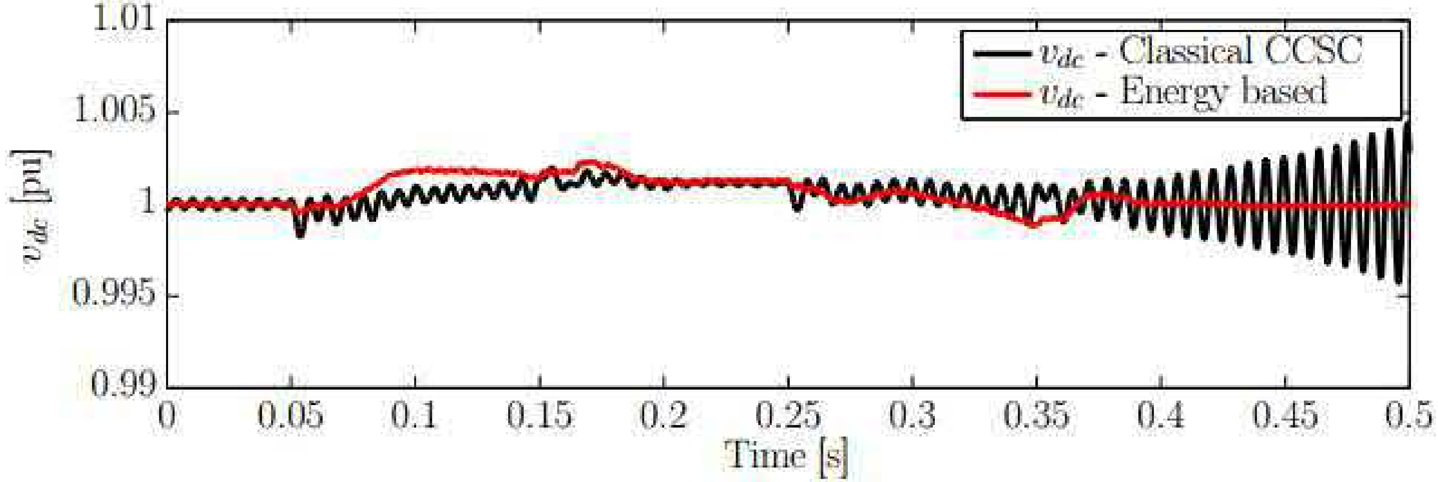
Validation

Analytical model

Power reversal



(a) P_{dc}[pu]



(b) v_{dc}[pu]

The analytical model allowed to find and solve the stability issues

Solved with a better management of the stored energy

- Context – Why MTDC grids?
- HVDC system description
- On dynamics of DC power systems: Challenges
- Multivendor schemes: Interoperability
- How to study the IOP ?
- **Conclusions**

Conclusions and perspectives

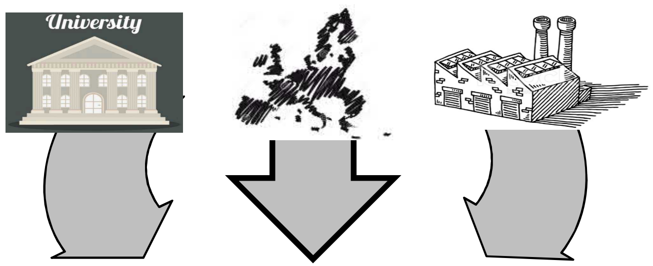
- The Modular Multilevel Converter is the state-of-the-art on HVDC systems
  - Already used in Point-to-point schemes
  - …and Multi-Terminal DC grids

- Modeling and control of MMCs presents a real challenge
  - Many models and control strategies are available in the literature
  - Different studies need suitable models

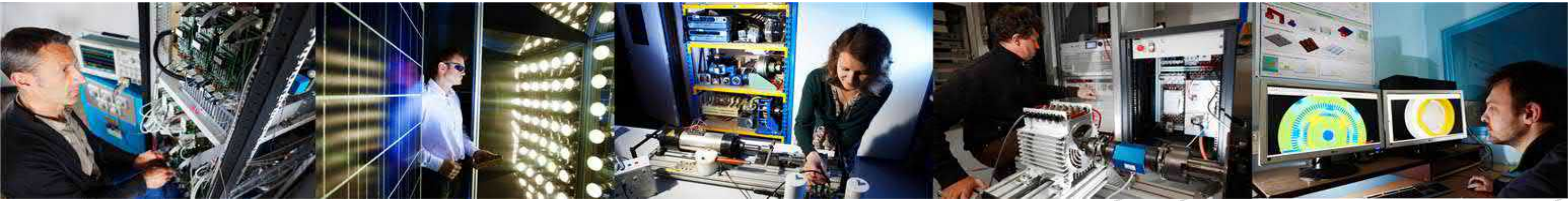
- Power electronics converters brings new functionalities to the existent grids
  - However, the converter by itself presents no “intelligence”
    → All the functions are governed by the control systems
    → Manufacturers surely have different control strategies

- Scientific approaches allow to quantify the impact of different strategies

Among many uncertainties, one thing is for sure…



Working together
towards the upcoming HVDC systems



Merci pour votre attention

GRID INTEGRATED VEHICLES: TECHNICAL ISSUES, BUSINESS MODELS AND REGULATORY FRAMEWORK FOR EV FLEETS

Paul CODANI & Damien-Pierre SAINFLOU

Soirée IEEE doctorants

May 16th, 2016

Tour RTE

La Défense

OUTLINE

1. Introduction
2. PhD work: modeling & simulations
3. PhD work: Experimentation
4. Conclusion

OUTLINE

1. Introduction
2. PhD work: modeling & simulations
3. PhD work: Experimentation
4. Conclusion

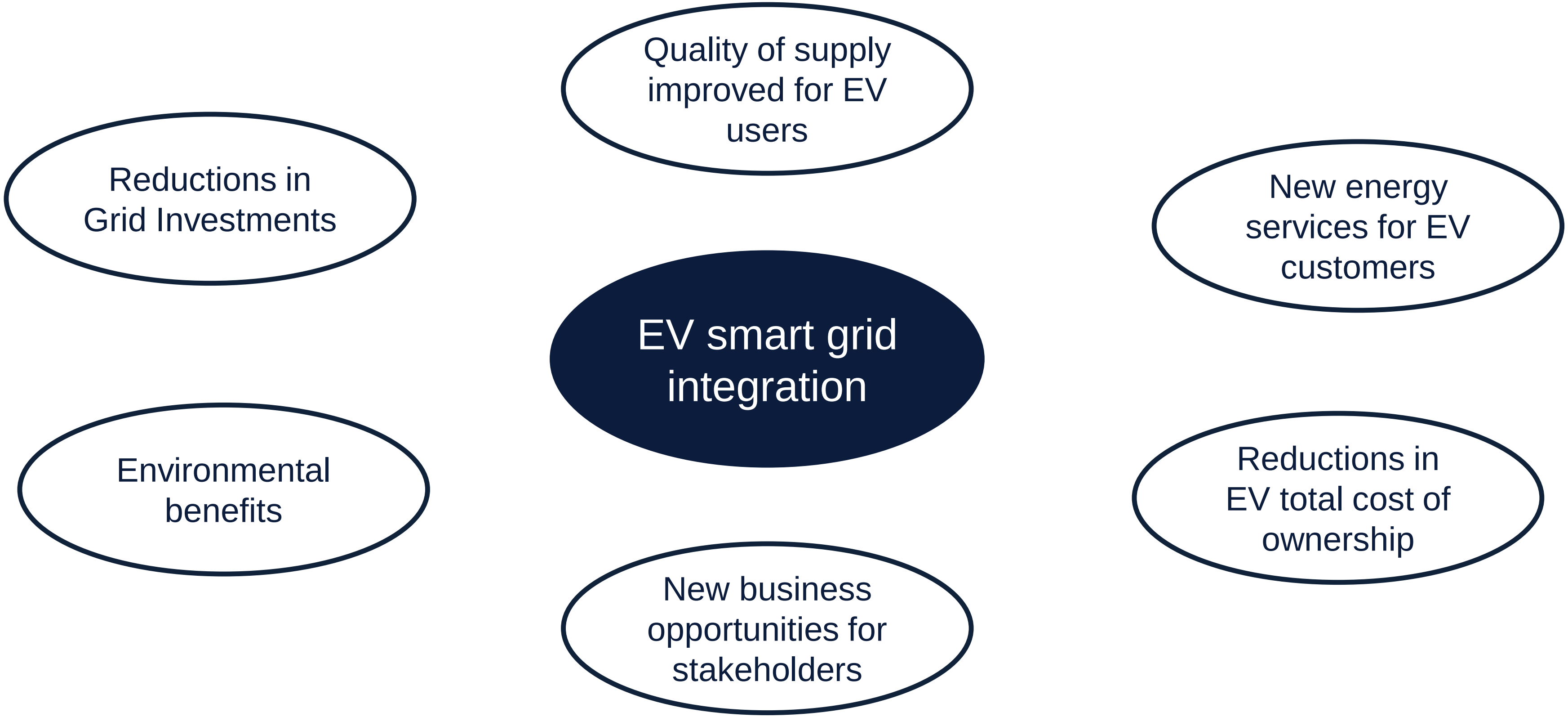
- EV penetration rate is increasing substantially
  - Technology improvements
  - Air pollution

- Critical evolutions in the power system sector
  - Renewable Energy Sources
  - Demand Side Management

➔ EVs could induce additional stress on the grids

➔ Smart Grid integration of Electric Vehicles

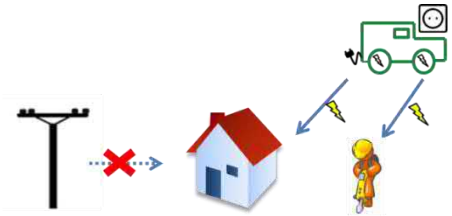
BENEFITS


Quality of supply improved for EV users
Reductions in Grid Investments
New energy services for EV customers
EV smart grid integration
Environmental benefits
Reductions in EV total cost of ownership
New business opportunities for stakeholders

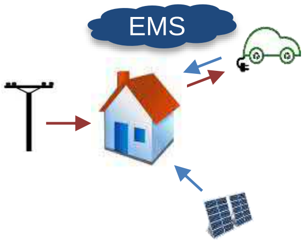
USE CASES

Fonction groupe électrogène
Alimentation objets nomades
Alimentation Back- up maison

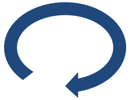
Vehicle-to-load (V2L)



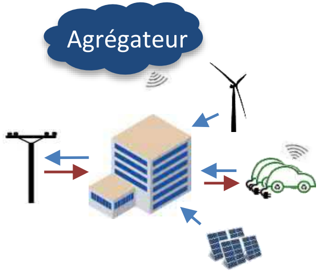
Vehicle-to-home (V2H)



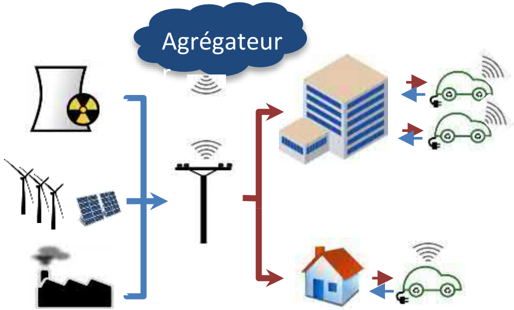
Optimisation conso électrique
Autoconsommation
Plan de recharge intelligent
➔ -10/-15% sur la facture d'élec.



Vehicle-to-building (V2B)



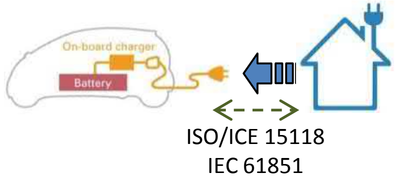
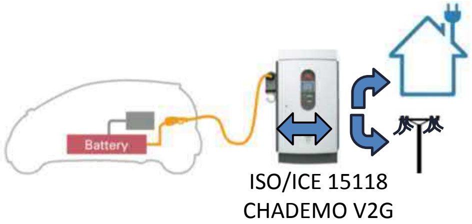
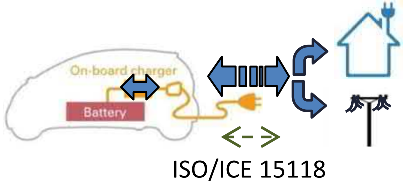
Vehicle-to-Grid (V2G)



- Différents niveaux de service disponibles en fonction du niveau d'intégration dans les réseaux
- Complexité et gains croissants avec le niveau d'intégration

Services réseaux monétisables
Réglage de fréquence/tension
Réserve capacitaire (délestage pilotable)
➔ jusqu'à 1400 €/an de rétribution directe

TECHNOLOGICAL IMPACTS ON VEHICLES

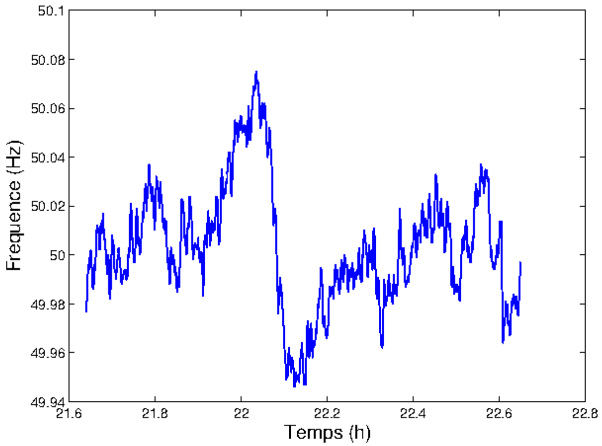
STEP	Schéma	Brique(s) techno(s) et normes
Smart charge		IEC 61851 ISO IEC 15118 Ed1
V2G with off-board charger		Chademo (standard japonais charge rapide) CCS (standard EU charge rapide) + ISO IEC 15118 Ed2
V2G with on-board charger		OBC bidirectionnel + ISO IEC 15118 Ed2 (système {borne + VE} moins cher que STEP 1)

OUTLINE

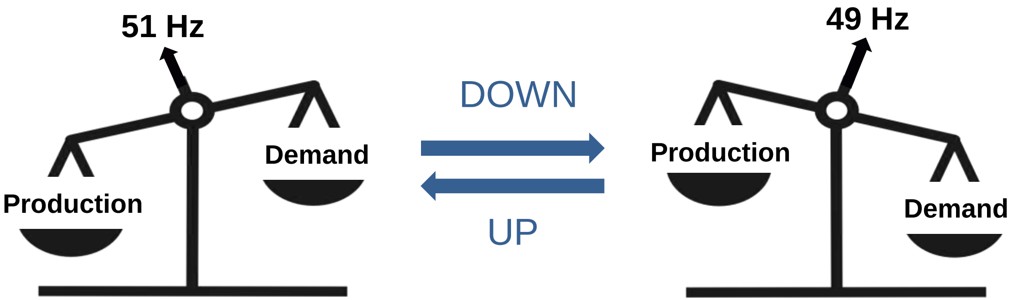
1. Introduction
2. PhD work: modeling & simulations
   A. Introduction
   B. Analysis of TSO rules
   C. Simulation Model
   D. Results and discussions
   E. Conclusion
3. PhD work: Experimentation
4. Conclusion

OUTLINE

- The frequency is a common value within an interconnected network
- The grid frequency permanently fluctuates around its nominal value
- TSOs implement 3 control levels to control frequency deviations

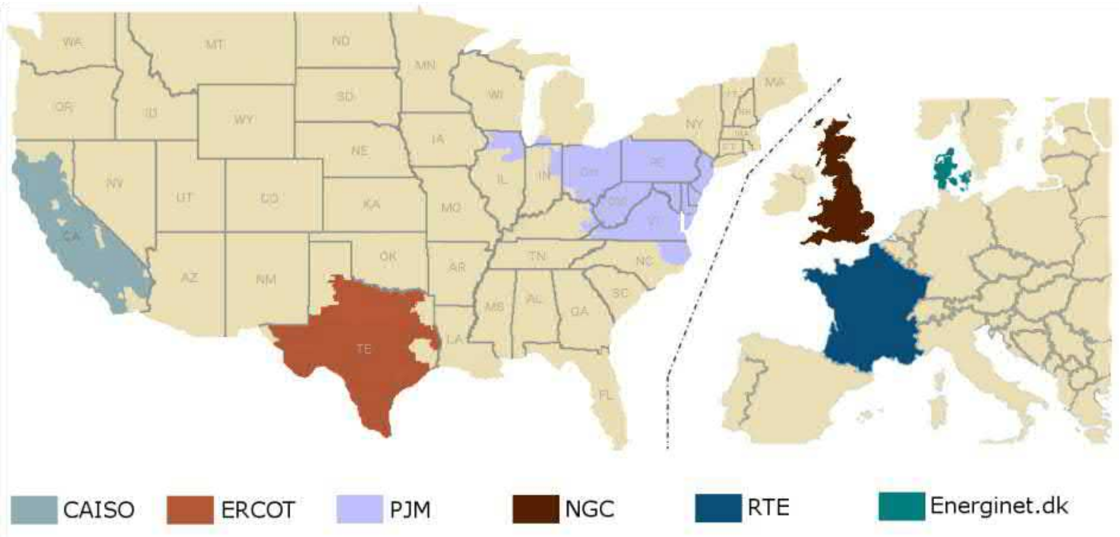


- Controlling frequency ←→ make sure that P = C at every moment
  - Today, traditional power plants increase / decrease their production level



OUTLINE

TSOs UNDER STUDY



Map of the six TSOs understudy

- The frequency control rules of six representative TSOs were studied
- 18 important rules for EV fleets were identified
- The most important ones were gathered into two modules

MOST IMPORTANT RULES IDENTIFIED

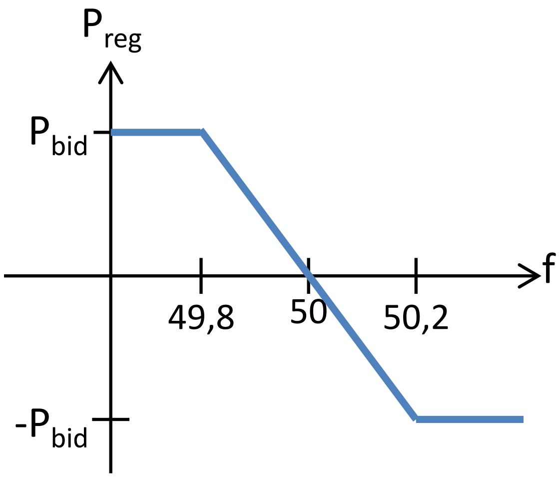
- The rules towards aggregation of EVs
  - Aggregators have fundamental roles in V2G architectures
  - The three criteria of this module are:
    - Minimum rated power to be included in the market
    - Possibility to aggregate units across various DSO technical zones
    - Requirements to disaggregate the contribution of each EV

- The rules for the payment of grid services
  - V2G → potential earnings for EV owners
  - The three criteria of this module are:
    - Nature of the payment scheme (regulated, contract-based or market-based)
    - Incompleteness of the payment scheme
    - Extra bonus for intense flexibility

→ Identification of key sets of rules…
→ …could be used as a tool to survey other TSOs
→ Definition of a regulatory framework for the simulations

REGULATORY CONCLUSIONS

- We focus on Frequency Containment Reserves (or primary control)
- Symmetrical market
- Hourly auction market
- ENTSO-E* safety rules
- Energinet.dk prices



Fleet's reponse to frequency fluctuations

➔ An optimistic regulatory framework for simulations was chosen based on the regulatory analysis
➔ Need for a simulation model to address business models

*European Network of Transmission System Operators for Electricity

OUTLINE

- Fleet of commuters:
  - Data used: CROME project results; internal PSA data; ministerial reports
  - Dynamic and stochastic fleet model
  - Bidirectional or unidirectional capabilities
  - Only commuting trips are taken into account
- We assume that all EVs have an EVSE at home
- Breakdown of EVSE power values based on current French values

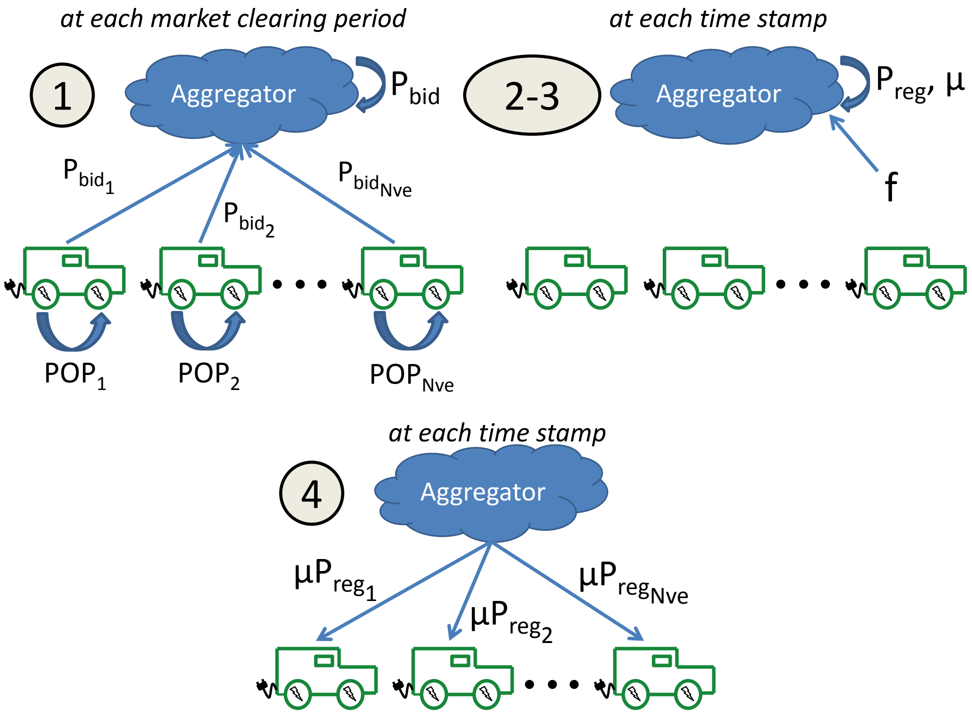
Scenario	EVSE penetration rate at workplaces
Scenario 1	0%
Scenario 2	25%
Scenario 3	50%
Scenario 4	75%

Charging Power	Primary EVSE	Secondary EVSE
Slow A – 3kW	95%	35%
Slow B – 7kW	5%	34%
Intermediate – 22kW	0%	29%
Fast – 43kW	0%	2%

AGGREGATOR MODELING

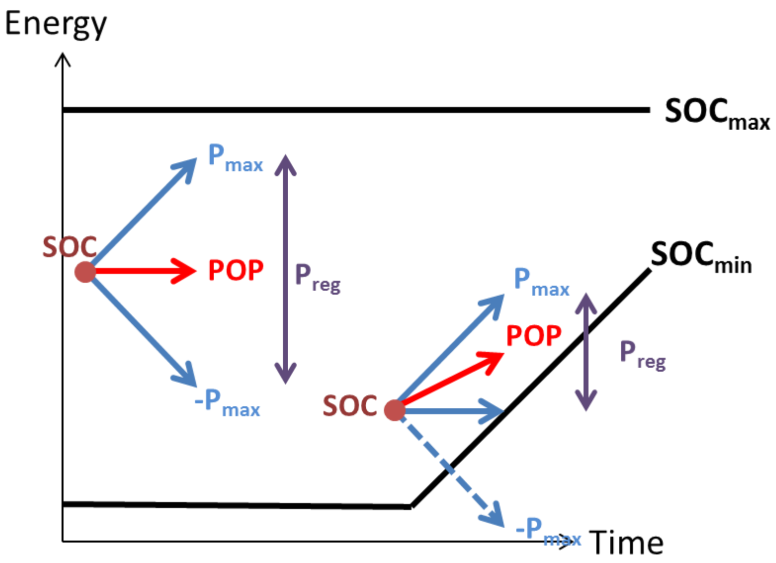
$$P_{reg} = \begin{cases} -\dfrac{f - f_0}{f_{max} - f_0} P_{bid}, & |f - f_0| < 0{,}2Hz \\ P_{bid}, & |f - f_0| > 0{,}2Hz \end{cases}$$

- Dispatch algorithm inspired from the algorithm developed at the University of Delaware
  - Proved efficient in real life demos
  - Proved scalable
- Drivers are assumed to communicate their driving needs

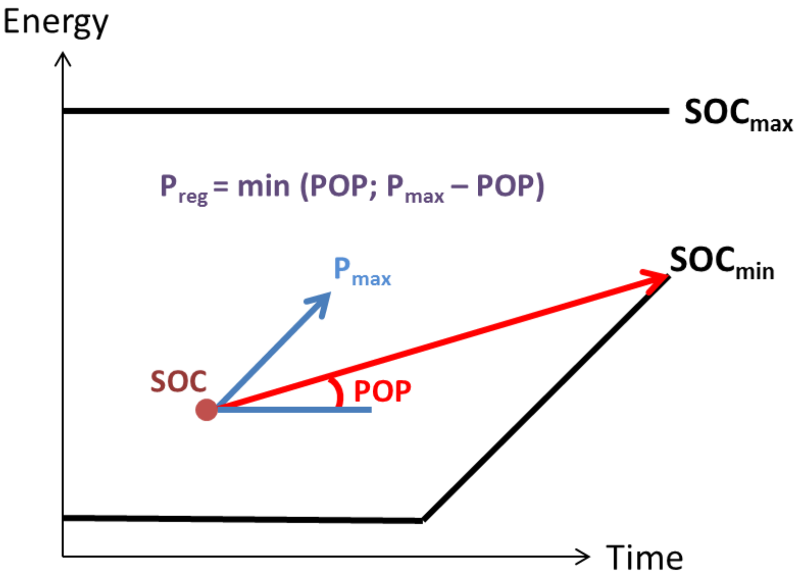


Operating principle of the dispatch algorithm

INDIVIDUAL EV STRATEGIES



Bidirectional Capabilities



Unidirectional Capabilities

➔ Decentralized solution: each EV is responsible for calculating its available power for regulation
➔ All driving needs are always fulfilled

OUTLINE

- Earnings per EV and per year were calculated for different EVSE power levels
- Individual earnings were averaged for all the EVs of the fleet
  - Depending on the breakdown of EVSE power levels considered
  - Assuming an equal remuneration for all EVs

Earnings per EV and per year

Scenario (% EVSE at work)	Bidirectio[illegible] EVs	[illegible]
Scenario 1 (0%)	149€	[illegible]
Scenario 2 (25%)	251€	28€
Scenario 3 (50%)	353€	[illegible]
Scenario 4 (75%)	456€	[illegible]

Average power provided by a fleet of 200,000 EVs

[illegible]	[illegible]ectional [illegible]Vs	Unidirectional EVs
[illegible]	[illegible] MW	102 MW
Scenario 2 (25%)	501 MW	109 MW
[illegible]	[illegible] MW	116 MW
[illegible]	[illegible] MW	123 MW

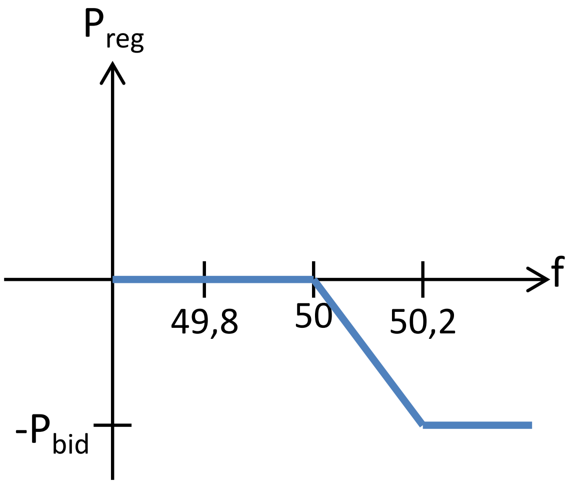
French primary reserve: ~600MW

- **Bidirectional EVs:**
  - Possible business model for EV fleets…
  - … but market could be saturated quickly

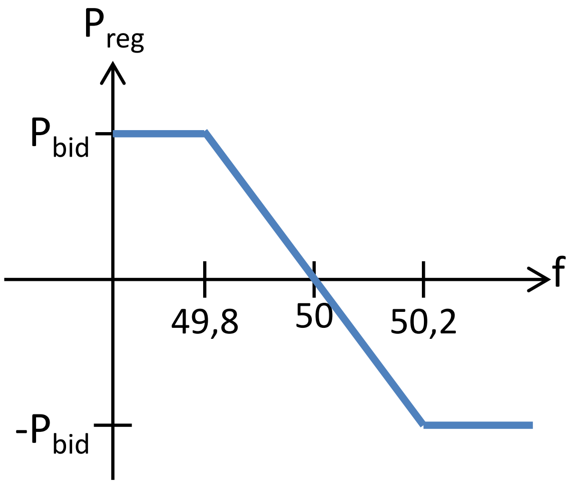
- Unidirectional EVs
  - Current market design
    → remuneration very low
    → New market design

NEW MARKET DESIGN: ASYMMETRICAL MARKETS

- Asymmetrical market design
  - Considering the creation of two separated sub markets: UP and DOWN markets
- Recommended by ENTSOE, already existing in some areas

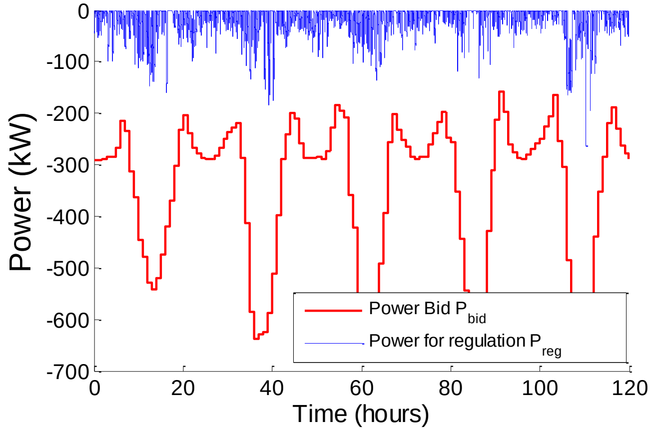


Asymmetrical market design

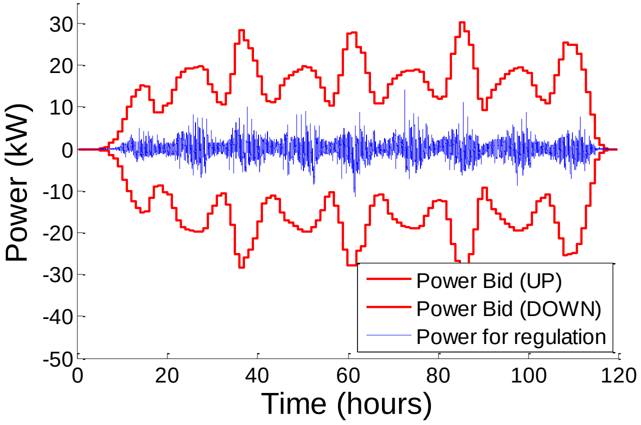


Symmetrical market design

RESULTS: ASYMMETRICAL VS SYMMETRICAL (unidirectional vehicles only)



!\ Negative values stand for charging power /!\



Asymmetrical market design
Example from one simulation

- Minimum power bid: 125kW
- First P_{bid} quartile: 243kW

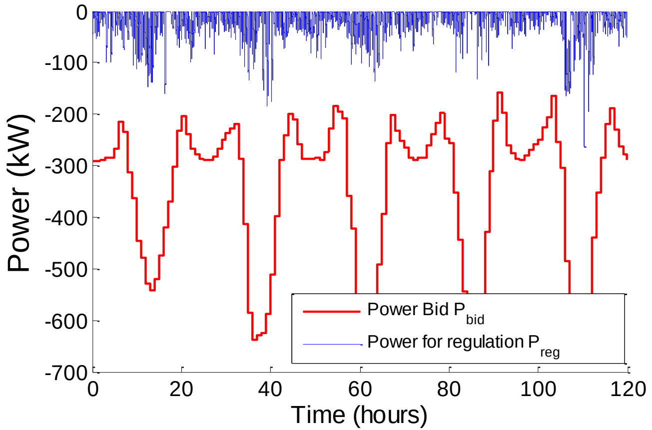
Symmetrical market design
Example from one simulation

- Minimum power bid: 0kW
- First P_{bid} quartile: 22kW

➔ Unidirectional EV fleets perform much better under asymmetrical market design
➔ TSOs should procure UP and DOWN products separately

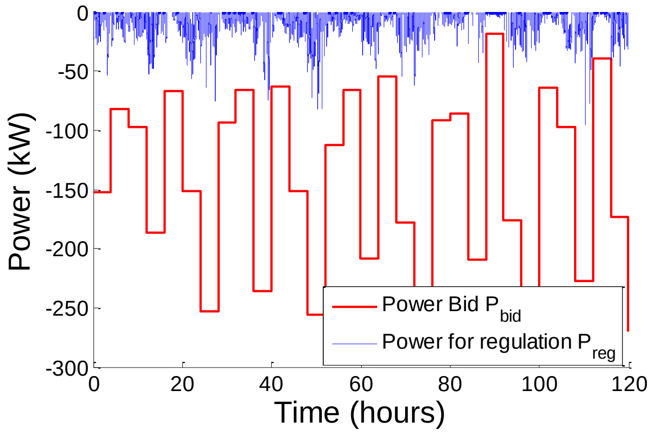
SENSITIVITY ANALYSIS: MARKET CLEARING PERIOD

- We have seen ranges from 1h to 1week for market clearing periods
- Comparison between 1h and 4h market clearing periods for the asymmetrical unidirectional use case



- Minimum power bid: 125kW
- First P_{bid} quartile: 243kW

Fleet response for 1h market clearing period



- Minimum power bid: 19kW
- First P_{bid} quartile: 70kW

Fleet response for 4h market clearing period

➔ Switching from 4h to 1h market clearing period represents a great opportunity for EV fleets

➔ TSOs should implement market clearing periods as short as possible

OUTLINE

1. Introduction
2. PhD work: modeling & simulations
   A. Introduction
   B. Analysis of TSO rules
   C. Simulation Model
   D. Results and discussions
   E. Conclusion
3. PhD work: Experimentation
4. Conclusion

PARTIAL CONCLUSION

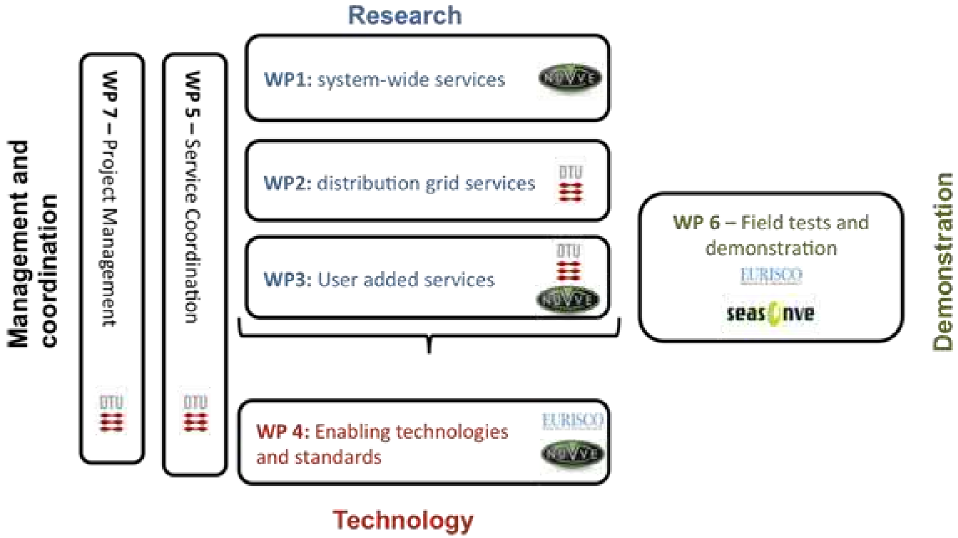
- EV fleets could expect significant earnings by participating to frequency control…
- …provided that the regulatory framework / market rules are adapted
  - the rules towards aggregation of EVs should be enhanced
  - the payment scheme of grid services should be properly addressed
- Coupling between simulation model and regulatory analysis showed that:
  - UP and DOWN products should be procured through separate markets
  - the market clearing period should be kept as short as possible
- ENTSO-E network codes are paving the way towards a suitable regulatory framework
- Bidirectional capabilities significantly increase the EV expected revenues
- From the TSO perspective:
  - EV fleets = potential cost effective reserve providing units
  - New sources of flexibility
- Frequency control reserves have limited sizes → other grid services should be investigated

OUTLINE

1. Introduction
2. PhD work: modeling & simulations
3. PhD work: Experimentation
    A. The NIKOLA Project
    B. Experiments with the Citroën Berlingo Electric
    C. Experiments with the Peugeot iOn
    D. Conclusion
4. Conclusion

OUTLINE

- Nikola is a Danish research and demonstration project with a focus on the synergies between the electric vehicle (EV) and the power system.
- 3-year project
- 2M€ budget (Danish public fund)
- Partners:



➔ Only project in Europe implementing frequency regulation services with series vehicles

OUTLINE

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    - B. Experiments with the Citroën Berlingo Electric
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    - D. Conclusion
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BERLINGO ELECTRIC CHARACTERISTICS

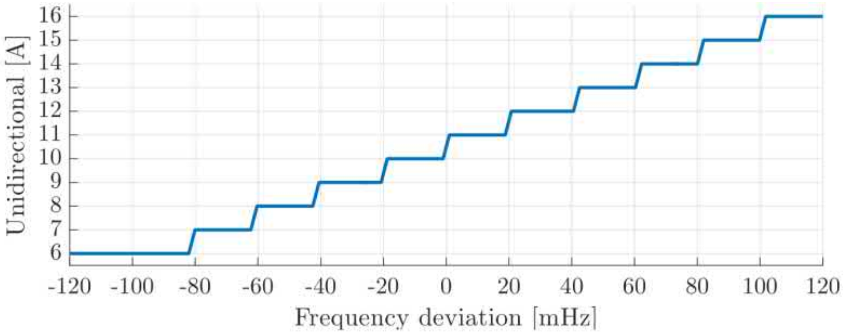
- Light duty vehicle
  - Battery: 22,5kWh
  - Charging in mode 2/3
  - Charging up to 3,7kW

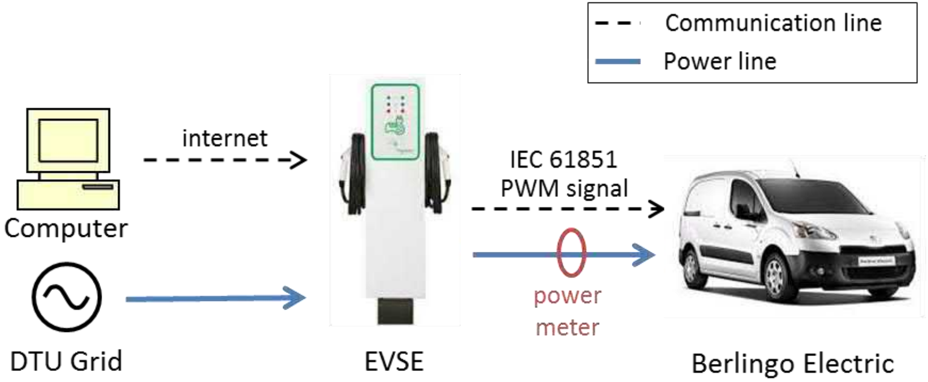
➔ Possibility to control the charging rate of the vehicle by means of the IEC 61851-1 standard

➔ From 6A to 16A, i.e. from 1,4kW to 3,7kW

TEST PROCEDURE

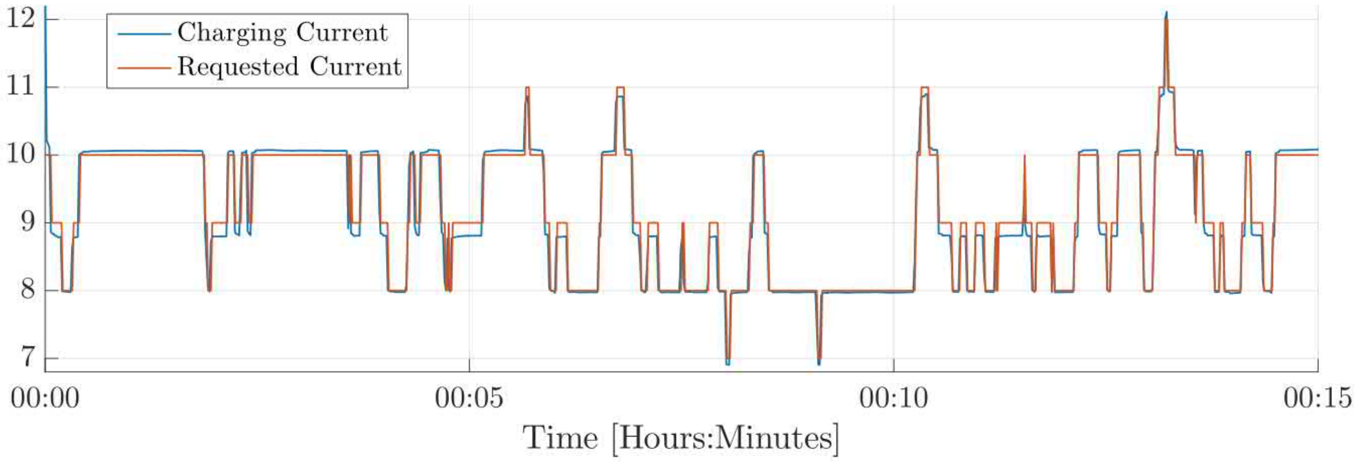
- Co-development of the test procedure with DTU
- Physical Simulation of participation in the Frequency-controlled Normal operation Reserves (FNR)
  - Linear response to frequency deviations between -100mHz and +100mHz





➔ Experimentation using the exact same strategies as in the simulation model for unidirectional EVs

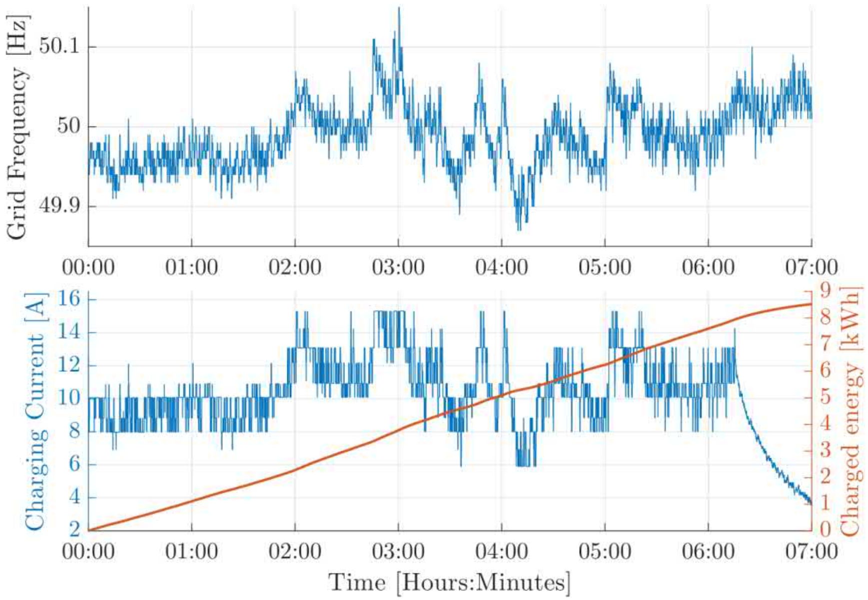
RESULTS (1/2)



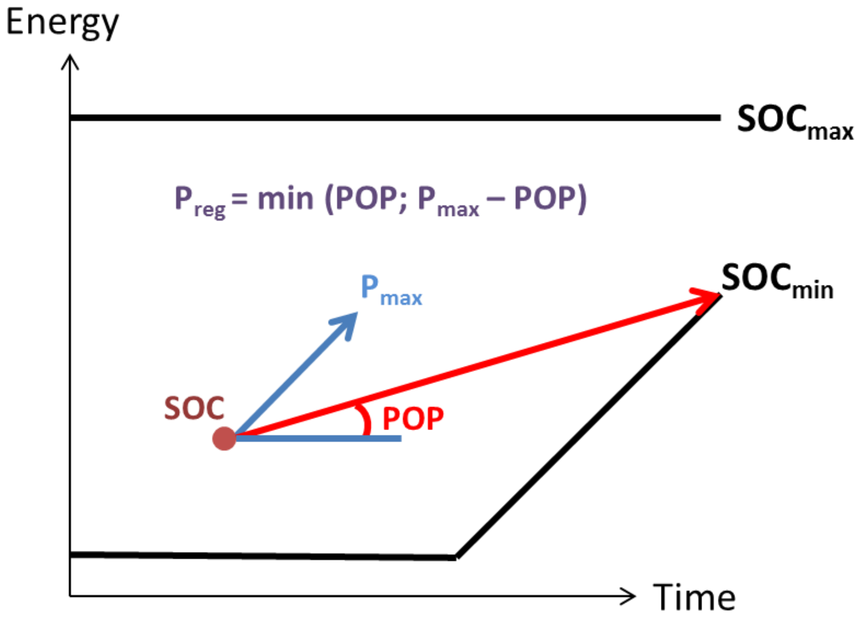
Request and Charging currents from the Berlingo (over 15 minutes)

- Accuracy and response time very good
- Protocol not initially designed for smart charging

➔ Technical abilities of a unidirectional vehicle demonstrated
➔ Validation of simulation model hypothesis



Experimental results for the 7 consecutive hours of test



Unidirectional EV strategy used in the simulations

OUTLINE

PEUGEOT ION CHARACTERISTICS

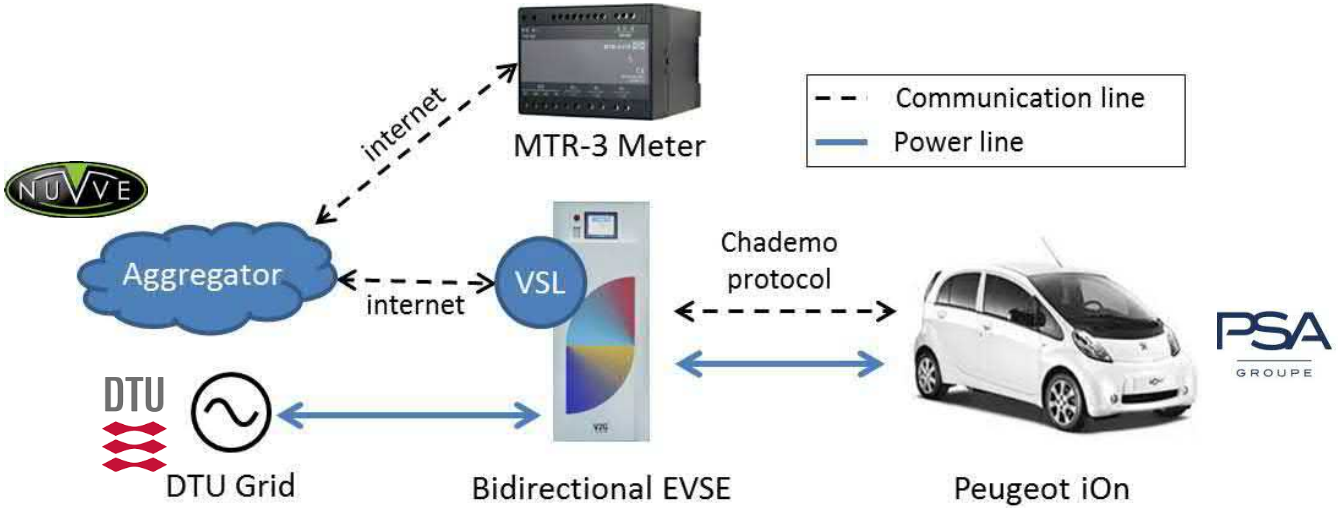
- Passenger vehicle:
  - Battery capacity: 16kWh
  - AC charging up to 3,7kW in AC mode 2/3
  - DC bidirectional charging ± 50kW (Chademo protocol)

- The Chademo protocol enables bidirectional power exchanges based on CAN communication
- ENDESA bidirectional charging stations are available

→ Bidirectional capabilities, from -10 to +10kW

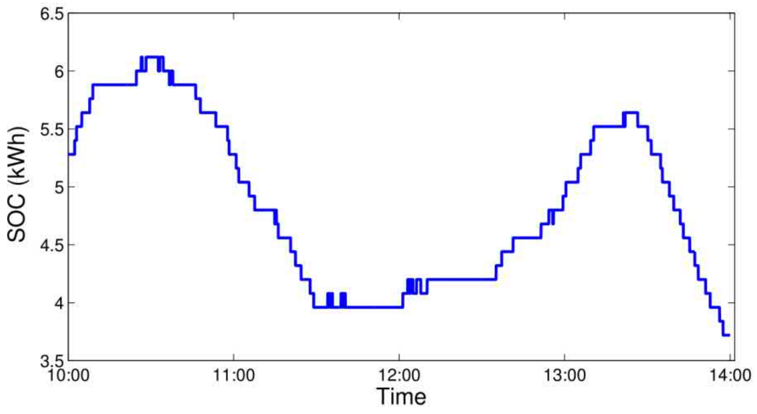
→ Controllability by means of the Chademo protocol

- Co-development of the test procedure with DTU
  - Participation in the FNR mechanism

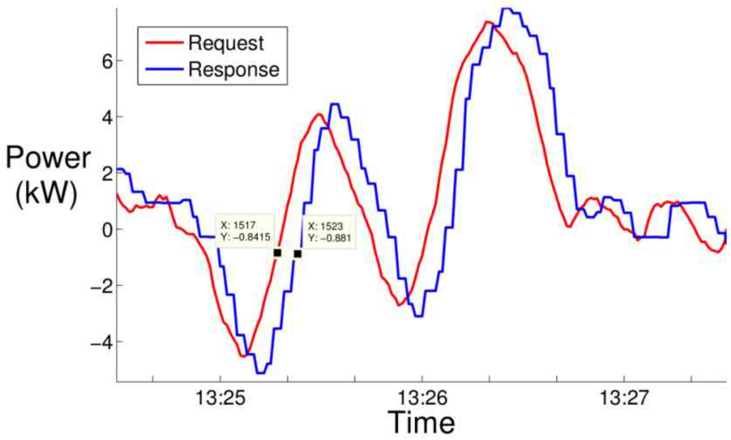


➔ Experimentation using the exact same strategies as in the simulation model for bidirectional EVs

RESULTS



SOC variations



Power requests and responses

- Response time < 5s (for the whole chain)
- Very good accuracy

➔ Technical abilities of a bidirectional vehicle demonstrated
➔ Validation of simulation model hypothesis

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CONCLUSION OF EXPERIMENTATION

- Experimental results of two different PSA Groupe series vehicles, using different HW & SW solutions
  - A unidirectional Berlingo Electric
  - A bidirectional Peugeot iOn
- Simulation model hypothesis were tested and validated
- Vehicles have been proved efficient frequency control providing units
  - Accuracy very satisfactory
  - Response time <5s for the whole IT chain

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GENERAL CONCLUSION

- Evaluation of potential business models

- Impacts of the regulatory framework on these potential earnings

- Experimentations carried out in order to validate simulation model hypothesis
  - ➔ Technical abilities of series EV were evaluated and validated
  - ➔ Unidirectional and bidirectional vehicles

- Next steps:
  - Medium scale demonstration project involving real life customers: **GridMotion project**
  - Press release
  - B2C Movie
  - B2B Movie

RESEARCH PERSPECTIVES

- Improvements of simulation models:
  - More complex EV fleet modelling
  - More sensitivity analysis
  - Improvement of algorithms

- Analysis of DSO flexibility markets
  - Why there are none of them
  - What should be done to have DSOs implement them
  - Economic value

- Analysis of other TSO markets
  - Balancing mechanisms
  - Capacity and energy markets
- Analysis of islanded systems

- Analysis of other regions of the world
  - China
  - Africa
  - …

- **International journals with peer-review process:**
  - Apostolaki, E., **Codani, P**., & Kempton, W. (2017). Measurement of Power Loss During Electric Vehicle Charging and Discharging. *Energy*.
  - **Codani, P**., Cassin, L., Petit, M., Perez, Y., (2016). Increasing power system reserve capacities by changing the reserve market design: the case of Electric Vehicle fleets. *IEEE Transaction on Power Systems*. Submitted for publication
  - **Codani, P**., Perez, Y., Petit, M., (2016). Financial shortfall for electric vehicles: Economic impacts of Transmission System Operators market designs. *Energy* 113.
  - Eid, C., **Codani, P**., Perez, Y., Reneses, J., & Hakvoort, R. (2016). Managing electric flexibility from Distributed Energy Resources: A review for incentives, aggregation and market design. *Renewable and Sustainable Energy Reviews*. 64
  - **Codani, P**., Le-Portz, P.-L., Claverie, P., Perez, Y., & Petit, M. (2015). Coupling local renewable energy production with electric vehicle charging : a survey of the French case. *International Journal of Automotive Technology and Management*, *16*(1)
  - **Codani, P**., Petit, M., & Perez, Y. (2014). Participation of an Electric Vehicle fleet to primary frequency control in France. *International Journal of Electric and Hybrid Vehicles, 7*(2).

- **Book chapter:**
  - **Codani, P**., Perez, Y., & Petit, M. (2015). Electric Vehicle as a mobile storage device. In J. Yan (Ed.), Handbook of Clean Energy Systems. Wiley.

PUBLICATIONS (2/2)

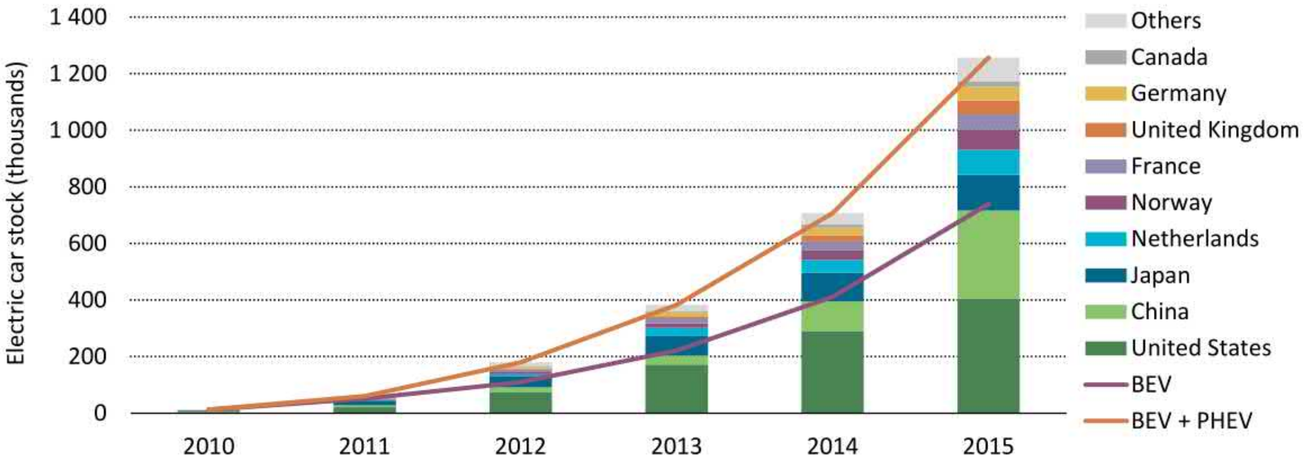
- **International conferences with peer-review process:**
  - Dang, X., Petit, M., & **Codani, P**. (2015). Transformer Operating conditions under introduction of PV and EVs in an Eco-district. In *2015 IEEE Power and Energy Society General Meeting*. Denver
  - Dang, X.-L., **Codani, P**., & Petit, M. (2015). Energy optimization in an Eco-district with Electric Vehicles smart charging. In *IEEE Powertech Eindhoven*. Eindhoven.
  - Eid, C., **Codani, P**., Chen, Y., Perez, P., Hakvoort, R. (2015). Aggregation of Demand Side flexibility in a Smart Grid: A review for European Market Design. In *2015 12th International Conference on the European Energy Market (EEM)*, IEEE.
  - Knezovic, K., **Codani, P**., Perez, Y., & Marinelli, M. (2015). Distribution Grid Services and Flexibility Provision by Electric Vehicles: a Review of Options. In *University Power Engineering Conference (UPEC)*. Staffordshire (UK).
  - **Codani, P**., Petit, M., & Perez, Y. (2014). Diversity of transmission system operators for Grid Integrated Vehicles. In *2014 10th International Conference on the European Energy Market* (EEM), IEEE.

- **Position Paper (French Standardization Committee (AFNOR) document):**
  - Caillat, O., Chevreau, M., **Codani, P**., Colet, F., Demay, I., Dobrowolski, B., Dumouchel, D., Dupuy, P., Mazzoni, S., Neau, E., and Ricaud, C. (2016). Feuille de route pour une intégration des véhicules rechargeables dans les réseaux électriques. *Position Paper for the French Association for Standardization (AFNOR).*

Thank you!

Annexes

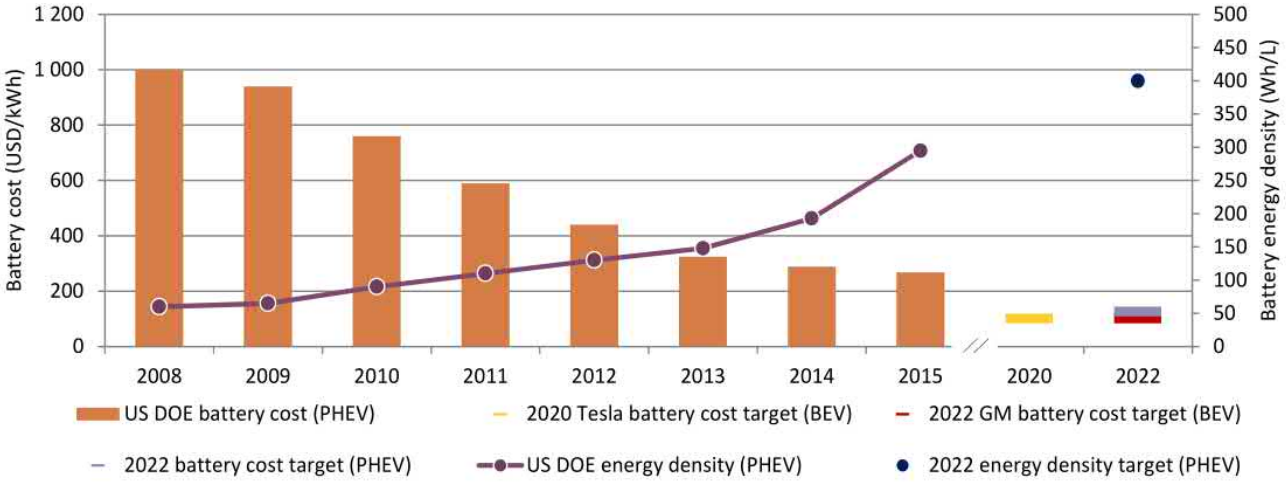
EVOLUTION OF THE GLOBAL PEV STOCK, 2010-15



- The global PEV stock is increasing quickly (+70% from 2014 to 2015)
- However, market shares remain low because of:
  - Limited driving ranges
  - Lack of charging infrastructure
  - High prices

Source: IEA Global EV Outlook 2016

EVOLUTION OF BATTERY ENERGY DENSITY AND COST



Source: IEA Global EV Outlook 2016

- Battery costs are decreasing drastically
- → Future PEVs will have larger batteries
- → Driving ranges will increase substantially

- Barriers to EV adoptions might be overcome; EV stock expected to continue to increase rapidly

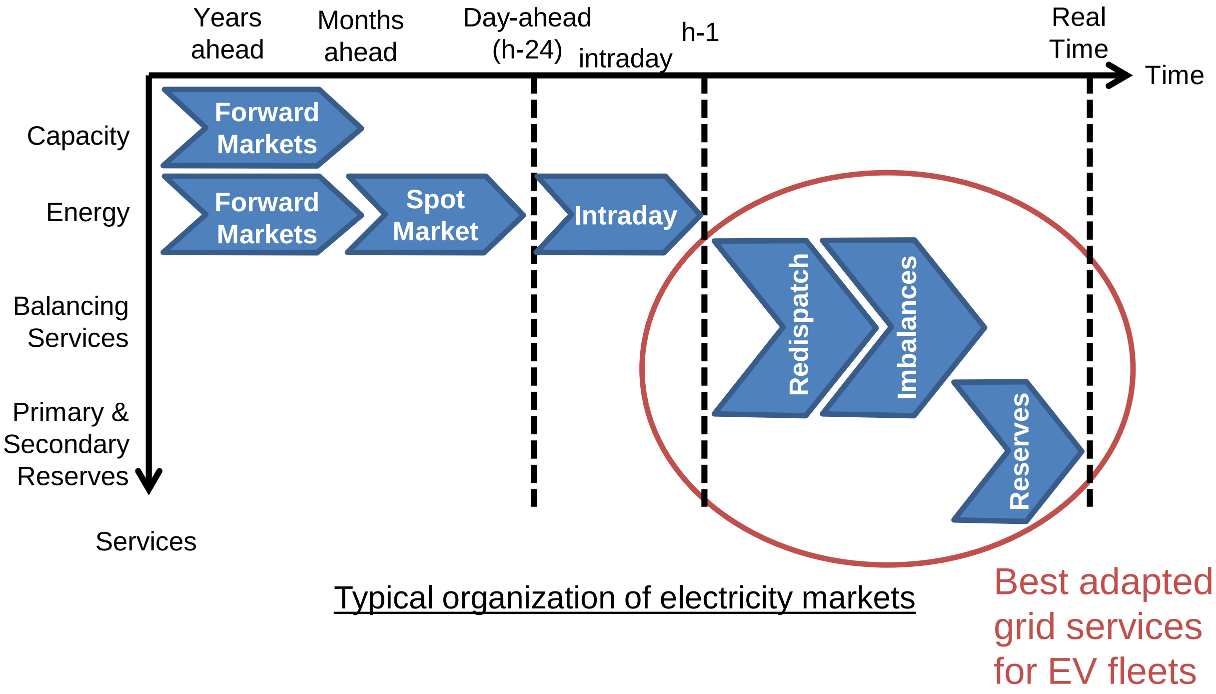
Level of grid integration (-- → ++)

Use Case	Expected benefits (customer)	Challenges	Schema
Vehicle-to-Load	• Additional services • Security of supply	• Bidirectional power flows • Safety aspects	
Vehicle-to-Home	• Electricity bill reduction: -10 / -15%	• Need for an EMS • Potentially, bidirectional power	
	possible		

Vehicle-to-Grid	• Remuneration: up to $1500/year	• Regulatory issues
		  • TSO rules not always adapted
		  • No DSO market
		• Communication requirements
		• Aggregator required	

- Various available new services depending on the level of grid integration
- Benefits increase with the level of grid integration
  - → V2G = most promising solutions
- Complexity also increases with the level of grid integration

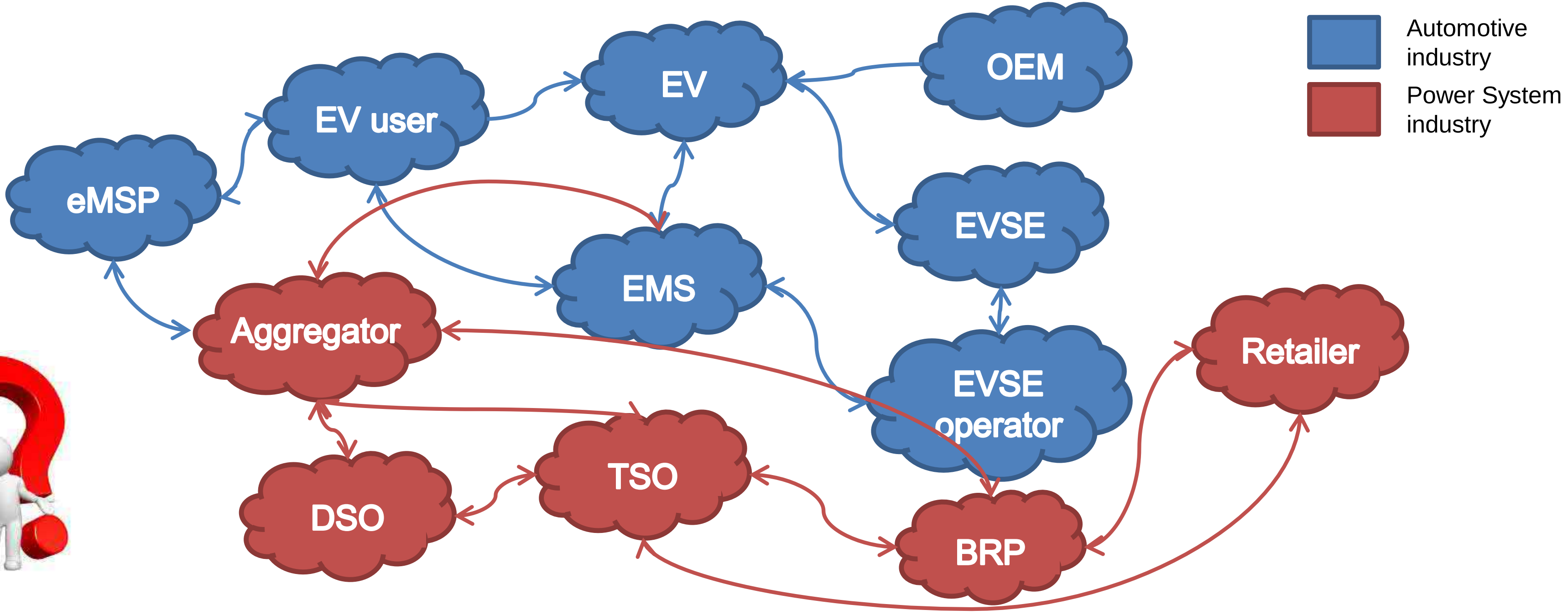
- Electricity markets address from years ahead to real time operations
- Forward markets
  - Secure investments
  - Ensure trading of large amount of electricity
- Reserves
  - Ensure balance on short time scale
- Characteristics of EV fleets
  - Good reactivity
  - Availability
  - Little amount of energy



Typical organization of electricity markets

- In the V2G use case, the most interesting grid services are those addressing real time balance

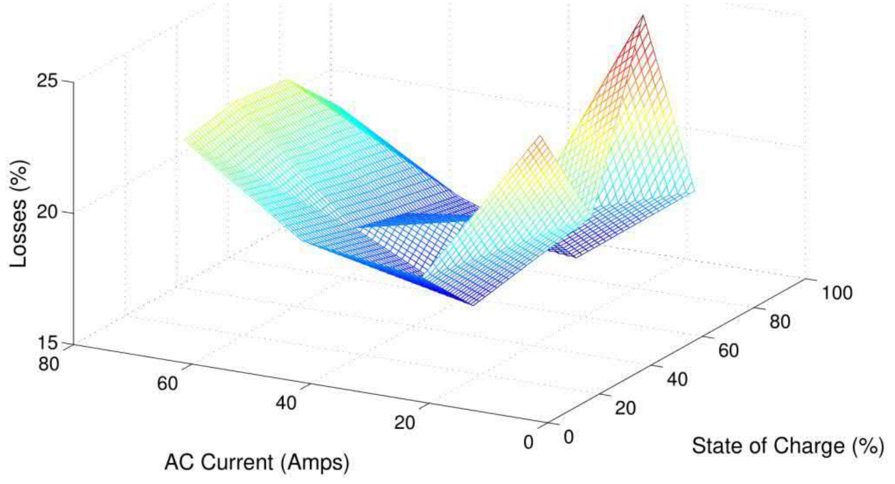
LIST OF STAKEHOLDERS



- Diversity of actors → complex value chain
- IT, automotive and power system industries are involved

POWER EFFICIENCY

- Round-trip efficiency might affect business models
- Charging system chain:
  - Charging station
  - Cables
  - Power Electronic Unit (PEU)
  - Battery
- Battery losses:
  - Marginal
- PEU losses
  - Depend on the operating conditions of the PEU
  - If operating far from its rating power, losses might be important



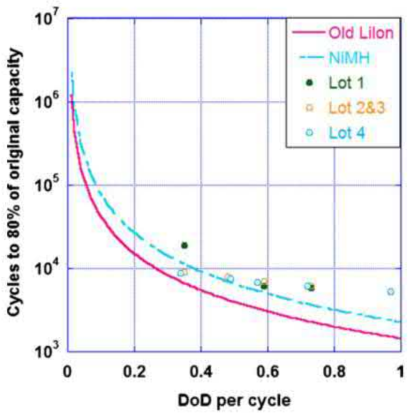
Power converter efficiency curve

Source: Apostolaki et. al (2016)

- The main losses occur in the power electronic unit
- Smart charging / discharging strategies should be designed with PEU losses in mind (and vice versa)

BATTERY DEGRADATION

- Crucial topic considering battery prices
- Main factors:
  - Temperature
  - SOC variation
  - Charging rate
  - Average operating SOC
- Large literature, but very few experimental results from real life tests



Battery aging as a function of the SOC variations
Peterson et al. (2010a)

- Unidirectional power flows:
  - Should not accelerate battery aging compared with a plug-and-charge situation
- Bidirectional power flows:
  - Much dependent on the cycles targeted
  - → Additional degradation should not be too substantial

ENABLING RULES

TABLE I
CHARACTERISTICS OF THE TSOS FOR ENABLING CRITERIA

Criterion	RTE	PJM	ERCOT	Energinet.dk	CAISO
Telemetry VS financial aggregation:	Telemetry	Telemetry	Financial	Telemetry	Financial
Ability to aggregate across various EDCs:	Yes	No	No	Yes	No
Framework and metering for retail producer:	No	Yes	No	No	No
Frequency control reserves dispatching method:	Historical load share	*Prim.*: N/A *Sec.*: Open market	*Prim.*: N/A *Sec.*: Historical load share + bilateral trade	Open markets	*Prim.*: N/A *Sec.*: Open markets
Remuneration:	*Prim.*: \$11.4/MW-30min *Sec.*: \$11.4/MW-30min + \$13.2/MWh	*Prim.*: not remunerated *Sec.*: ±\$37/MW-h[1]	*RR*: \$17/MW-h[2] *Sec. UP*: \$17/MW-h[2] *Sec. DN*: \$6/MW-h[2]	DK1: *Prim. UP*: \$45/MW-h[2] *Prim. DN*: \$4.7/MW-h[2] DK2: *FNR*: \$24.5/MW-h[3] *FDR*: \$13/MW-h[3]	*Prim.*: not remunerated *Sec. UP*: \$6.2[2] *Sec. DN*: \$4.6[2]
References:	[12]	[13], [14]	[15]–[18]	[19]	[20]

DK1: Western Denmark; *DK2*: Eastern Denmark; *DN*: DOWN; *FDR*: Frequency controlled Disturbance Reserve; *FNR*: Frequency controlled Normal operation Reserve; *N/A*: Not Applicable; *Prim.*: Primary control market; *RR*: Responsive reserves; *Sec.*: secondary control market
Average clearing prices from: [1]10/01/12 to 09/04/13; [2]08/01/11 to 08/31/13; [3]10/06/12 to 08/31/13. Conversion rate: 1€=1.35\$

PROFITABLE RULES

TABLE II
CHARACTERISTICS OF THE TSOS FOR PROFITABLE CRITERIA

Criterion	RTE	PJM	ERCOT	Energinet.dk	CAISO
Net metering:	Not Applicable	In Delaware, yes Other states: no	No	No	Yes
Value fast-ramping resources:	No	Yes	No	No	Yes
Type compliance for qual. tests:	Not Indicated	No	Not Indicated	Not Indicated	Not Indicated
Ongoing Validation:	Record inspection	Record inspection	Record inspection	Frequency disturbance simulation	Not Indicated
References:	[12]	[13], [14]	[15]–[18]	[19]	[22], [23]

OPERATIONAL CRITERIA

TABLE III
CHARACTERISTICS OF THE TSOs FOR OPERATIONAL CRITERIA

Criterion	RTE	PJM	ERCOT	Energinet.dk	CAISO
Minimum bidding amount:	N/A	*Prim.*: N/A *Sec.*: 0.1MW	*Prim.*: N/A *Sec.*: 0.1MW	0.3MW	*Prim.*: N/A *Sec.*: 0.5MW
Granularity:	1MW	*Prim.*: N/A *Sec.*: 0.1MW	NI	0.1MW	*Prim.*: N/A *Sec.*: 0.1MW
POP modification frequency:	NI	2s	1s	5 min	NI
Droop modification frequency:	30 days	N/A	N/A	One hour	N/A
Frequency meter location:	NI	N/A	N/A	NI	N/A
Frequency dead-band:	10mHz	N/A	N/A	DK1: 10mHz DK2: *FNR*: 0mHz *FDR*: 100mHz	N/A
Energy neutral signal:	No	Yes	No	No	No
Last moment to adjust bid capacity:	N/A	Hour-1	Hour-1	Day ahead at 7:00PM	Hour-1
Symmetrical market:	Yes	*Prim.*: N/A *Sec.*: Yes	*RR*: Yes *Sec.*: No	DK1: *Prim.*: No / *Sec.*: Yes DK2: *FNR* & *FDR*: Yes	*Prim.*: N/A *Sec.*: No
References:	[12], [25]–[27]	[28], [29]	[16], [30], [31]	[19]	[32]

DK1: Western Denmark; *DK2*: Eastern Denmark; *DN*: DOWN; *FDR*: Frequency controlled Disturbance Reserve; *FNR*: Frequency controlled Normal operation Reserve; *N/A*: Not Applicable; *NI*: Not Indicated; *Prim.*: Primary control market; *RR*: Responsive reserves; *Sec.*: secondary control market

- Aggregators have fundamental roles in V2G architectures
- The three criteria of this module are:
  - Minimum rated power to be included in the market
  - Possibility to aggregate units across various DSO technical zones
  - Requirements to disaggregate the contribution of each EV

Aggregation rules	Organization	
	Best option	**Conservative Option**
R1 : Minimum Size	100 kW	10 MW
R2 : Interoperability among DSOs	Possible	Impossible
R3 : Deaggregation	Not requried	Required; each unit should respond separately

1. V2G → A mean to reduce the TCO of EVs
2. The three criteria of this module are:
   A. Nature of the payment scheme (regulated, contract-based or market-based)
   B. Incompleteness of the payment scheme
   C. Extra bonus for intense flexibility

Payment scheme rules	Organization	
	Best Option	**Conservative Option**
R4 : Nature of the payment	Market based	Regulated
R5 : Incompleteness of the payment	All AS should be paid	Incomplete payment scheme
R6 : Extra bonus	Set at the efficient level, or separate market created	Not existing

COMPARISON OF THE TSOs UNDERSTUDY

Table 3.3: Evaluation of the representative TSOs

TSO	*R1*	*R2*	*R3*	*R4*	*R5*	*R6*
RTE	X	√	√	X	√	X
PJM	√	X	√	√	X	√
ERCOT	√	X	X	√	X	X
Energinet.dk	~	√	√	√	√	X
CAISO	~	X	X	√	X	√
NGC	X	√	√	~	X	X

√: good ~: so so X: bad

Table 3.4: Ideal TSO VS ENTSOE guidelines

Rule	*Ideal TSO*	*ENTSOE Proposals*
Minimum size	100kW	Not addressed
Interoperability among DSOs	Possible	Not clearly defined, but TSOs and DSOs should make all endeavors and cooperate in order to ease the participation to Demand Side Response
Aggregation level	Telemetry	Status of *aggregator* defined. Telemetry aggregation considered for FCR up to 1.5MW
Nature of the payment	Market Based	Market Based
Incompleteness of the payment	All AS should be paid	All AS should be paid
Extra bonus for flexibility	Set at the efficient level / separate market created	Demand Side Response Very Fast Active Power Response should be implemented

- We use one month of frequency recordings recorded at CentraleSupélec in March 17th to April 17th 2015
- Thanks to Martin Hennebel

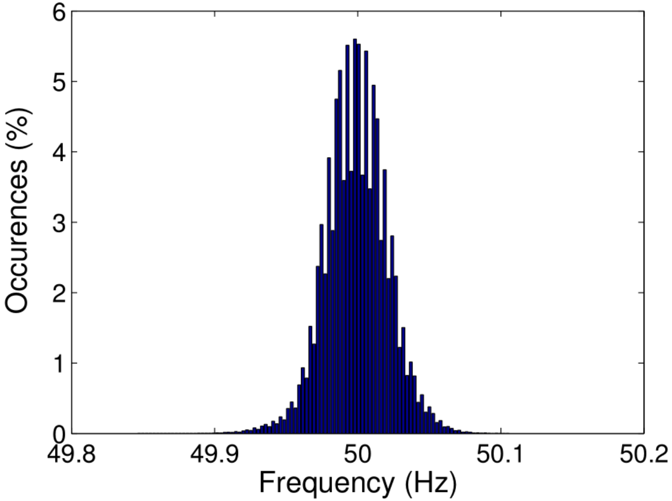


Figure 3.6: Distribution function of the frequency recordings

Table 3.8: Main characteristics of the frequency data set used, and comparison with RTE measurements

	Criteria	*Author data set*	*RTE data set*	*Difference (%)*
f	Mean (Hz)	50	50	-0,002
	Std (Hz)	0,02	0,02	0,4
	Min (Hz)	49,9	49,9	-0,01
	Max (Hz)	50,1	50,1	0
	P(49,95 < f < 50,05)	0,97	0,97	-0,22
$\frac{df}{dt}$	Mean ($Hz.s^{-1}$)	9.8E-4	n/a[a]	n/a[a]
	Std ($Hz.s^{-1}$)	0.001	n/a[a]	n/a[a]
	Min ($Hz.s^{-1}$)	0.09	n/a[a]	n/a[a]
	Max ($Hz.s^{-1}$)	-0.09	n/a[a]	n/a[a]

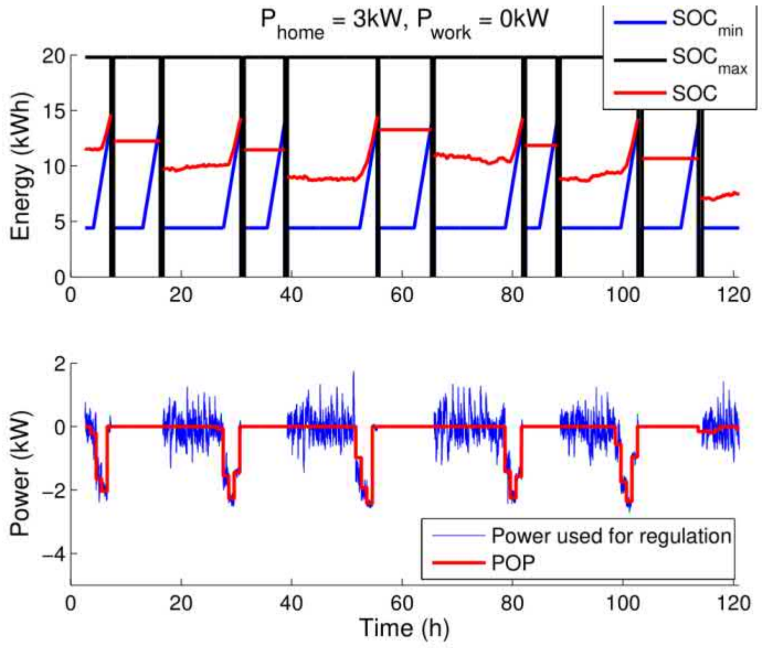
[a]n/a: not applicable, as RTE data set has a 10 second time stamp

1. EVSE charging power repartition depending on the charging location :

Charging Power	Primary EVSE	Secondary EVSE
Slow A – 3kW	95%	35%
Slow B – 7kW	5%	34%
Intermediate – 22kW	0%	29%
Fast – 43kW	0%	2%

- Simulation parameters
  - Regulatory framework as explained previously
  - Fleet modelling
  - 100 simulations are run following the Monte Carlo approach for 100 EVs
  - five continuous hourly market prices are selected randomly from the data set
  - Same for the frequency values
  - Winter and summer seasons considered

- Implementation working
- Extreme conditions were tested; algorithm validation



Simulation results for a single bidirectional capable EV over 5 working days, with P_{home} = 3kW and P_{work} = 0kW

- Earnings per EV per year

EVSE Power Level (kW)		Earnings per EV and per Year (€)
Home EVSE	Work EVSE	
3	0	138
3	3	239
3	7	389
3	22	1,036
7	0	365
7	3	418
7	7	600
7	22	1,114

- Average power provided by a fleet of 200,000 EVs:

Scenario (% EVSE at work)	P_{min} (MW)	P_{moy} (MW)
Scenario 1 (0%)	1,6	311
Scenario 2 (25%)	6,5	501
Scenario 3 (50%)	11,4	692
Scenario 4 (75%)	16,2	882

French primary reserve: ~600MW

- Potentially substantial earnings
- Business model may be considered
- Market could be saturated quickly

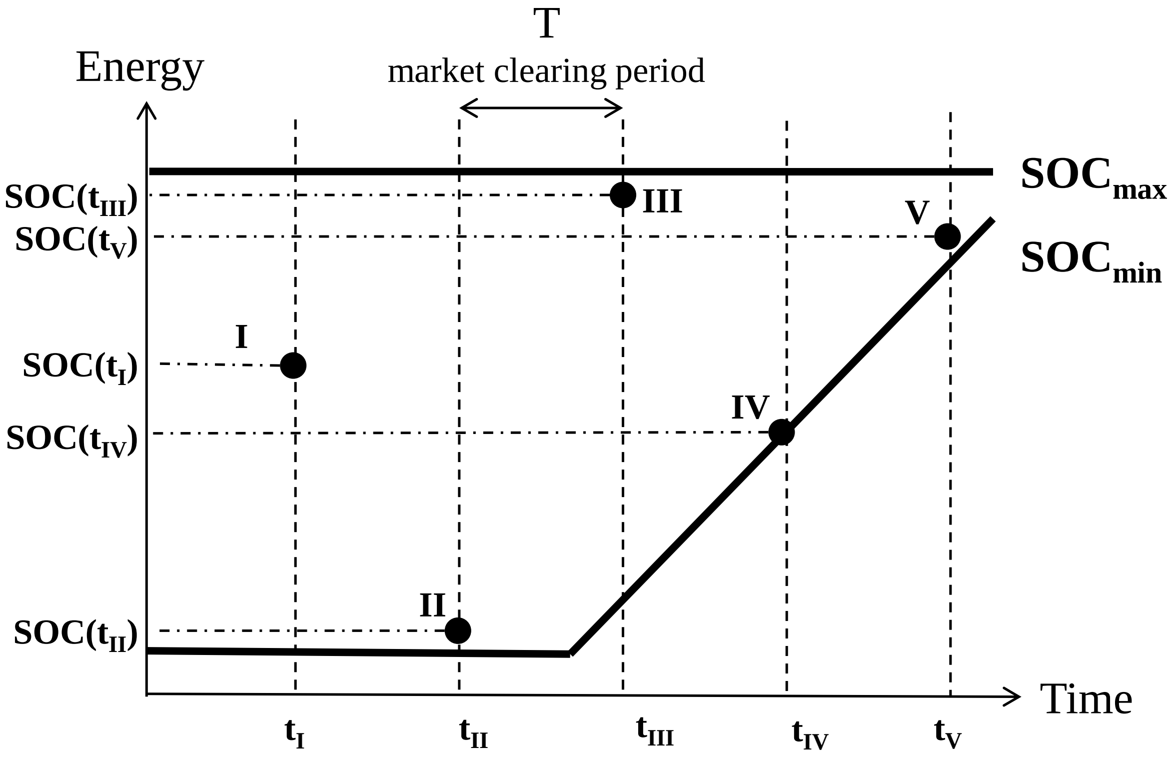
- Earnings per EV per year

EVSE Power Level (kW)		Earnings per EV and per Year (€)
Home EVSE	**Work EVSE**	
3	0	26
3	3	42
3	7	29
3	22	27
7	0	26
7	3	27
7	7	28
7	22	40

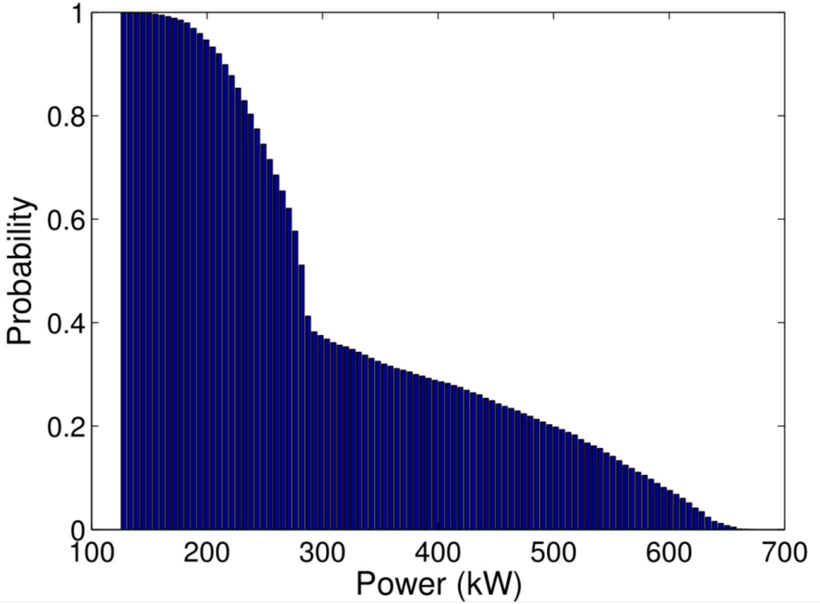
- Average power provided by a fleet of 200,000 EVs:

Scenario (% EVSE at work)	Pmin (MW)	Pmax (MW)
Scenario 1 (0%)	0	102
Scenario 2 (25%)	0	109
Scenario 3 (50%)	0	116
Scenario 4 (75%)	0	123

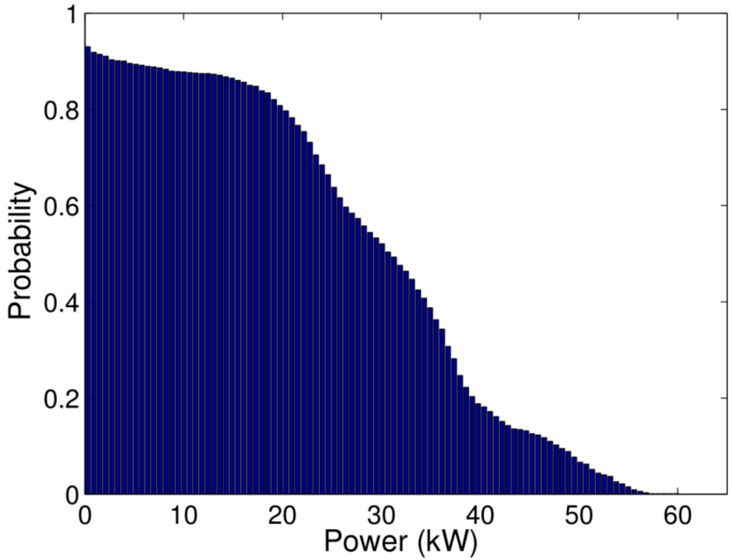
- Current market design
  → remuneration very low for unidirectional vehicles
- → New market design



EV DECISION PROCESS FOR ASYMMETRICAL MARKET DESIGN

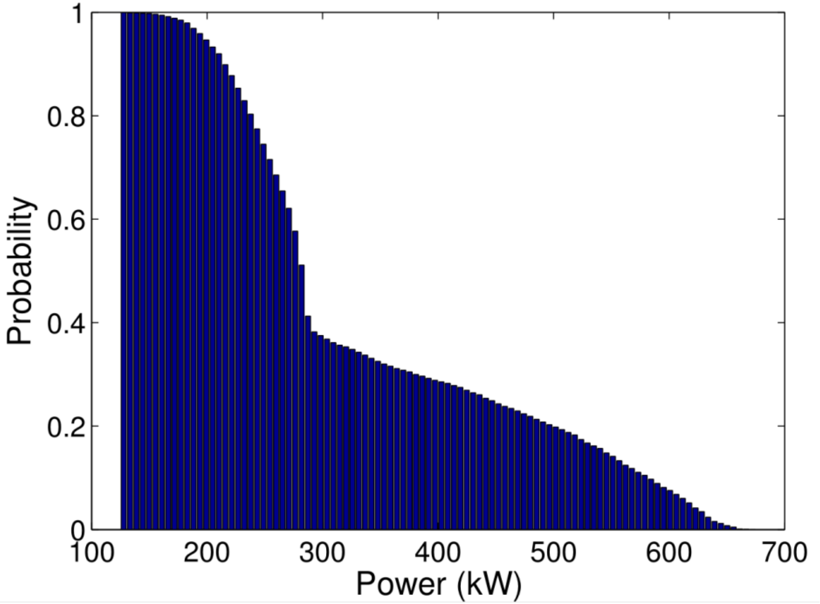


Asymmetrical market

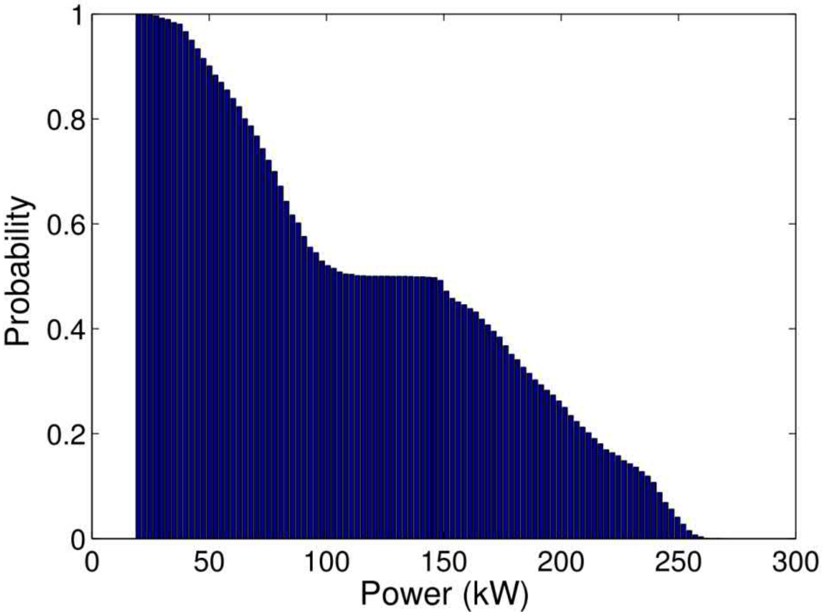


Symmetrical market

Probability that the power bid P bid be superior to a certain value, for two different market designs



One hour market clearing period



Four hour market clearing period

Probability that the power bid P_{bid} be superior to a certain value for two different market clearing periods

Asymmetrical markets

FLEET SENSITIVITY ANALYSIS

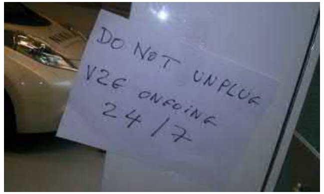
	Parameter			
Fleet	*Average speed (km/h)*	*Trip distances (km)*	*Departure times*	*EVSE charac.*
Private Fleet	40	22	8h & 17h30	See Table 3.6 and Table 3.7, scenario 2
Postal Mail Fleet	10	AM: 50 PM: 30	8h & 14h	22kW available at all times
Airport Fleet	10	6	8h & 12h	3kW, charge overnight
Company fleet	40	commuting trips: 44 working trip: 15	8h & 17h30	100% EVSE at work 50% 3kW; 50% 7kW

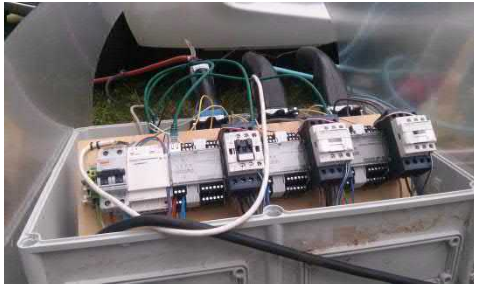
Mean values of the characteristics of the different fleets understudy

Fleet	*Earnings (€)*
Private Fleet	251
Postal Mail Fleet	2004
Airport Fleet	215
Company Fleet	501

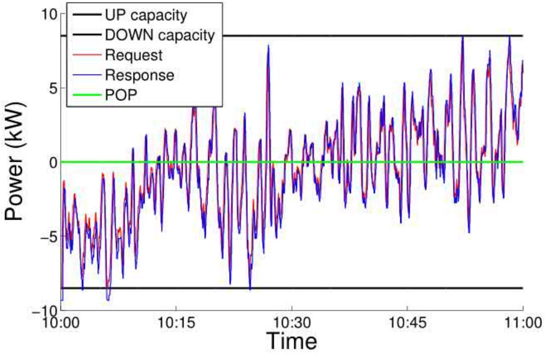
Yearly earnings per vehicle and per fleet

THE NIKOLA PROJECT

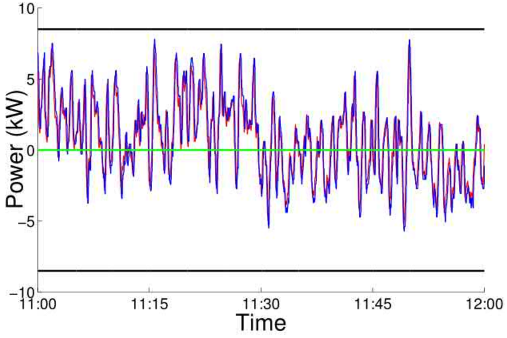




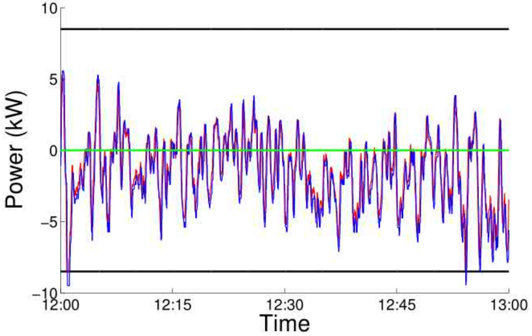
RESULTS (1/2)



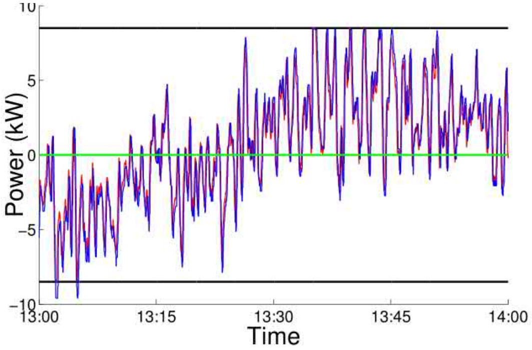
(a) From 10:00 to 11:00



(b) From 11:00 to 12:00



(c) From 12:00 to 13:00



(d) From 13:00 to 14:00

Power requests from the aggregator, and responses from the iOn

SURVEY OF TSO RULES

- Survey conducted at the beginning of the PhD (2013 – 2014)
- Using state of the art regulatory manuals at these dates
- Since then, some evolutions happened, mainly driven by ENTSO-E network codes in Europe
- ENTSO-E network codes were analyzed; they mainly deal with:
  - Contractual aspects
  - Cross-border exchanges and common market
- What is not changed in ENTSO-E network codes
  - Safety relevant and technical aspects
    - Same power-frequency curves
    - For instance, RTE still refers to UCTE Operation Handbook in its Technical Documents
    - The documents studied for Energinet.dk back in the days are still valid

- Some current evolutions are happening
- The evolutions were screened during in order to identify the main changes
- The changes are not critical, and would not change the rationale of the analysis conducted here
- The changes go in the direction of the selected regulatory framework for simulations

Table 3.4: Ideal TSO VS ENTSOE guidelines

Rule	*Ideal TSO*	*ENTSOE Proposals*
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Incompleteness of the payment	All AS should be paid	All AS should be paid
Extra bonus for flexibility	Set at the efficient level / separate market created	Demand Side Response Very Fast Active Power Response should be implemented

COST STRUCTURE

- Hardware costs:
  - Metering equipment
  - Bidirectional power electronic unit
    - On board
    - Off board
  - Additional electronic breakers
- Software costs:
  - Full IT architecture (very different between V2H and V2G solutions)
    Should remain not too important
  - Risk management costs
- Opportunity costs
- Compare with traditional reserve providing units ?
- ➔ Difficult to evaluate the costs; markets should set the right price

> - Cost of reserve provision probably low by EVs
> - Markets should be implemented to identify the real costs of reserve products