

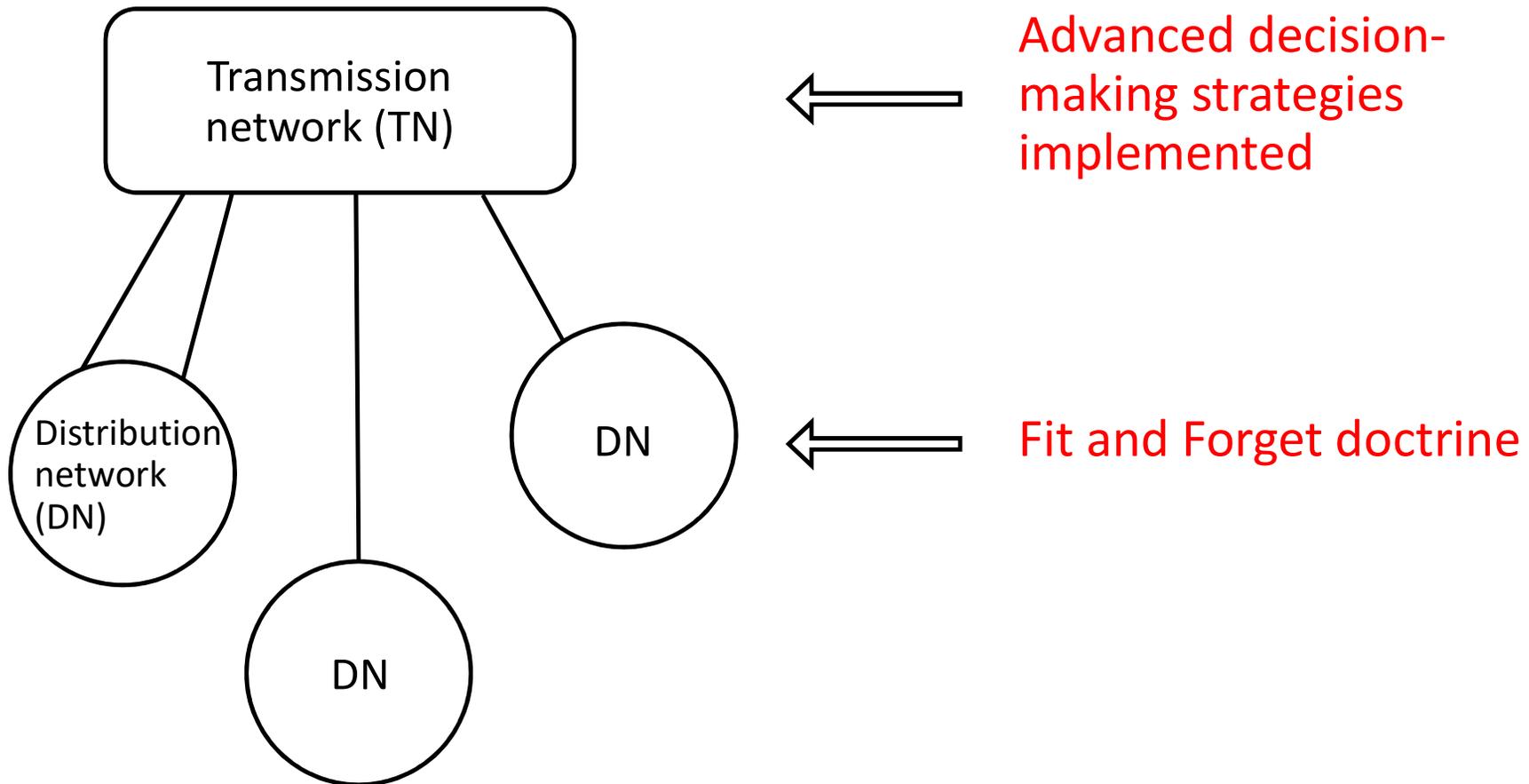
Soirée des Grands Prix SEE

A glimpse at the research work of the
laureate of the Blondel Medal 2018

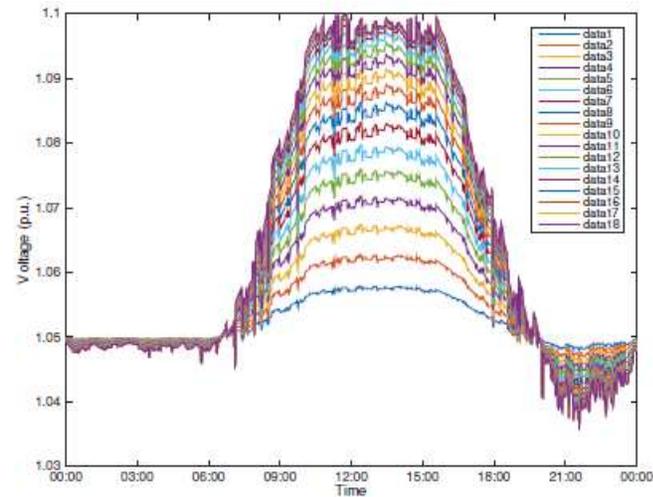
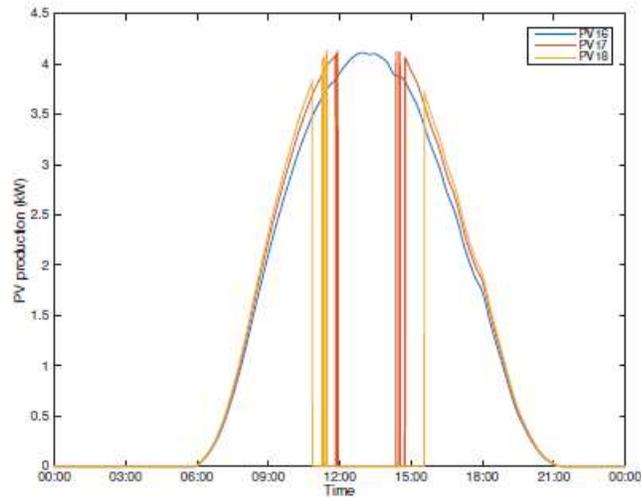
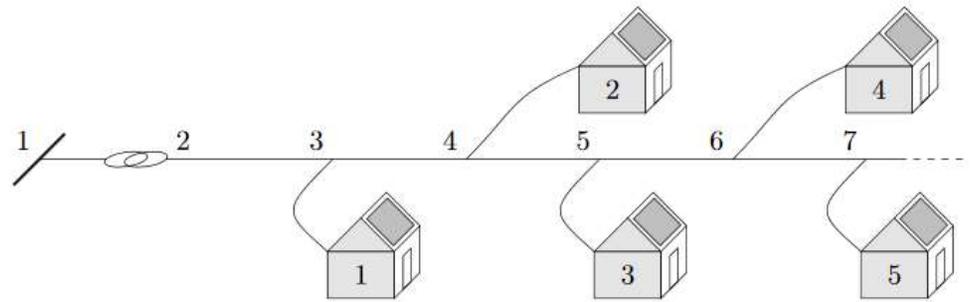
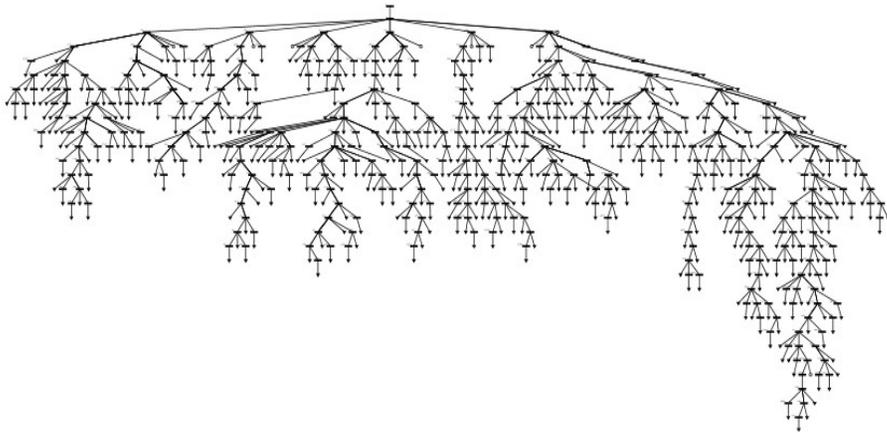
Prof. Damien ERNST



The electrical grid as it used to be



F&F doctrine too conservative for keeping pace with the rise of renewables and new electricity uses



Active Network Management

Smart modulation of generation sources, loads and storages so as to safely operate the electrical network without having to rely on significant investments in infrastructure.

Decision chain in distribution networks

The **four stages of the decision chain** for managing distribution networks:

1. Interaction models
2. Investments
3. Operational planning
4. Real-time control

Our integrated approach for designing ANM

- \mathcal{M} : Set of possible **m**odels of interaction
- \mathcal{I} : Set of possible **i**nvestment strategies
- \mathcal{O} : Set of possible **o**perational planning strategies
- \mathcal{R} : Set of possible **r**eal-time control strategies

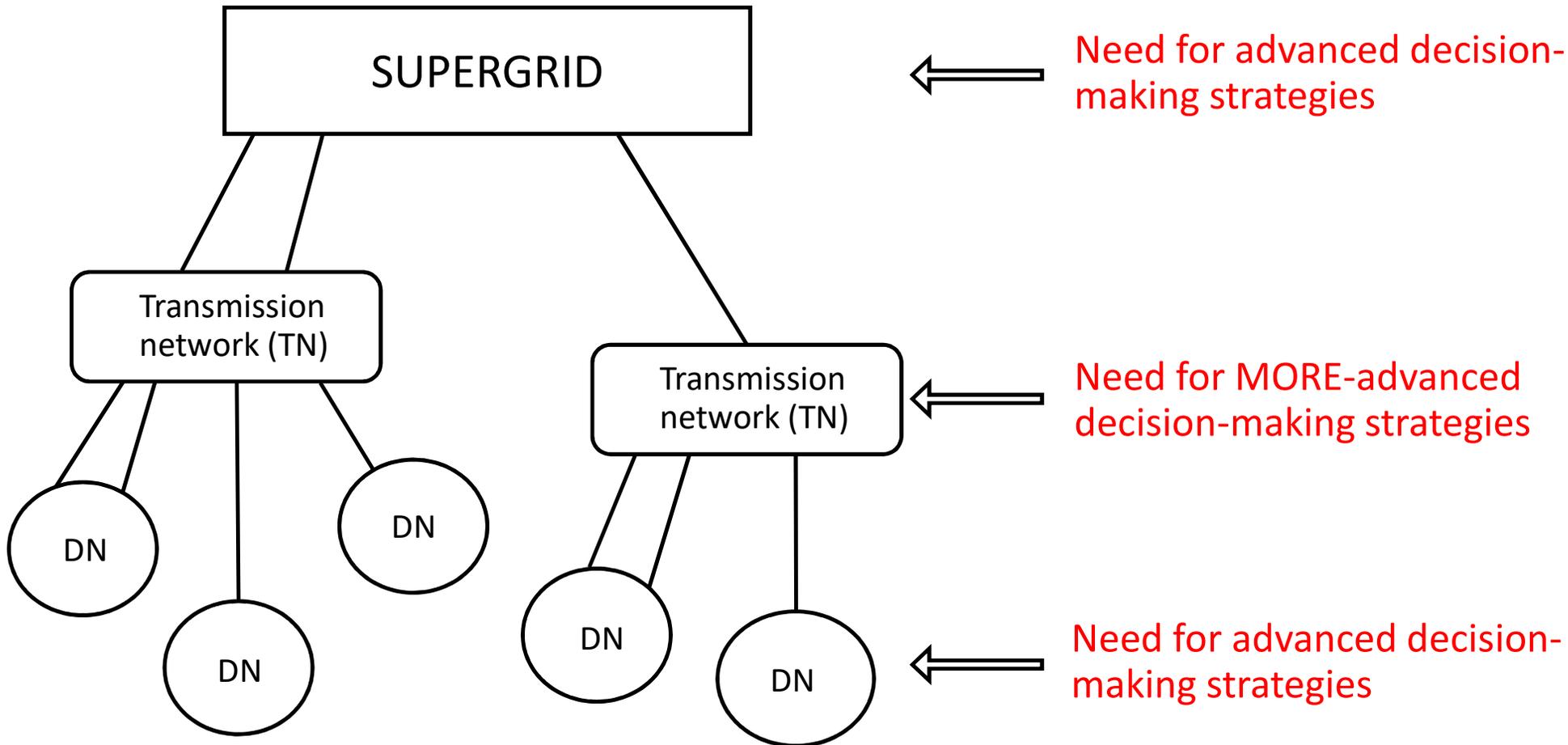
Solve:

$$\arg \max_{(m,i,o,r) \in \mathcal{M} \times \mathcal{I} \times \mathcal{O} \times \mathcal{R}} \text{social_welfare}(m, i, o, r)$$



www.blacklight-analytics.com

A startup from the ULiège commercializing intelligent software solutions for active network management and energy systems



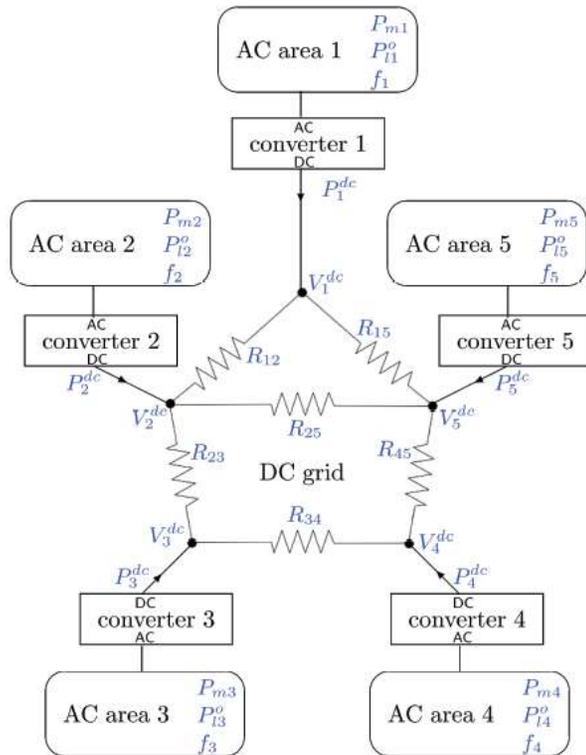
Controlling a HVDC supergrid to share primary frequency reserves

Power-injection-based control scheme

Control scheme composed of $N - 1$ subcontrollers, one for each HVDC converter except converter N which maintains the voltage of the DC grid. Modifies P_i^{dc} such that:

$$\frac{dP_i^{dc}}{dt} = \alpha \sum_{j=1}^N b_{ij} (\Delta f_j - \Delta f_i) + \beta \sum_{j=1}^N b_{ij} \left(\frac{df_j}{dt} - \frac{df_i}{dt} \right)$$

- $\Delta f_i = f_i - f_{nom,i}$ is the frequency deviation of area i
- α and β are control gains
- b_{ij} 's are the coefficients representing the communication graph between the AC areas. The value of b_{ij} equals 1 if subcontroller i receives frequency information of area j , and 0 otherwise.



Theoretical analysis

Assumption 1. The graph representing frequency deviations communication among the subcontrollers is (i) constant in time (ii) undirected and (iii) connected.

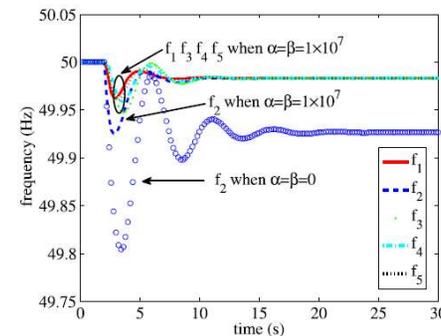
Assumption 2. The variation of the net overall power flow injected into the DC grid can be neglected.

Theorem 1. Consider that the power system, initially operating at its nominal equilibrium, is suddenly subjected to a step change in the load demand in one or several of its AC areas. Then, under Assumptions 1 and 2 the (linearized) HVDC system has a unique equilibrium point, at which the frequency deviations of all AC areas are equal.

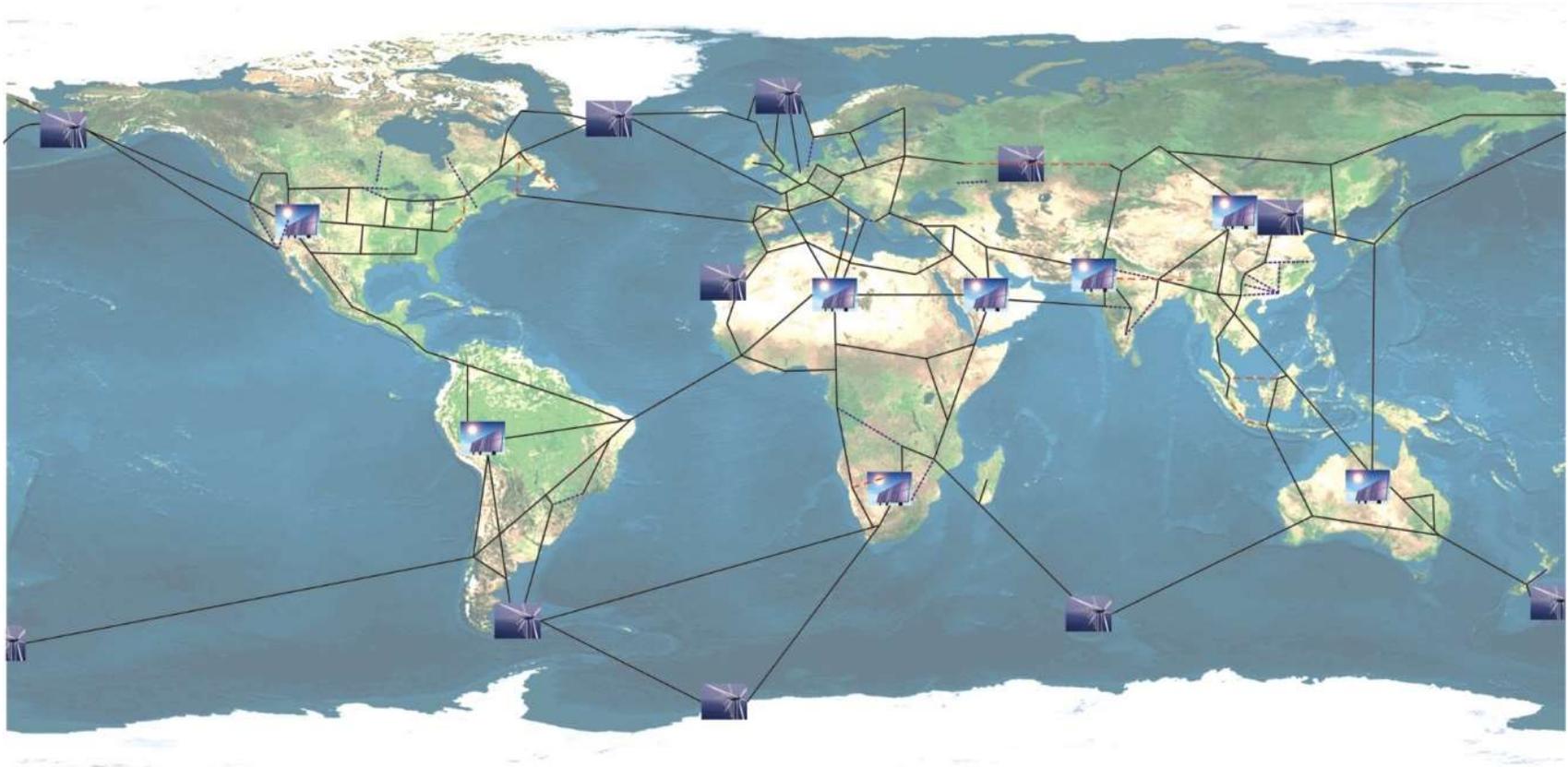
Theorem 2. The linearized system is exponentially stable for any $\alpha > 0$ and $\beta \geq 0$.

Results

Variations of the f_i s after a 5 % load increase in area 2:

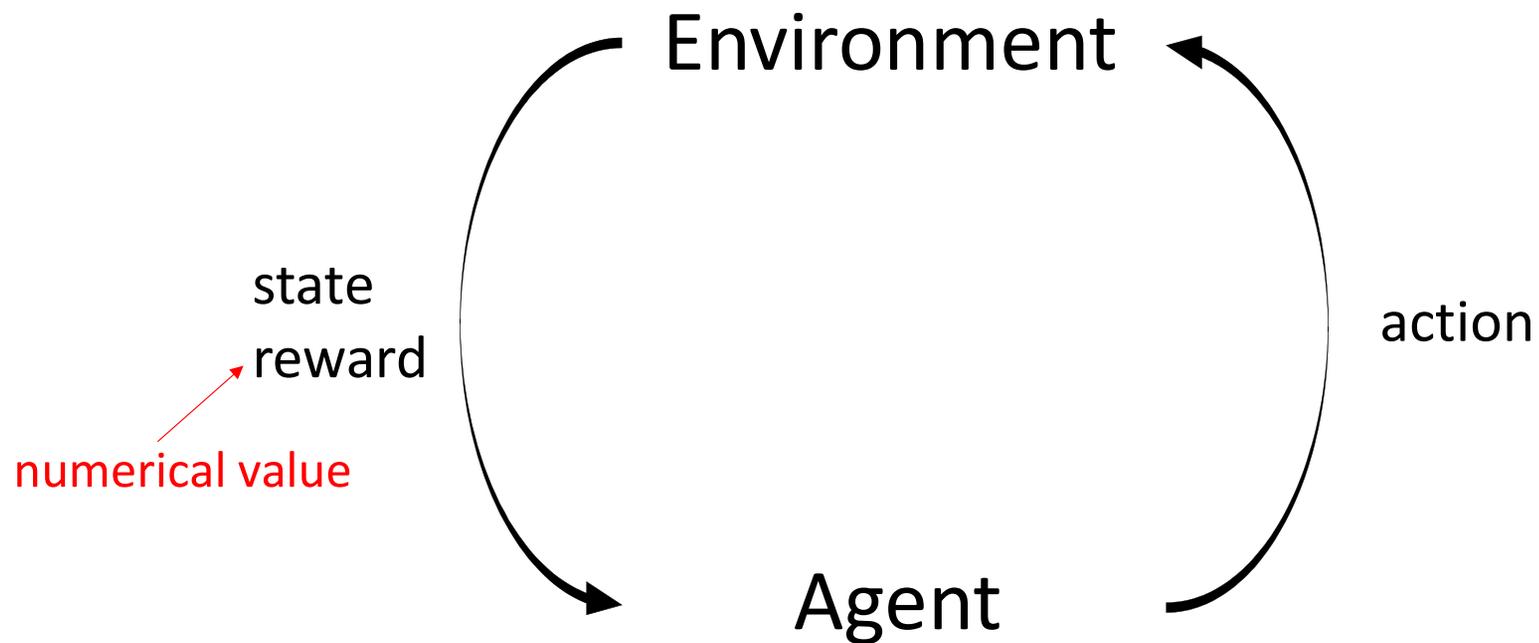


From supergrids towards a global grid – a key infrastructure for a fast energy transition



More at: <http://blogs.ulg.ac.be/damien-ernst/tedx-talk-the-global-grid-for-empowering-renewable-energy/>

Reinforcement learning (RL) agent



We pioneered the use of these techniques for controlling power systems and many others followed.

Table 1. Summary of RL considerations for electric power system control/decision

Problem	Type of control	RL method	Reference(s)
Electricity market simulation	Market decision	Q-learning	Harp et al. (2000)
			Rahimiyan et al. (2010)
			Nanduri and Das (2007)
			Lincoln et al. (2012)
			Kim et al. (2016)
Transient angle instability	Emergency	Q-learning	Ernst et al. (2004)
			Glavic (2005)
			Glavic et al. (2005a)
			Glavic et al. (2005b)
		Li and Wu (1999)	
		Fitted Q iteration	Ernst et al. (2009)
		Policy search	Mohagheghi et al. (2006)
Oscillatory angle instability	Emergency	Q-learning	Ernst et al. (2004)
			Wang et al. (2014)
			Glavic et al. (2005a)
			Ademoye and Feliachi (2012)
			Karimi et al. (2009)
Voltage control	Normal	Q-learning	Xu et al. (2012)
			Vlachogiannis et al. (2004)
AGC (Automatic) generation control)	Normal	Q(λ) with elig. traces	Yu et al. (2011)
		Q-learning	Daneshfar and Bevrani (2010)
Economic dispatch	Normal	Q-learning	Ahamed et al. (2002)
		$R(\lambda)$	Yu et al. (2012b)
Wide-area control	Emergency	TD	Yousefian et al. (2016)
		Q-learning	Yan et al. (2016)
Households control	Normal	Q-learning	Hadidi and Jeyasurya (2013)
		Q-learning	Wang et al. (2016)
Wind generation control	Normal	Q-learning	Yan et al. (2016)
		$Q(\lambda)$	Wei et al. (2015)
Demand control	Normal	Fitted Q iteration	Tang et al. (2015)
		Fitted Q iteration	Yu et al. (2012a)
System restoration	Restorative	Q-learning	Ruelens et al. (2016)
		Q-learning	Vandael et al. (2015)
Congestion management	Emergency	Q-learning	Ye et al. (2011)
		Q-learning	Zarabbian et al. (2016)
Microgrids control	Normal	Q-learning	Khorrababady et al. (2015)
		Policy search	Li et al. (2012)
		Policy search	Venayagamorthy et al. (2016)

Contributions to Reinforcement learning (RL)

Information generalization in reinforcement learning (fitted Q iteration, ...)

Learning RL policies with performance guarantees

Inputs: a set of four-tuples \mathcal{F} and a regression algorithm.

Initialization:

Set N to 0.

Let \hat{Q}_N be a function equal to zero everywhere on $X \times U$.

Iterations:

Repeat until stopping conditions are reached

- $N \leftarrow N + 1$.

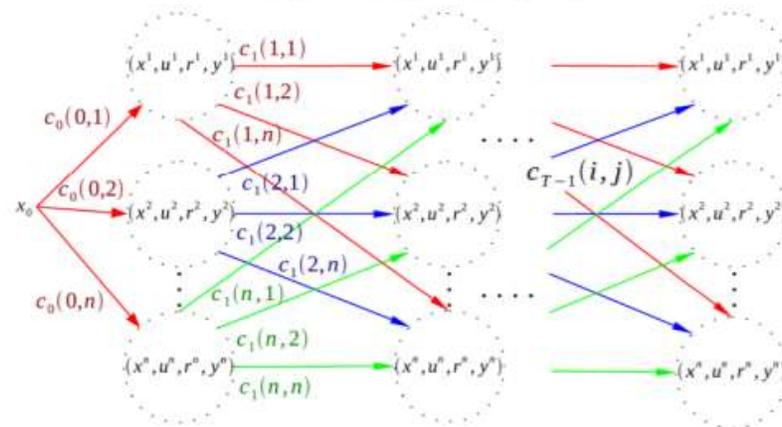
- Build the training set $\mathcal{TS} = \{(l^i, o^i), i = 1, \dots, \#\mathcal{F}\}$ based on the the function \hat{Q}_{N-1} and on the full set of four-tuples \mathcal{F} :

$$l^i = (x_t^i, u_t^i), \quad (12)$$

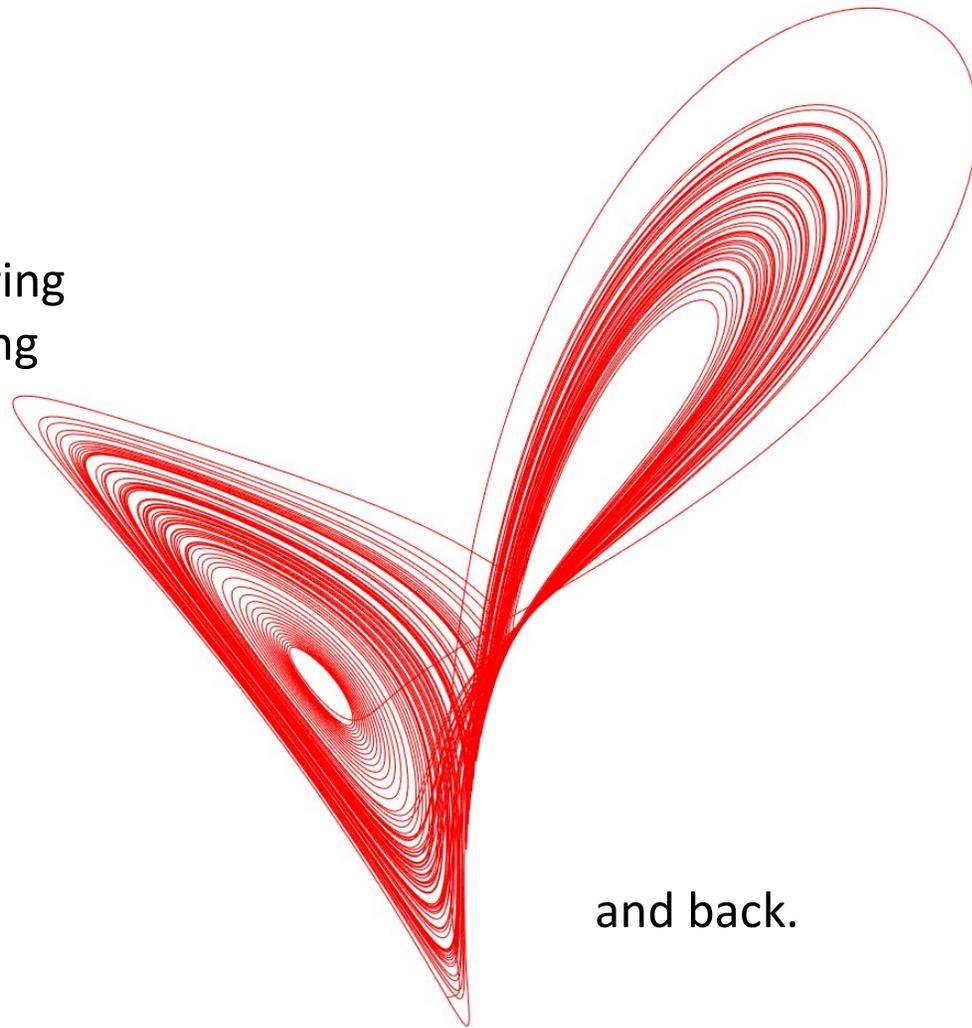
$$o^i = r_t^i + \gamma \max_{u \in U} \hat{Q}_{N-1}(x_{t+1}^i, u). \quad (13)$$

- Use the regression algorithm to induce from \mathcal{TS} the function $\hat{Q}_N(x, u)$.

Figure 1: Fitted Q iteration algorithm



A research interplay,
from electrical engineering
to reinforcement learning



and back.

The Lorenz oscillator illustres admirably well this interaction.



To my PhD advisor, my principal referee for this Blondel Medal, my colleague and my friend, Prof. Louis Wehenkel : THANK YOU