NEURAL INFORMATION PROCESSING SYSTEMS

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Thursday 23rd of July 2020

Learning to Run a Power Network in a sustainable world

A NeurIPS 2020 Competition https://l2rpn.chalearn.org/

01

Introduction

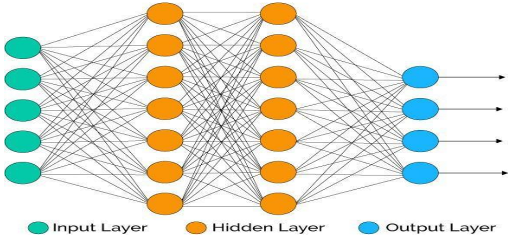
AI is BOOMing

IMAGENET

ImageNet (2012) & NLP (2018) moments

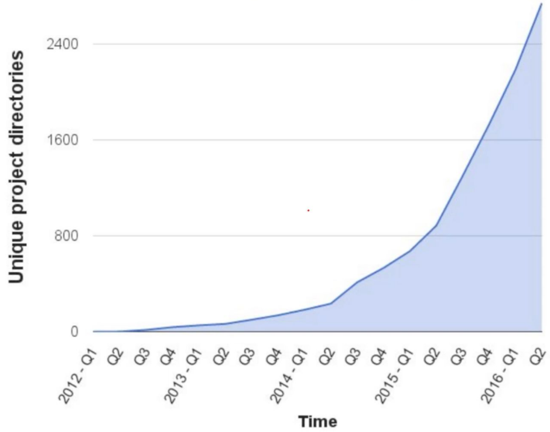
Keys of success:
- Large Benchmarks & leverage big data
- Leverage computation
- Open-source platform & papers
- Deep Learning revival

NB: not much new algorithms & theory

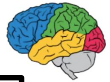


Growing Use of Deep Learning at Google

# of directories containing model description files



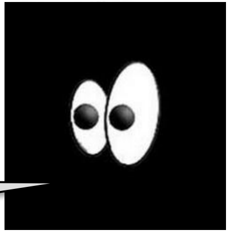
Across many products/areas:
Android
Apps
drug discovery
Gmail
Image understanding
Maps
Natural language understanding
Photos
Robotics research
Speech
Translation
YouTube
... many others ...



AI based on Deep Learning started to impact many fields & layers of society at a fast pace

AI & Electricity

« Artificial Intelligence is the new Electricity », Andrew Ng



Are blackouts a story of the past ?

Quizz : How much time a grid could run without human intervention ?

1 minute

1 hour

Up to the next storm

Forever

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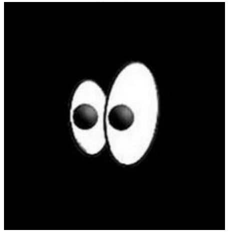


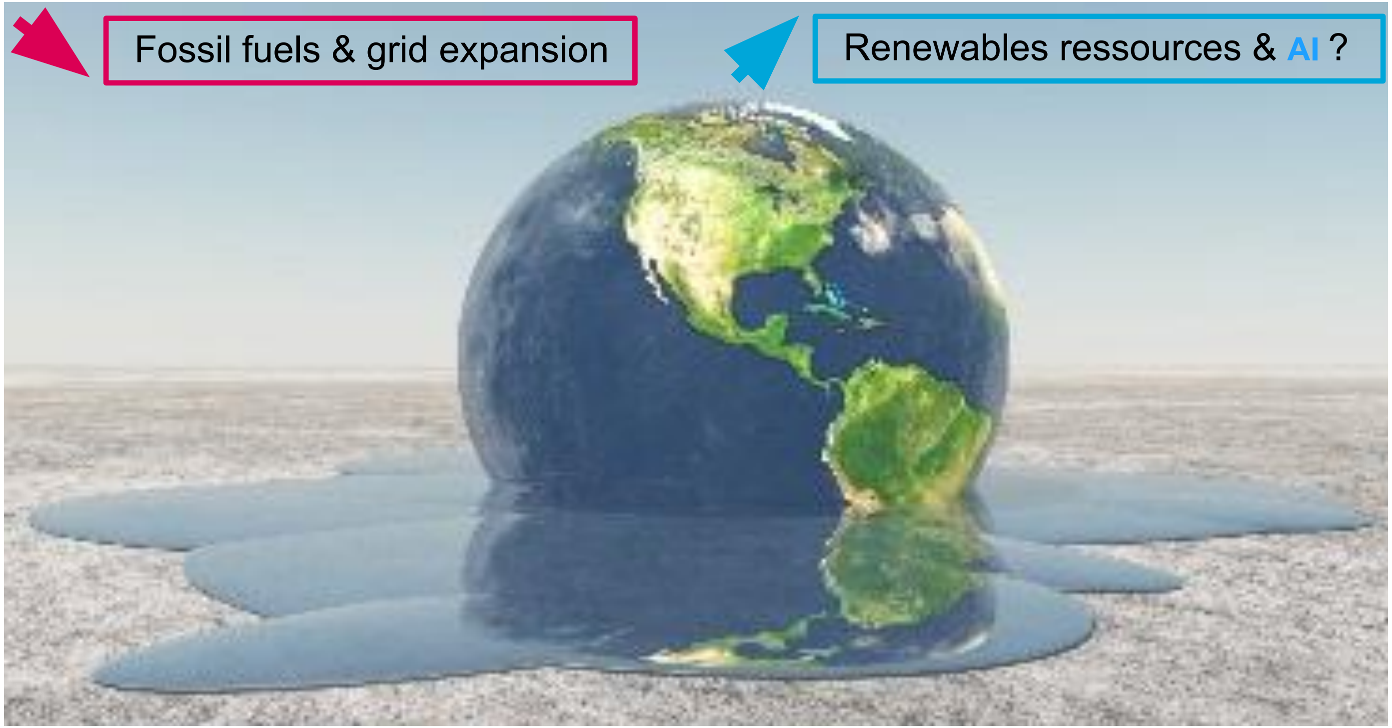
Are blackouts a story of the past ?

NOT REALLY!

A control room today

Quite a complex work environment !

Yet, Another system to consider : Earth!



⇒ Sustainability is the key, future smart grids have to do better with less

AI & Electricity

« Artificial Intelligence is the new Electricity », Andrew Ng

Yet power grids are one of the most complex artificial systems

AI & Electricity

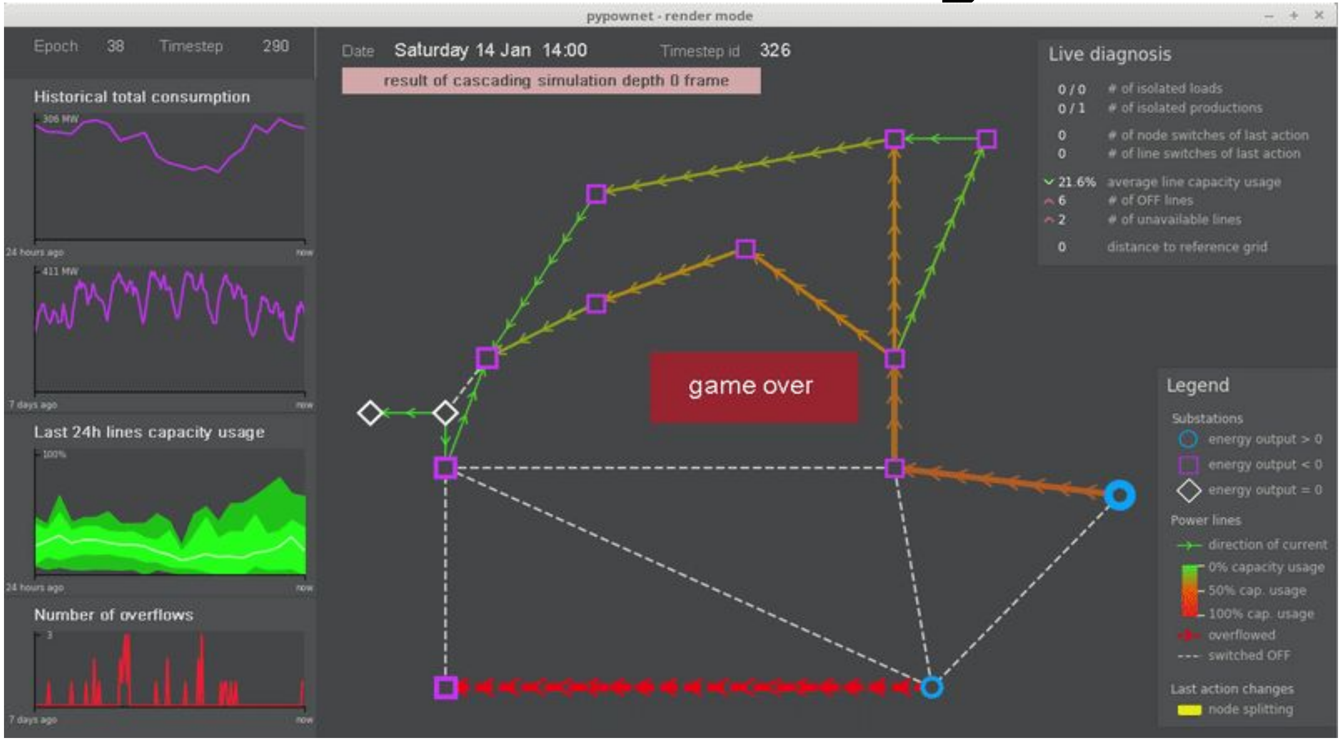
« Artificial Intelligence is the new Electricity », Andrew Ng

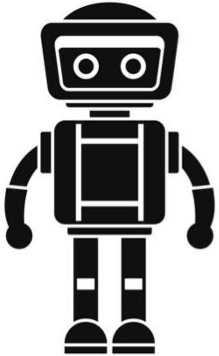
How AI can be of any help here ?

02

L2RPN challenge

« Learning To run a power network » L2RPN Challenge





1) Test the potential of AI to robustly operate a power grid in real-time given operational constraints.

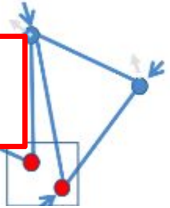
Different kind of flexibilities

On Grid Flexibilities

Topology:

Little research

- Node merging/splitting



Power devices:

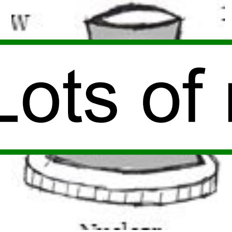
Some research

- HVDC
- …

All over the grid & 0$!

Few & local & 0$

On Production and Load Balancing



Redispatching

Lots of research

Load shedding

Many over the grid & $$$

Many over the grid & $$$$$

2) Explore underutilized cheap topology controls with methods can deal with non-linear, non-convex and combinatorial complexity

Motivations for a challenge

Exhibit important real-world problems to the research community

Large Benchmark for Reproducible Science:

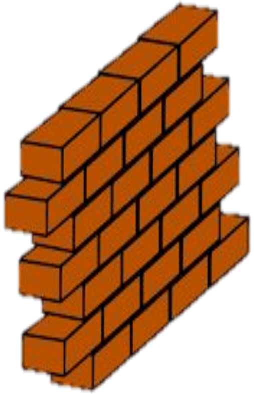
- Decouple the modeler (problem design) & the solver

Attract new communities, especially AI community, through an easy-to-use platform & a gameified problem

Machine Learning & power systems

Mainly Today

Power System Community



AI Community

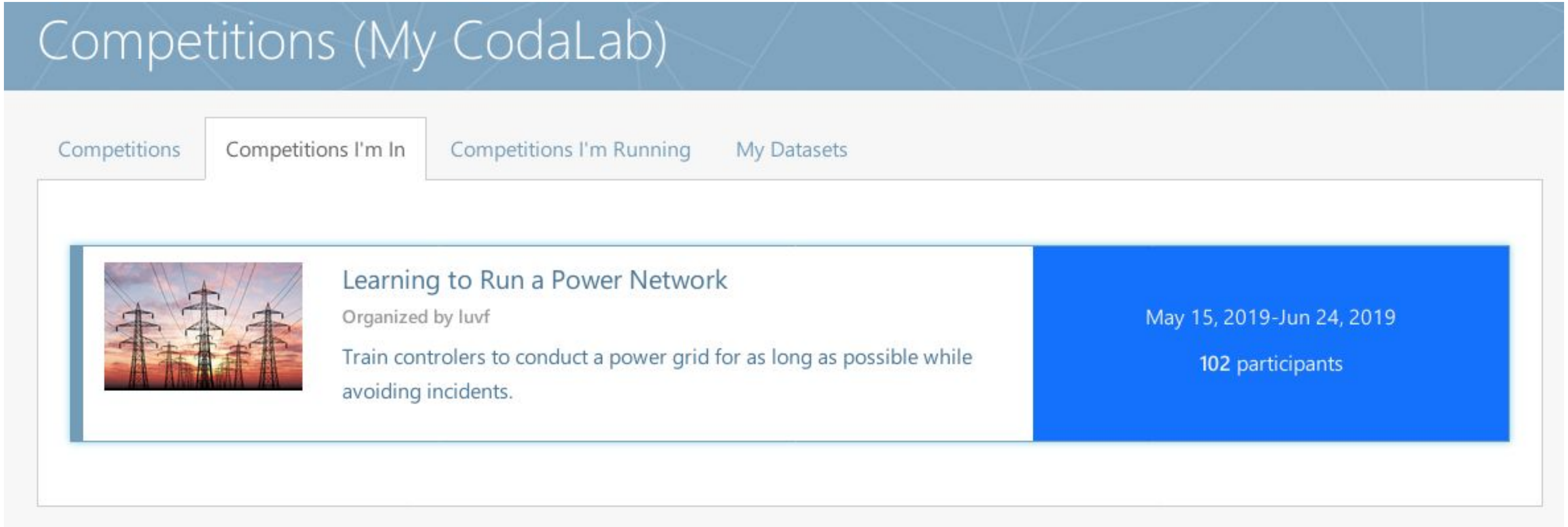
Artificial Intelligence & Power Grids

One small step for **Electricity**, one giant leap for **Sustainability** !

02

Challenge overview

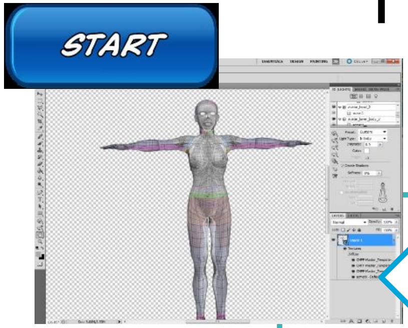
2019 Challenge overview



- 6-week challenge
- Participants from both power system & ML communities all around the world
- To get the prize, winning teams had to open-source their code
- Travel expanse Award for the best 2 teams (IJCNN conference or Paris at RTE)

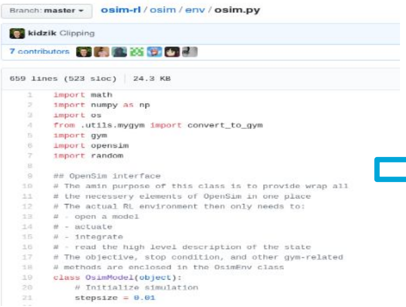
« Learning to run » inspiration

How to build a smart controller ?



Simulator + Model

Python API

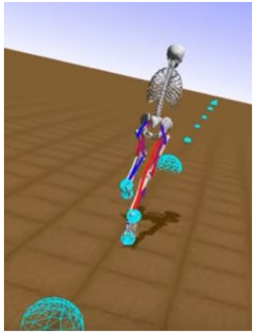



```
import math
import numpy as np
import os
from .utils.mygym import convert_to_gym
import gym
import opensim
import random

## OpenSim interface
# The amin purpose of this class is to provide wrap all
# the necessery elements of OpenSim in one place
# The actual RL environment then only needs to:
# - open a model
# - actuate
# - integrate
# - read the high level description of the state
# The objective, stop condition, and other gym-related
# methods are enclosed in the OsimEnv class
class OsimModel(object):
    # Initialize simulation
    stepsize = 0.01
```

openSim.py

Game Environment



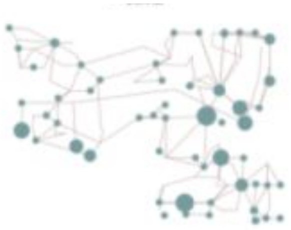
Gym openAI framework

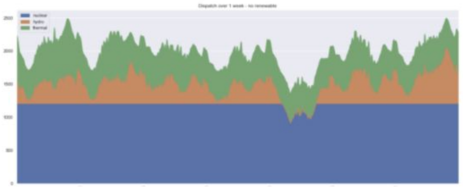
Smart controler!

GridAlive ecosystem

Repo to share open-source models
https://github.com/rte-france/l2rpn-baselines

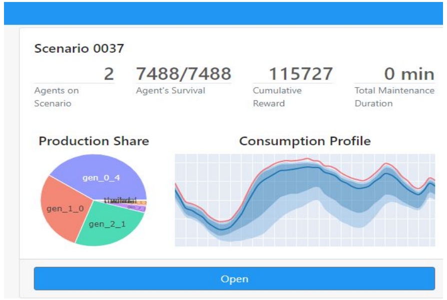
AGENT





Data

Analysis



Power Grid time serie generation
https://github.com/mjothy/ChroniX2Grid

Grid2Op: **testbed platform** to model real-time operations, run & benchmark control algorithms
https://github.com/rte-france/Grid2Op

Scenario & agents study
https://github.com/mjothy/grid2viz

Modeling of power system operation world

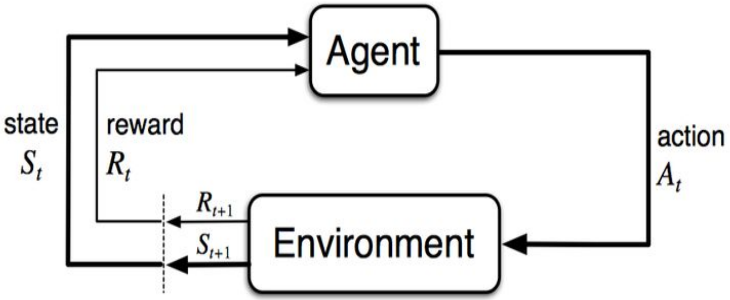


Fig. 1 - *Reinforcement Learning interaction loop*

Observation: flows, productions, consumptions, power grid topology, month, day, hour, etc

Action: connect/disconnect **one** transmission line **or** change the electrical configuration within a substation

Reward: penalize overflowed lines, distance to reference grid topology, number of disconnected loads/prods, etc.

Maximize

$$\sum_{t=0}^{\infty} \gamma^t r(s_t, a_t)$$

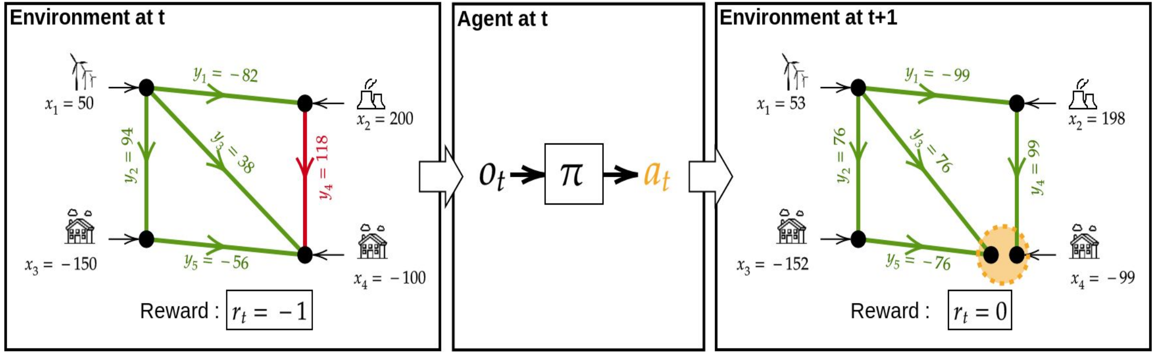


Fig. 2 - *Step-by-step evolution of the RL environment*

Agent evaluation – score function

Control the power flows to **optimize the cost of operations** on the power grid while being **robust** to blackouts.

We can hence define our overall operational cost $\boldsymbol{c}_{\text{operations}}(\boldsymbol{t})$:

$$c_{\text{operations}}(t) = c_{\text{loss}}(t) + c_{\text{redispatching}}(t) \quad \& \quad c_{\text{blackout}}(t) = \text{Load}(t) * \beta * p(t), \ \beta \geqslant 1$$

Now we can define our cost $\boldsymbol{c}$ for an episode:

$$c(\boldsymbol{e}) = \sum_{t=1}^{t_{\text{end}}} c_{\text{operations}}(t) + \sum_{t=t_{\text{end}}}^{T_e} c_{\text{blackout}}(t)$$

Under N episodes, the final score to minimize is:

$$Score = \sum_{i=1}^{N} c(e_i)$$

=> Participants are tested over 10-20 scenarios of different difficulties, with duration between 3-7 days.

03

Environment design

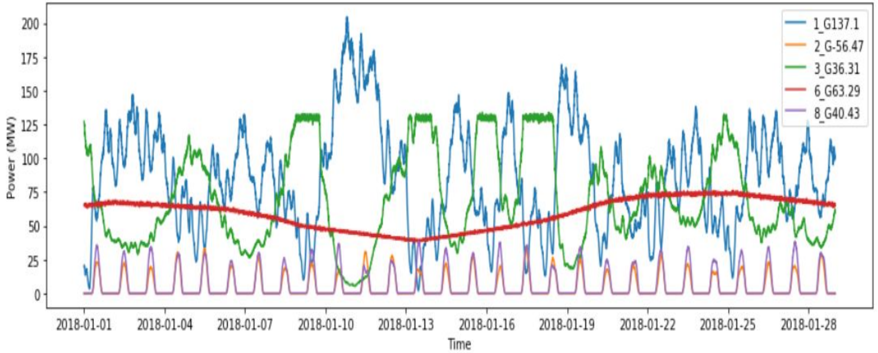
Game requirements

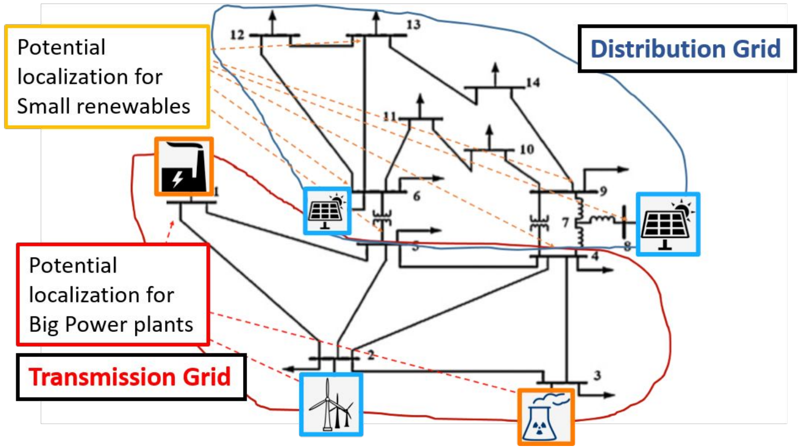
Criteria to Design and calibrate an environement:

- Be Realistic (represent real world caracteristics)
- Be Interesting (Diverse actions in diverse context to control the game)
- Be Feasible (existance of solutions to avoid game overs)

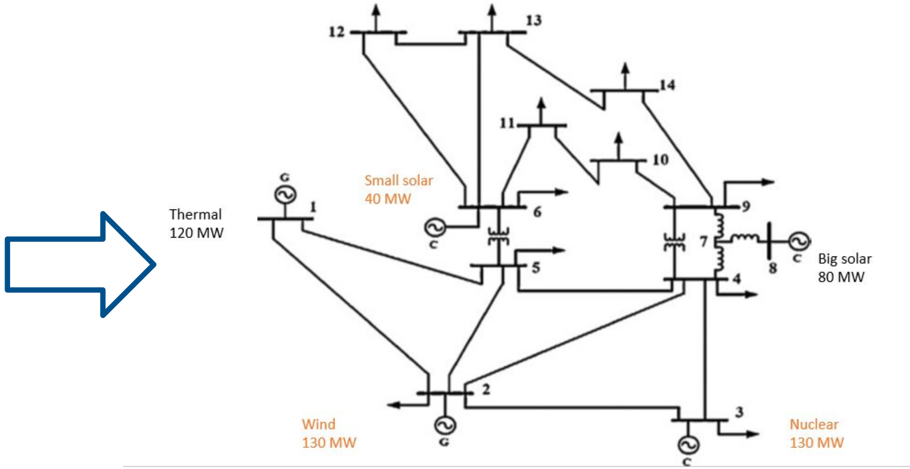
Line Capacities were the main design parameters to make a trade-off between feasible and interesting.

Realistic: Production energy mix



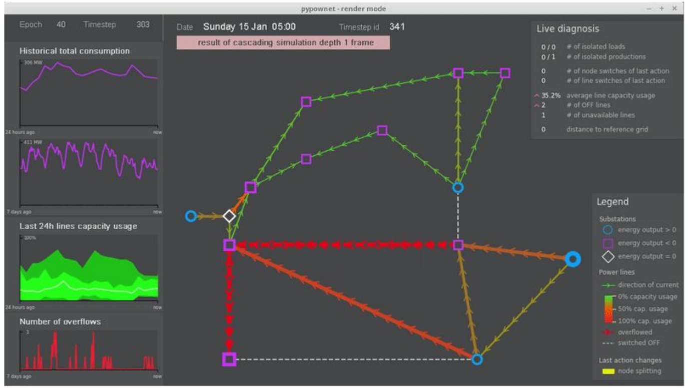


Generate chronics & Localize generation units



Realistic: Line Capacity Calibration

When building a line, its capacity should be properly **sized according to the expected flows over a year**.



The **line capacity** should be:

1) Close to the **max flow** we can observe.

2) Sometimes below
   - Because the line has been built few years ago, the system has changed and will not be replaced soon.
   - This is when **congestions** can appear and needs to be controlled few % of the time.

Realistic & Interesting: Operational Constraints

The game should represent operational constraints:

1) A limited time to react to a congestion (2 ts)

2) A limited number of simultaneous action (1/ts)

3) A cooldown time before reusing an asset (3 ts)

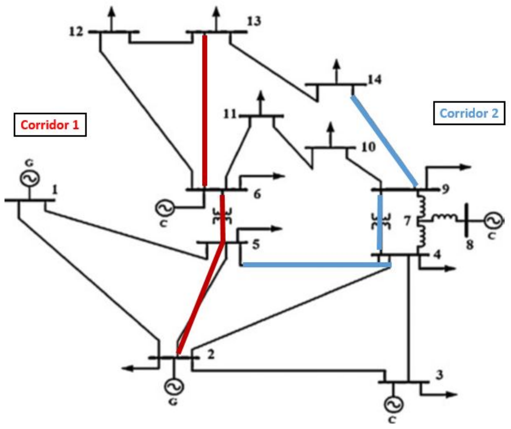
There is hence a **budget** associated to the actions you take: they should be picked up carefully !

Interesting & Feasible: existence of solutions

Minimal Grid: IEEE14 is the minimal grid to play with the topology because it is sufficiently meshed

Strutural feasability: Existence of Multiple electrical path to reroute power flows and avoid overloads.

- Easier with larger meshed grids
- But choice of the grid for a minimalist problem and facilitate challenge analysis



2 electrical corridors cannot be overloaded at the same time

Contextual feasability:
Found an ensemble of simple baselines that solve a high percentage of overloads (85%)

Interesting - Selecting test scenarios

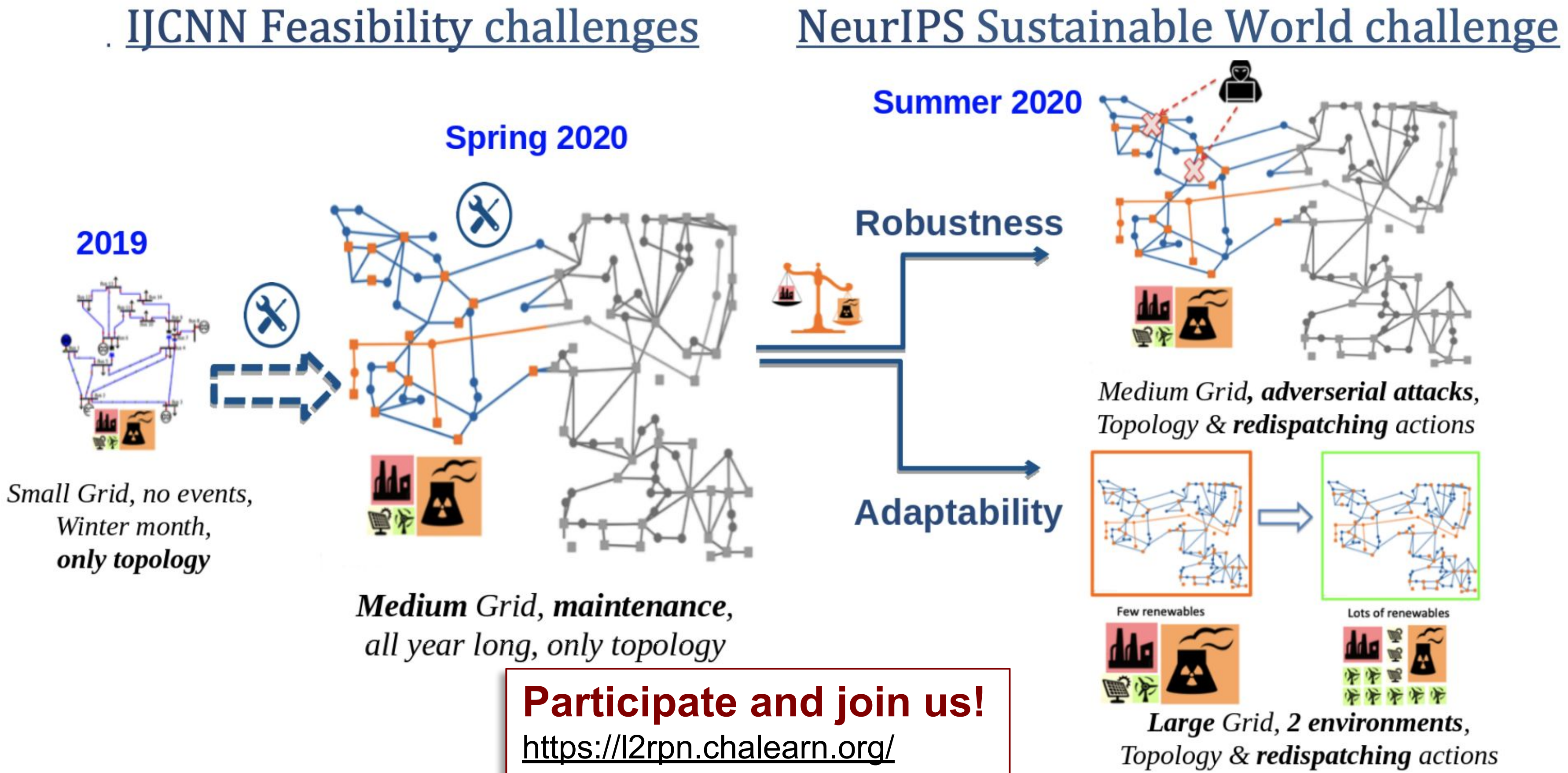
Our goal was to pick up 10 scenarios of different length (1 to 3 days) over different days of the week and with varying difficulties:

- Easy: 2 scenarios in which Do Nothing agent finishes the scenarios
- Medium: 6 scenarios were Overloads exists & Do Nothing fails, but which are solved by our baselines.
  - Overloads could happen around peak consumption or under high renewable production.
- Hard: 2 scenarios our expert baselines could not solve

04

L2RPN: competition series

Ongoing L2RPN serie competitions



Participate and join us!
https://l2rpn.chalearn.org/

Sponsors & Collaborators

Principal coordinators:

- Antoine Marot (RTE, France)
- Isabelle Guyon (U. Paris-Saclay; UPSud/INRIA, France and ChaLearn, USA)

Protocol and task design:

- Gabriel Dulac-Arnold (Google Research, France)
- Olivier Pietquin (Google Research, France)
- Isabelle Guyon (U. Paris-Saclay; UPSud/INRIA, France and ChaLearn, USA)
- Patrick Panciatici (RTE, France)
- Antoine Marot (RTE, France)
- Benjamin Donnot (RTE, France)
- Camilo Romero (RTE, France)
- Jan Viebahn (TenneT, Netherlands)
- Adrian Kelly (EPRI, Ireland)
- Mariette Awad (American University of Beirut, Lebanon)
- Yang Weng (Arizo State Univ., USA)

Data format, software interfaces, and metrics:

- Benjamin Donnot (RTE, France)
- Mario Jothy (Artelys, France)
- Gabriel Dulac-Arnold (Google Research, France)
- Aidan O'Sullivan (UCL/Turing Institute, UK)
- Zigfried Hampel-Arias (Lab 41, USA)
- Jean Grizet (EPITECH & RTE, France)

Environment preparation and formatting:

- Carlo Brancucci (Encoord, USA)
- Vincent Renault (Artelys, France)
- Camilo Romero (RTE, France)
- Bri-Mathias Hodge (NREL, USA)
- Florian Schäfer (Univ. Kassel/pandapower, Germany)
- Antoine Marot (RTE, France)
- Benjamin Donnot (RTE, France)

Baseline methods and beta-testing:

- Kishan Prudhvi Guddanti (Arizo State Univ., USA)
- Loïc Omnes (ENSAE & RTE, France)
- Jan Viebahn (TenneT, Netherlands)
- Medha Subramanian (TenneT & TU Delft, Netherlands)
- Benjamin Donnot (RTE, France)
- Jean Grizet (EPITECH & RTE, France)
- Patrick de Mars (UCL, UK)
- Lucas Tindall (Lab 41 & UCSD, USA)

Materials available

- Visit our **website** https://l2rpn.chalearn.org/ for an interactive introduction to power grid operations
- Reading the companion white paper as well as the description of the competition, and also our L2RPN 2019 paper should help you understand the problem deeper.
- Visit the **Instructions** subsection to get started with the competition
- Understand the rules of the **game** and the evaluation of your submission in the related subsection
- Review the **terms and conditions** that you will have to accept to make your first submission.
- Dive into the **starting kit** for a guided tour and tutorial to get all set for the competition and start make submissions. It helps you **TROUBLESHOOT** your submission if you are having troubles
- Take a look at the Grid2op documentation

04

2019 Results

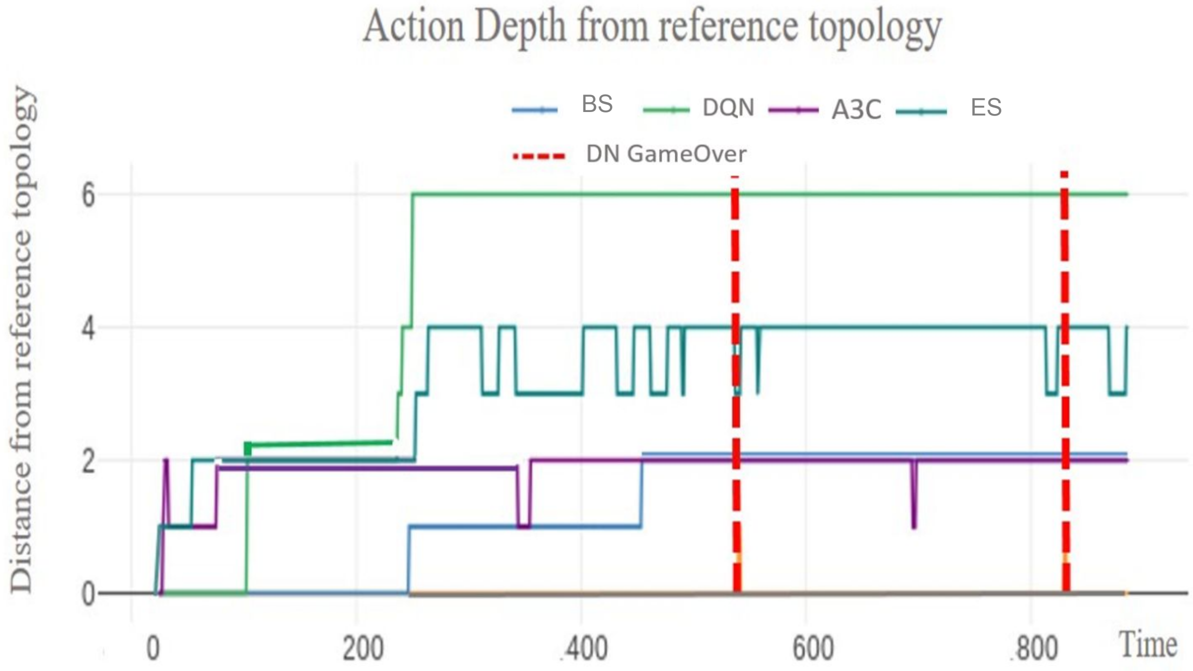
Final Leaderboard

Results					
#	User	Entries	Date of Last Entry	Score ▲	Duration ▲
1	LebronJames	6	06/24/19	83375.59 (1)	348.37 (13)
2	learning_RL	1	06/24/19	83273.99 (2)	116.13 (7)
3	Stephen_Curry	1	06/20/19	82812.91 (3)	297.33 (11)
4	Kamikaze	6	06/24/19	73737.75 (4)	124.13 (8)
5	smart_dispatcher	5	06/07/19	72375.45 (5)	955.03 (16)
6	menardprr	3	06/24/19	70104.65 (6)	1161.25 (18)
7	learning_rate	6	06/24/19	67913.35 (7)	488.53 (14)

A mix of Machine Learning agents, expert systems and power system controllers were submitted

Explanatory videos of the winning teams describing their approach are available here:
https://l2rpn.chalearn.org/competitions#h.p_6EGPeZwih5BD

Agent behavior over time

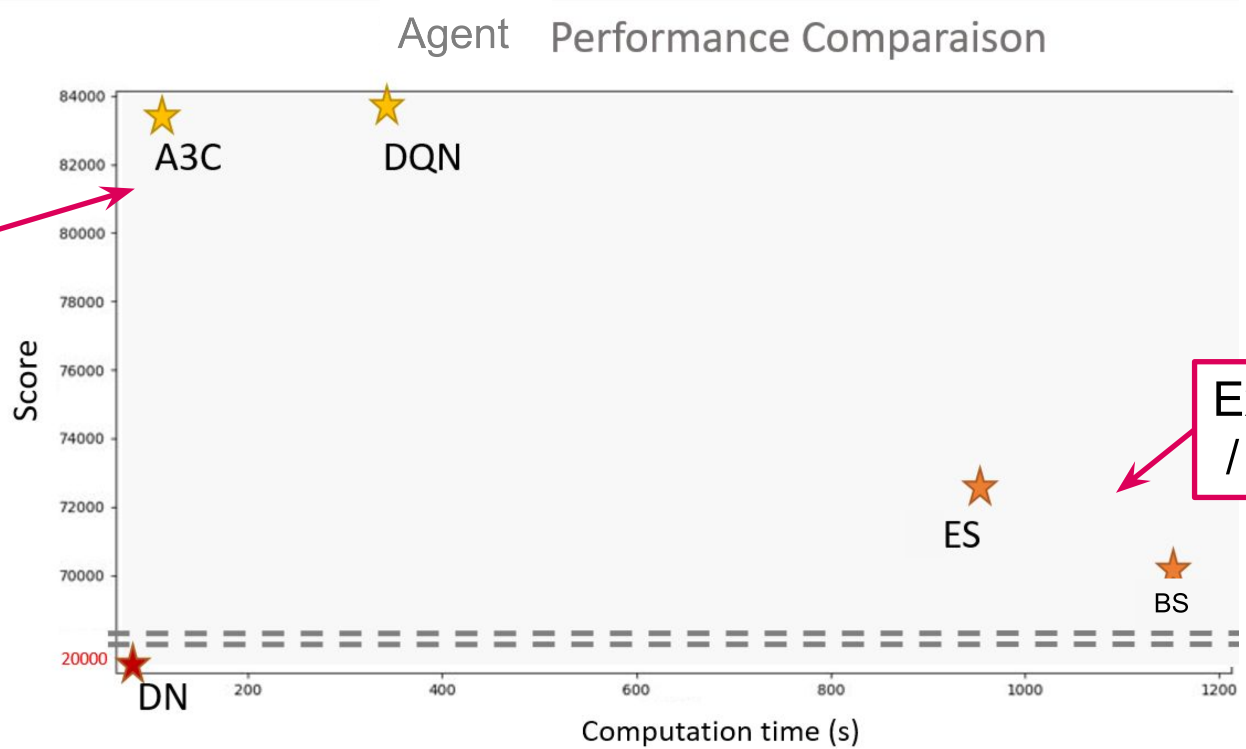


Agent behavior over validation scenario 3 showing the depth of agent actions at time-step

Expert system tries a lot more instantaneous actions while Leaning agent take less actions but with more anticipation. Overall, Learning agents showed to be more robust.

Performance comparison

Machine Learning

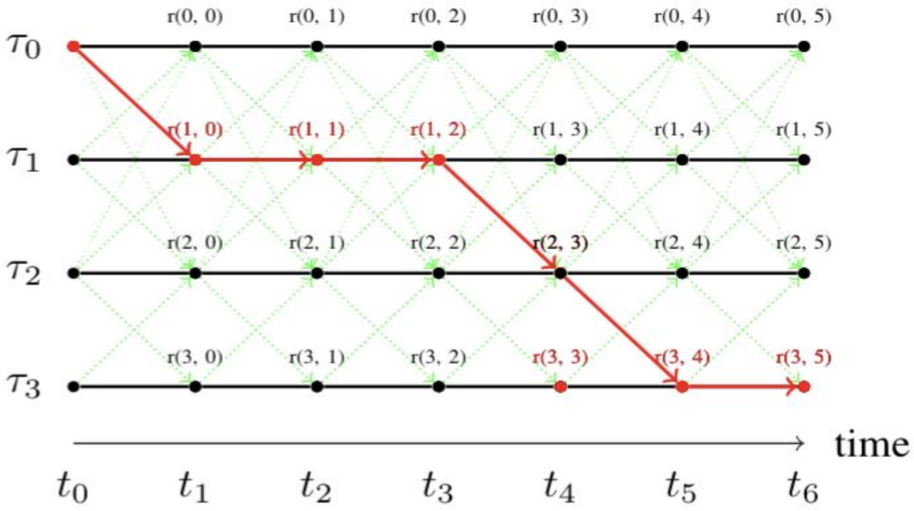


Expert System / OPF

Room for improvements

Assessing how good agents did given an oracle

Oracle actions over time



Normalized Agent scores (Oracle=100)

Scenario	ES	DQN
1	72,5	61,5
2	-10,5	90,2
3	53	82,5
4	49,5	81,5
5	47,5	70,0
6	48	47
7	19,5	63
8	39,5	77,5
9	52,5	93
10	56,5	56,5

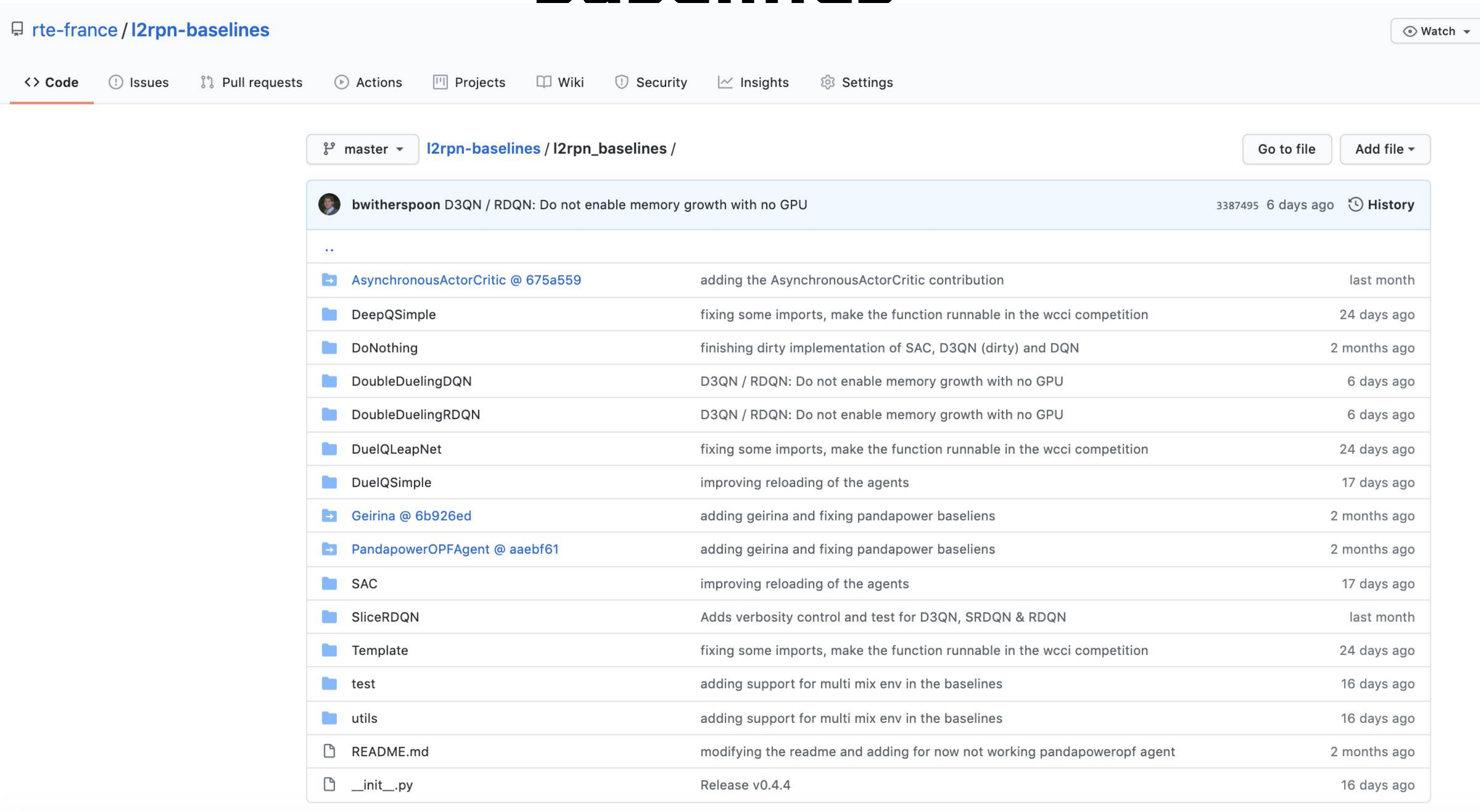
Oracle to find the best topology actions **aposteriori**:

- Run many topology in parallel
- Create edges between topologies you can transition to
- Find the best scoring path (longest path)

Beside overcomming overloads, not yet **learning to optimize the flows continuously**

Best models are now open-source baselines

https://github.com/rte-france/l2rpn-baselines



rte-france / l2rpn-baselines

Watch

Code | Issues | Pull requests | Actions | Projects | Wiki | Security | Insights | Settings

master | l2rpn-baselines / l2rpn_baselines / | Go to file | Add file

bwitherspoon D3QN / RDQN: Do not enable memory growth with no GPU — 3387495 6 days ago — History

..		
AsynchronousActorCritic @ 675a559	adding the AsynchronousActorCritic contribution	last month
DeepQSimple	fixing some imports, make the function runnable in the wcci competition	24 days ago
DoNothing	finishing dirty implementation of SAC, D3QN (dirty) and DQN	2 months ago
DoubleDuelingDQN	D3QN / RDQN: Do not enable memory growth with no GPU	6 days ago
DoubleDuelingRDQN	D3QN / RDQN: Do not enable memory growth with no GPU	6 days ago
DuelQLeapNet	fixing some imports, make the function runnable in the wcci competition	24 days ago
DuelQSimple	improving reloading of the agents	17 days ago
Geirina @ 6b926ed	adding geirina and fixing pandapower baseliens	2 months ago
PandapowerOPFAgent @ aaebf61	adding geirina and fixing pandapower baseliens	2 months ago
SAC	improving reloading of the agents	17 days ago
SliceRDQN	Adds verbosity control and test for D3QN, SRDQN & RDQN	last month
Template	fixing some imports, make the function runnable in the wcci competition	24 days ago
test	adding support for multi mix env in the baselines	16 days ago
utils	adding support for multi mix env in the baselines	16 days ago
README.md	modifying the readme and adding for now not working pandapoweropf agent	2 months ago
__init__.py	Release v0.4.4	16 days ago

04

2020 WCCI first results

WCCI competition is over

Score					
#	User	Entries	Date of Last Entry	score ▲	Computation time ▲
1	shhong	39	06/30/20	75.72 (1)	812.49
2	zenghsh3	3	06/30/20	66.21 (2)	1406.45
3	yzm_test	5	06/30/20	48.62 (3)	1233.08
4	CHWYT	1	06/30/20	27.78 (4)	1.76
5	ArtificialStupid	1	06/30/20	27.47 (5)	1.61
6	xinzhixu	11	06/27/20	26.60 (6)	1322.02
7	djmax008	23	06/27/20	26.19 (7)	495.12
8	mod-jid2020	1	06/27/20	26.05 (8)	483.91
9	anonymity	4	06/30/20	25.76 (9)	0.25
10	HJX	3	06/29/20	25.76 (9)	10.69
11	Echo-Huang	4	06/30/20	20.39 (10)	227.54
12	UESTC	1	06/29/20	20.39 (10)	228.58
13	charliedhw_s	5	06/11/20	17.98 (11)	116.43
14	KUMA	1	06/30/20	13.85 (12)	1.76
15	SEU_PSA	1	06/27/20	13.75 (13)	9.70

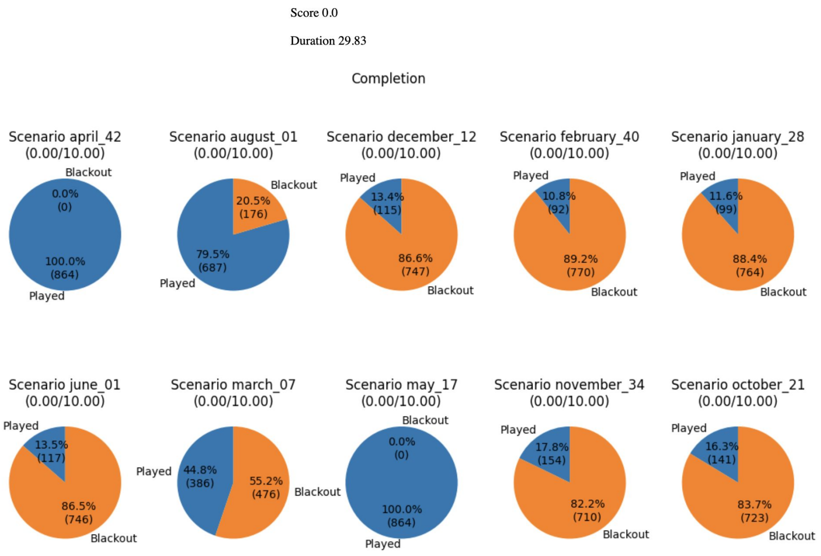
Strong scores for top 3 participants:

1) South Corean working at Naver
2) Chinese working at Baidu
3) PHD at Singapour (Data Science et Power system)
4) Chinese Researcher (working in cyber physical power systems) - but double account

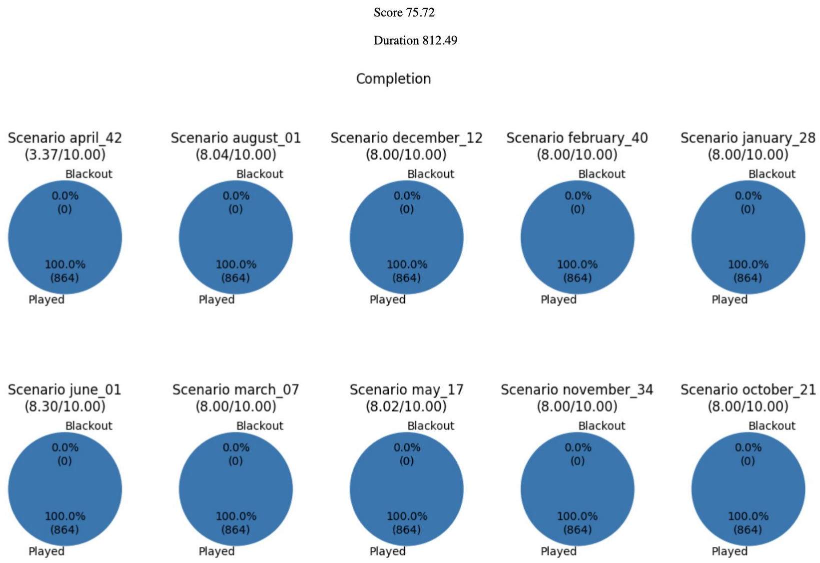
=> We check the leaderboard and give prizes to those who share their code and complied with the

Detailed winner results on test set

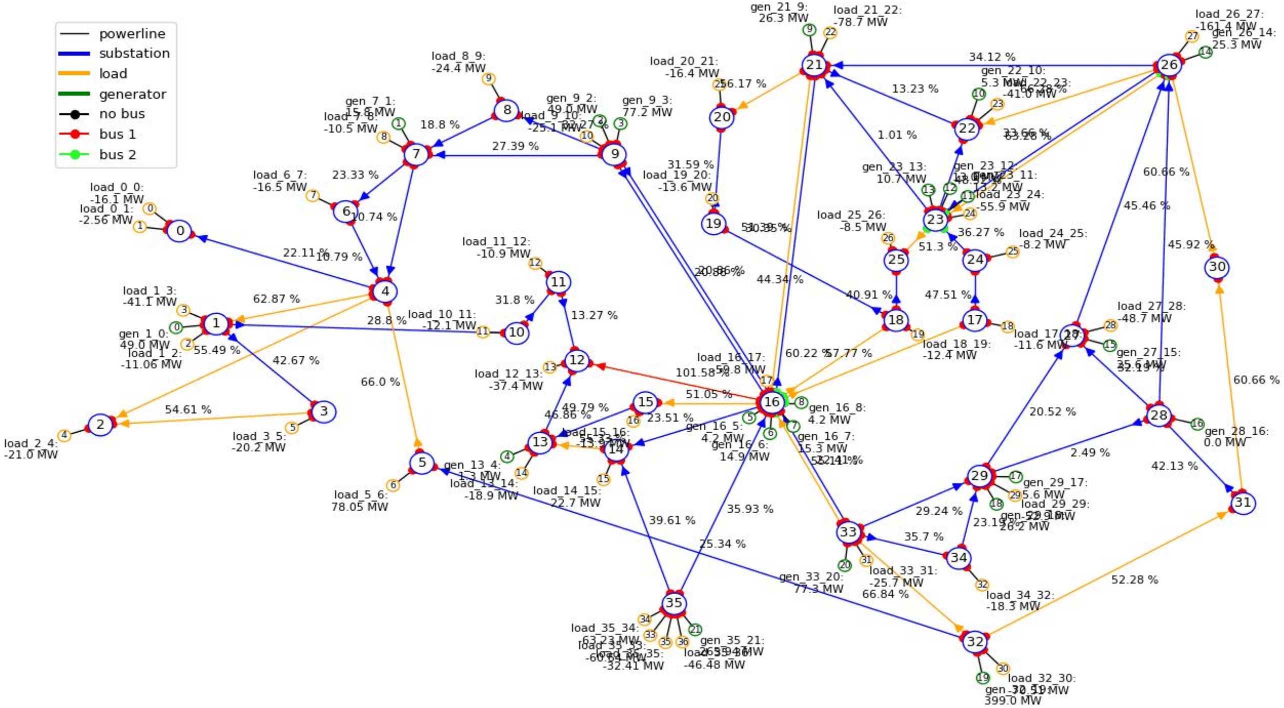
Do Nothing



Winner

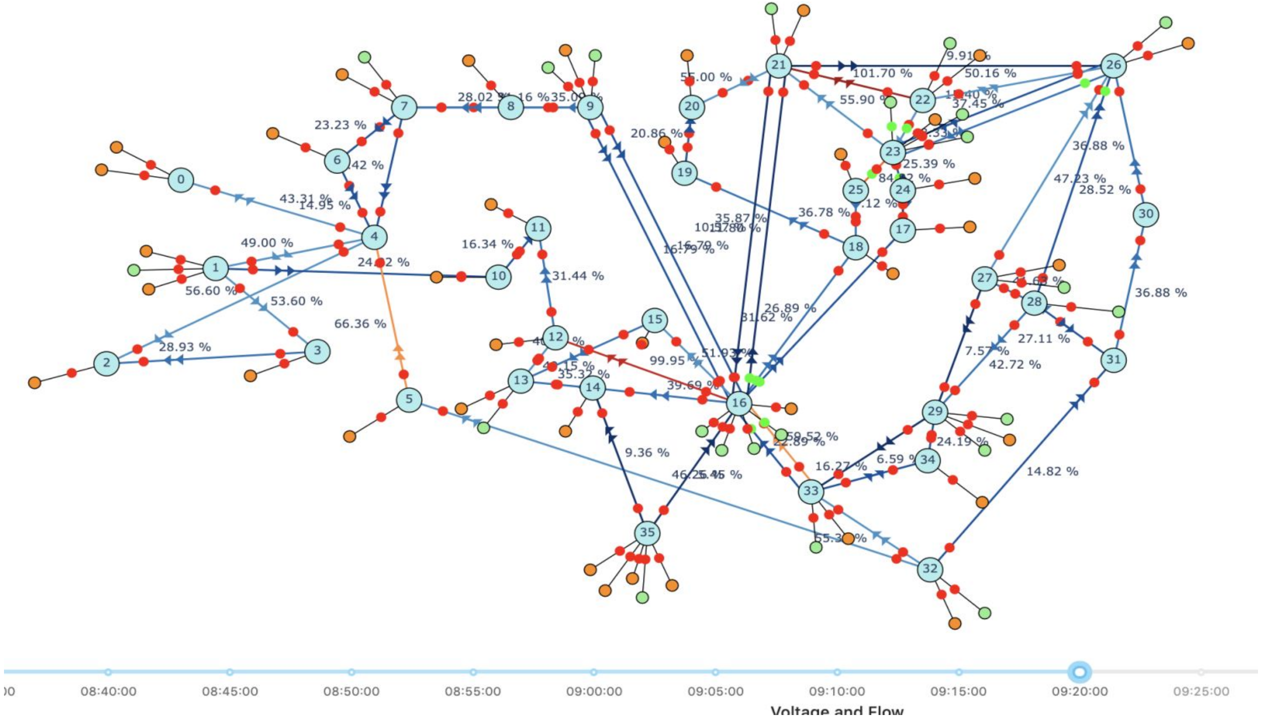


Smart but risky strategy



- When a line is overloaded, the agent disconnects its extremity before it gets disconnected automatically (=> it remains available)
- To avoid cooldown time, it uses the multiple ways to connect and disconnect lines

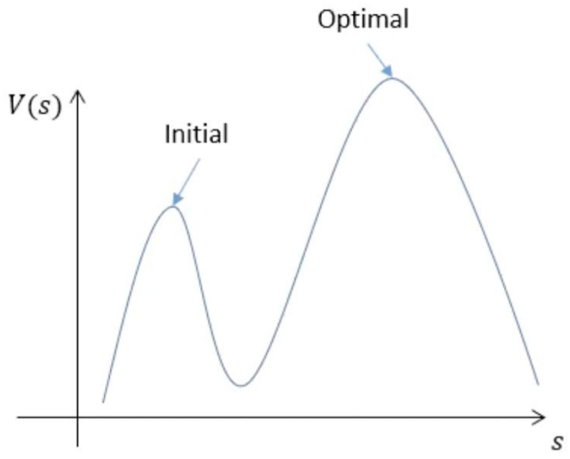
It learns interesting Topologies



Changing the topologies (in green) of 3 substations (16,23,26) leads to a robust grid topology

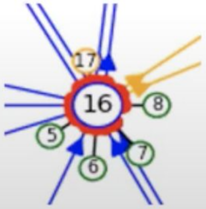
Challenges

- Exploration is difficult
    - Random agent can survive 5 steps on average.



- Initial topology is safe suboptimal
    - DoNothing agent can survive 500 steps on average.

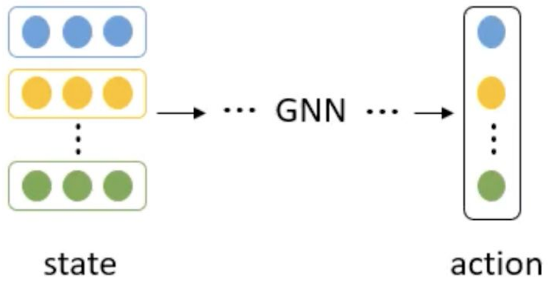
- Too many possible actions per step
    - Agent has to decide one of 134,199 possible actions.



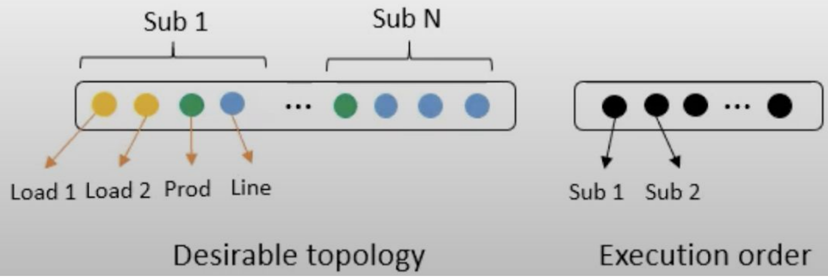
Naïve approach yields an agent that do only one or two specific actions.

Approach

- State – (177 × 6 × F)
  - We define a state as a graph.
  - Powerlines, loads, and prods are nodes of graph (177).
  - Each node contains active power, bus and so on (6).
  - We stack multiple frames (F).
  - We aim to keep graph structure as long as possible.



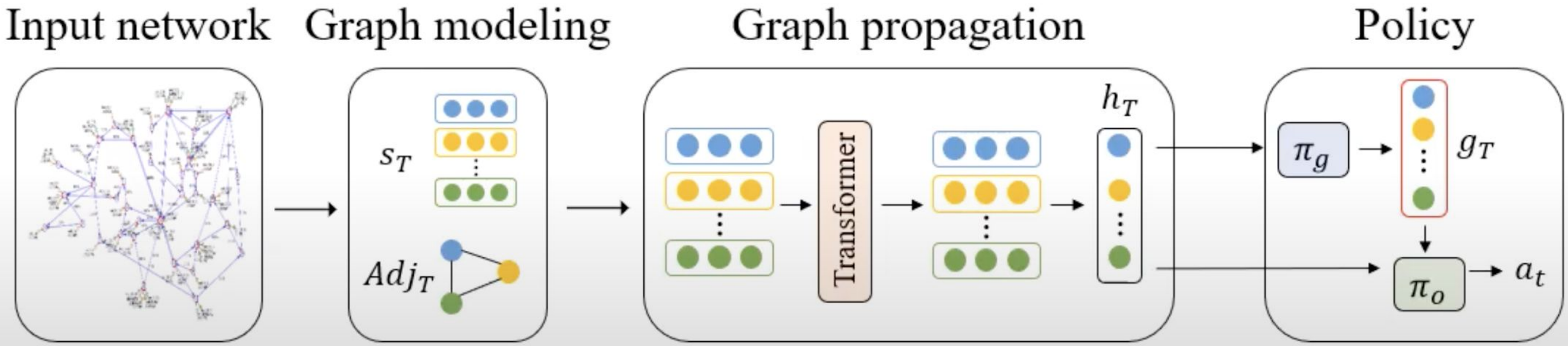
- Action – (127)
  - We define a goal action as **desirable topology** (108) and **execution order** (19).
  - Due to the symmetry, we fix the bus for the first node of each substation to 1.
  - The action which isolates the generator and load is not allowed.



Approach

- Overview

GNN + Transformer + SAC



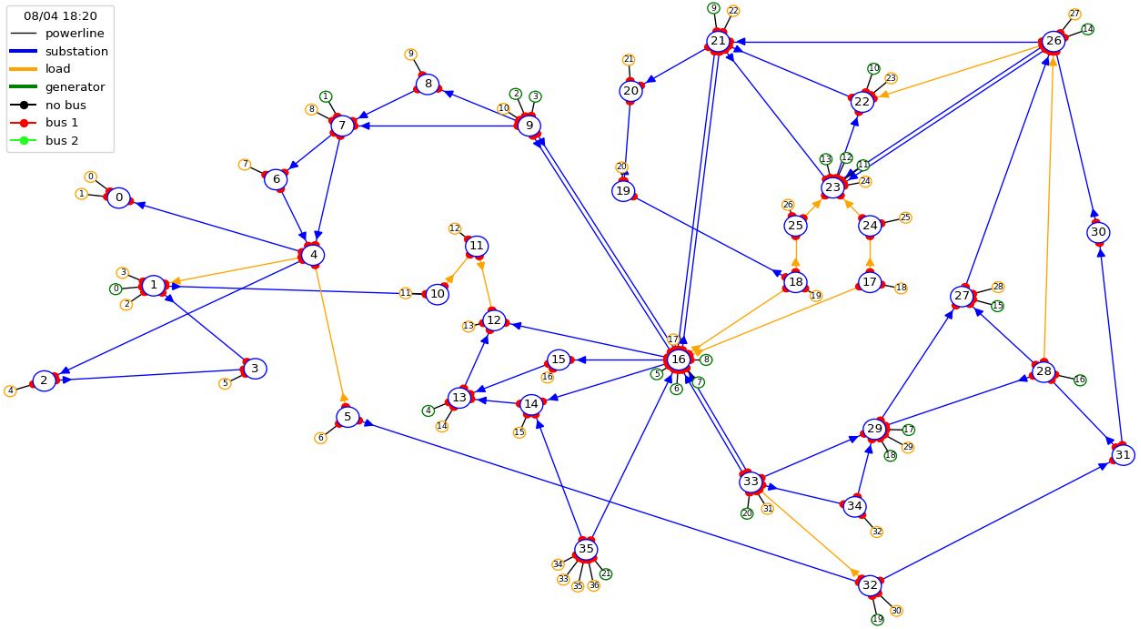
More at : https://l2rpn.chalearn.org/competitions#h.p_X7vG2_hacIL_

05

Join us now!

L2RPN NEURIPS 2020 - Robustness Track

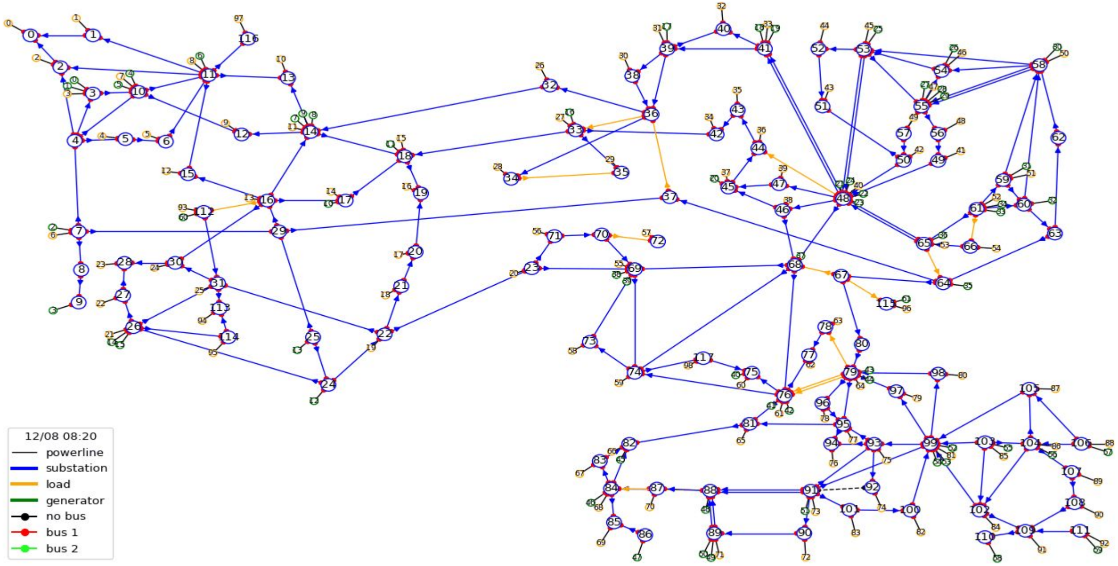
Develop your agent to be robust to unexpected events and keep delivering reliable electricity everywhere even in difficult circumstances.
You will have to **overcome an opponent attacks** and keep operating the grid safely.



https://competitions.codalab.org/competitions/25426

L2RPN NEURIPS 2020 - Adaptability Track

In this track, develop your agent to adapt to new energy productions in the grid with an increasing share of less controllable renewable energies over years. You are given a multi-mix environment, that is a set of environments with varying amount of **renewables (varying from 1x to 3x)**.



https://competitions.codalab.org/competitions/25427

Conclusions

1. Machine Learning approaches are promising for control problems and here showed to **generalize** better than Expert Systems

2. It is **now** possible to **learn topology controllers**, opening a new field for research and smart grid flexibilities.

3. Challenge **helps develop benchmarks** and enforce reproducibility to make faster and stronger progress as a community

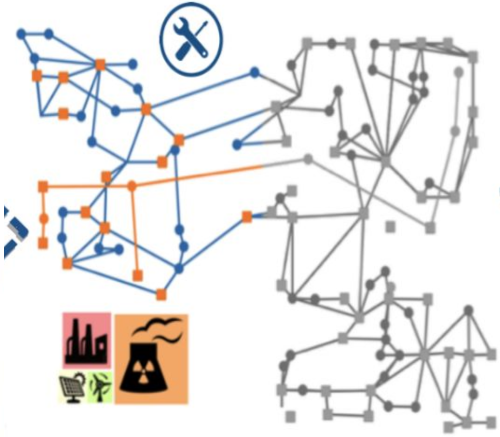
4. We should keep working on **attracting AI researchers** and collaborating with them on power system related problems

Ongoing L2RPN serie competitions

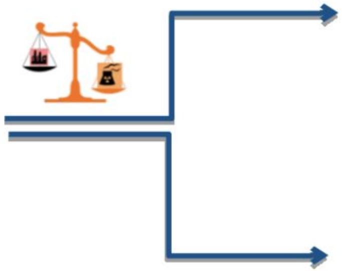
IJCNN Feasibility challenges

NeurIPS Sustainable World challenge

Spring 2020



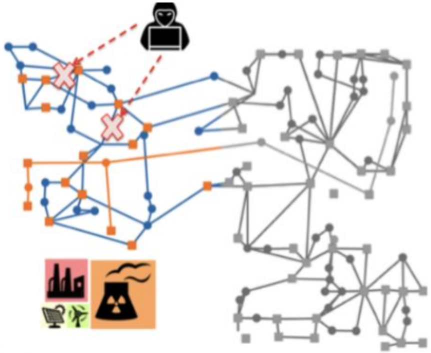
***Medium** Grid, **maintenance**,*
all year long, only topology



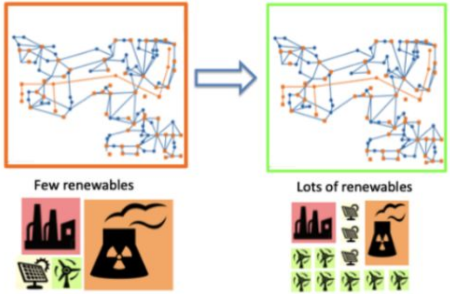
Robustness

Adaptability

Summer 2020



*Medium Grid, **adverserial attacks**,*
*Topology & **redispatching** actions*



***Large** Grid, **2 environments**,*
*Topology & **redispatching** actions*

Participate and join us!
https://l2rpn.chalearn.org/