Learning to Run a Power Network
Delft 2023

27 September 2023

L2RPN Delft
2023

Organized by Delft-AI-Energy Lab
## Talk

<table>
<thead>
<tr>
<th>Topic</th>
<th>Speakers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction and history of L2RPN</td>
<td>Jochen Cremer (TU Delft)</td>
</tr>
<tr>
<td>From L2PRN to the real grid – challenges we face as a TSO</td>
<td>Christian Merz (Elia Group)</td>
</tr>
<tr>
<td>Practical Challenges in AI Development for Real-World Congestion Management at TenneT</td>
<td>Davide Barbieri (TenneT)</td>
</tr>
<tr>
<td>Overview of winners of L2RPN 2023</td>
<td>Ali Rajaei (TU Delft)</td>
</tr>
<tr>
<td>Winner’s pitch and Industrial panel discussion (RTE, Elia, and TenneT) (zoom link)</td>
<td>Jochen Cremer (TU Delft)</td>
</tr>
<tr>
<td>- 3&lt;sup&gt;rd&lt;/sup&gt; team HybridAgent pitch (video link)</td>
<td>Anandsingh Chauhan (TCS)</td>
</tr>
<tr>
<td>- Q&amp;A with panel</td>
<td></td>
</tr>
<tr>
<td>- 2&lt;sup&gt;nd&lt;/sup&gt; team ACT SMART pitch (video link)</td>
<td>Pusen Dong (Beihang Uni)</td>
</tr>
<tr>
<td>- Q&amp;A with panel</td>
<td></td>
</tr>
<tr>
<td>- 1&lt;sup&gt;st&lt;/sup&gt; team BYZ-UCSC pitch (video link)</td>
<td>Shourya Bose (UC Santa Cruz)</td>
</tr>
<tr>
<td>- Q&amp;A with panel</td>
<td></td>
</tr>
</tbody>
</table>
Organizer team

Ali Rajaeei
PhD student
TU Delft

Geert Jan Meppelink
MSc student
TU Delft

Jochen Cremer
Assistant Professor
TU Delft

Benjamin Donnot
Data Scientist
RTE
Energy Transition
Energy Transition

To meet the net-zero carbon emission target and tackle Climate change

2020 ~ 10% solar+wind

2050 > 50% solar + wind
New actors & scales

Evolving grid

Operators will need to get assisted!
Artificial Intelligence (AI)

2013

2017

Soon?
Develop an AI-based Assistant for human operators

Make trusted remedial action recommendations

Line Overload to redispatch urgently
Learning to Run a Power Network (L2RPN) Competition

Test the potential of AI to robustly operate a power grid in real-time given operational constraints.
Learning to Run a Power Network (L2RPN) Competition

L2RPN competition series

Feasibility challenges

IJCNN 2019
WCCI 2020
Small Grid, no events, Winter month, only topology

WCCI 2020
Medium Grid, maintenance, all year long, only topology

NeurIPS 2020
Medium Grid, adversarial attacks, Topology & redispetching actions

ICAPS 2021
Ability to send timely alert in risk of failure

ICAPS 2021

Real-World challenges

Robustness
Trust

Large Grid, Multi Energy Mixes, Topology & dispatching actions

Battery
High renewable penetration, battery storage

WCCI 2022

For AI Startup...2023...

remake

L2RPN Delft 2023
Organized by Delft AI Energy Lab
Thank you for your attention!
<table>
<thead>
<tr>
<th>Talk</th>
<th>Speakers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction and history of L2RPN</td>
<td>Jochen Cremer (TU Delft)</td>
</tr>
<tr>
<td>From L2PRN to the real grid – challenges we face as a TSO</td>
<td>Christian Merz (Elia Group)</td>
</tr>
<tr>
<td>Practical Challenges in AI Development for Real-World Congestion Management at TenneT</td>
<td>Davide Barbieri (TenneT)</td>
</tr>
<tr>
<td>Overview of winners of L2RPN 2023</td>
<td>Ali Rajaei (TU Delft)</td>
</tr>
<tr>
<td>Winner’s pitch and Industrial panel discussion (RTE, Elia, and TenneT) (zoom link)</td>
<td>Jochen Cremer (TU Delft)</td>
</tr>
<tr>
<td>• 3rd team HybridAgent pitch (<a href="#">video link</a>)</td>
<td>Anandsingh Chauhan (TCS)</td>
</tr>
<tr>
<td>• Q&amp;A with panel</td>
<td></td>
</tr>
<tr>
<td>• 2nd team ACT SMART pitch (<a href="#">video link</a>)</td>
<td>Pusen Dong (Beihang Uni)</td>
</tr>
<tr>
<td>• Q&amp;A with panel</td>
<td></td>
</tr>
<tr>
<td>• 1st team BYZ-UCSC pitch (<a href="#">video link</a>)</td>
<td>Shourya Bose (UC Santa Cruz)</td>
</tr>
<tr>
<td>• Q&amp;A with panel</td>
<td></td>
</tr>
</tbody>
</table>
## PowerWeb L2RPN Session

**September 27, 14:00-15:15 CET, Delft X, Theater Hall**

### Talk

<table>
<thead>
<tr>
<th>Introduction and history of L2RPN</th>
<th>Jochen Cremer (TU Delft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From L2PRN to the real grid – challenges we face as a TSO</td>
<td>Christian Merz (Elia Group)</td>
</tr>
<tr>
<td>Practical Challenges in AI Development for Real-World Congestion Management at TenneT</td>
<td>Davide Barbieri (TenneT)</td>
</tr>
<tr>
<td>Overview of winners of L2RPN 2023</td>
<td>Ali Rajaei (TU Delft)</td>
</tr>
</tbody>
</table>

### Speaker's Schedule

**Winner’s pitch and Industrial panel discussion (RTE, Elia, and TenneT) ([zoom link](#))**

- **3rd team HybridAgent pitch** ([video link](#))
- **Q&A with panel**

- **2nd team ACT SMART pitch** ([video link](#))
- **Q&A with panel**

- **1st team BYZ-UCSC pitch** ([video link](#))
- **Q&A with panel**

**Panelists**

- **Anandsingh Chauhan (TCS)**
- **Pusen Dong (Beihang Uni)**
- **Shourya Bose (UC Santa Cruz)**
L2RPN Delft 2023 Environment

- IEEE 118-bus system.
- Observation space: more than 4,000
- Action space: more than 70,000

“l2rpn_wcci_2022” environment
Modeling of real-time operation decision making

**State:** flows, generations, demands, grid topology, etc

**Action:** re-dispatch or topology change

**Reward/cost function:** number of overflowed lines, cost,

... Participant design choice

**Score:** scaled to 100.

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

Time resolution considered: 5 minutes (human operators work with snapshots every 5 minutes)
L2RPN Delft 2023

• 90 registrations from around the world.
• 12 teams.
• 410 submissions.
Winner teams!

- 1\textsuperscript{st} place: €1500
- 2\textsuperscript{nd} place: €1000
- 3\textsuperscript{rd} place: €500
3rd Team: Hybrid Agent

- Members:
  - Anandsingh Chauhan
  - Dr. Mayank Baranwal

- Score: 42.44
2nd Team: ACT SMART

- Members:
  - Pusen Dong
  - Tianchen Zhu
  - Chang Liu
  - Yue Qiu
  - Haoyi Zhou
  - Yingying Zhao

- Score: 54.44 and 52.01
1st Team: BYZ-UCSC

- Members:
  - Shourya Bose
  - Qiuling Yang
  - Yu Zhang

- Score: 58.98
Thank you for your attention!
<table>
<thead>
<tr>
<th>Talk</th>
<th>Speakers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction and history of L2RPN</td>
<td>Jochen Cremer (TU Delft)</td>
</tr>
<tr>
<td>From L2PRN to the real grid – challenges we face as a TSO</td>
<td>Christian Merz (Elia Group)</td>
</tr>
<tr>
<td>Practical Challenges in AI Development for Real-World Congestion Management at TenneT</td>
<td>Davide Barbieri (TenneT)</td>
</tr>
<tr>
<td>Overview of winners of L2RPN 2023</td>
<td>Ali Rajaei (TU Delft)</td>
</tr>
<tr>
<td>Winner’s pitch and Industrial panel discussion (RTE, Elia, and TenneT) (zoom link)</td>
<td>Jochen Cremer (TU Delft)</td>
</tr>
<tr>
<td>• 3&lt;sup&gt;rd&lt;/sup&gt; team HybridAgent pitch (video link)</td>
<td>Anandsingh Chauhan (TCS)</td>
</tr>
<tr>
<td>• Q&amp;A with panel</td>
<td></td>
</tr>
<tr>
<td>• 2&lt;sup&gt;nd&lt;/sup&gt; team ACT SMART pitch (video link)</td>
<td>Pusen Dong (Beihang Uni)</td>
</tr>
<tr>
<td>• Q&amp;A with panel</td>
<td></td>
</tr>
<tr>
<td>• 1&lt;sup&gt;st&lt;/sup&gt; team BYZ-UCSC pitch (video link)</td>
<td>Shourya Bose (UC Santa Cruz)</td>
</tr>
<tr>
<td>• Q&amp;A with panel</td>
<td></td>
</tr>
</tbody>
</table>
From L2RPN to the real grid
Challenges we face as a TSO

27.09.2023 | Christian Merz
Agenda

1. Why do we need to optimize for grid topology?
2. Our approach
3. The challenges
4. Next steps
Elia Group: one of Europe’s top 5 TSOs

Elia Group is active in electricity transmission. It encompasses two leading TSOs strategically located in two European regions:

- Elia in Belgium
- 50Hertz in Germany

International consulting services

Connect to energy data and digital products via APIs

Accelerate development of offshore energy
1. Why do we need to optimize for grid topology?
Why do we need to optimize for grid topology?

Increasing redispatch costs

Volume and Cost for Congestion Management in Germany

In 2022 redispatch costs nearly doubled to 4,2 billion €.

Increasing grid complexity

Future epicenter of energy

Demand will follow generation

Prosumer centric
2. Our Approach
There is a strong need to find topological grid actions to resolve congestion in the grid and to lower redispatch costs.

Can we optimize for topological actions in the grid?

1. Proof of Concept
   „Advanced Analytics for Topology Optimization“ 2020-2022

2. Proof of Concept
   RL & optimized load flow solver approach (Q2 2023)

Together with InstaDeep™
Our goal is to work on the challenges that have been discovered during the first proof of concept phase.

- RL Demonstration of a test grid
- Requirements to implement RL for Congestion Management to Elia’s grid + first steps
- Analysis of potential use-cases for RL in Elia Group
From a topology optimizer different departments would benefit. In addition,

Elia Group

<table>
<thead>
<tr>
<th>Grid development</th>
<th>Operational Planning</th>
<th>(Close-to)-Realtime</th>
</tr>
</thead>
</table>

European level / TSO / academia

and probably many more.
3. The challenges
From L2RPN to the real grid – three main challenges need to be tackled

1. Show the potential of RL to the business
2. Get the real grid into the environment
3. Speed up load flow calculations
Grid2op / L2RPN – great starting point to demonstrate RL to the business but currently difficult to adapt to the Elia Group grids.
Data artifacts and inconsistent data make it difficult to set-up a RL environment

Requirements
- Load and generation data with sufficient critical situations
- A consistent number of elements between the timesteps
- Loaded into Pandapower

Data sources
- Elia Group tools: Integral (50 Hertz), PowerFactory (Elia), Pandapower
- The bnm_gridmodel_importer used to do the conversion to pandapower

CGMES Files
- Grid operation (DACF (50Hertz & Elia) (PowerFactory & AMICA exports)
- Test files

Pandapower
- VoltControl project files (Belgium)

Integral .dat files
- Grid Planning (50Hertz) Integral exports

Challenges
- Inconsistent numbers of elements
- AC load flow would not converge
- Converter would introduce artifacts
- Discovering new bugs in the converter
- Some elements not modelled in Pandapower
Speed up the load flow calculations to handle the big grid and enable various solving methodologies.
4. Next steps
Next steps

1. Start in October:
   - 50Hertz grid from grid planning

2. Milestone 1 in November:
   - Speed up power flow computation on DC for N-1
   - Create a baseline (search) for topology optimization

3. Milestone 2 in February:
   - Train and benchmark RL Agents
   - Transition to business

Partner/collaboration

- 1. Benchmark the costs
  - VS. redispatch + topology redispatch

- 2. Transfer of grid planning results to other use-cases
  - Grid op. planning
  - Grid operation
  - Coreso/ROSC
Summary

1. Why do we need to optimize for grid topology?
2. Our approach
3. The challenges
4. Next steps
Let’s get in touch and exchange!

Community of Practice

Christian Merz  
Data Scientist  
Christian.merz@eliagrou.eu
Practical Challenges in AI Development for Real-World Congestion Management at TenneT

PowerWeb L2RPN Session
Davide Barbieri (TenneT)
Control Room of the Future (CROF) Programme

Overview

- Established in Summer 2020
Control Room of the Future (CROF) Programme

Overview

• Established in Summer 2020
• Why?
  • Develop new (smart) functionalities to mitigate future risk
  • Congestion management given high priority
Control Room of the Future (CROF) Programme Overview

- Established in Summer 2020
- Why?
  - Develop new (smart) functionalities to mitigate future risk
  - **Congestion management** given high priority
- Main tracks
  - Congestion management project (**GridOptions tool**)
  - Forecasting project
  - Dynamic line rating
  - Etc...
Overview

Control Room of the Future (CROF) Programme

- Established in Summer 2020
- Why?
  - Develop new (smart) functionalities to mitigate future risk
    - Congestion management given high priority
- Main tracks
  - Congestion management project (*GridOptions* tool)
  - Forecasting project
  - Dynamic line rating
  - Etc...
- Goal
  - Embed available *SOTA* tools and technologies *within TenneT*
Control Room of the Future (CROF) Programme Overview

• Established in Summer 2020
• Why?
  • Develop new (smart) functionalities to mitigate future risk
  • **Congestion management** given high priority
• Main tracks
  • Congestion management project (**GridOptions tool**)
  • Forecasting project
  • Dynamic line rating
  • Etc...
• Goal
  • Embed available **SOTA** tools and technologies **within TenneT**
  • Develop/maintain some (smart) **functionalities in-house**
Control Room of the Future (CROF) Programme Overview

• Established in Summer 2020
• Why?
  • Develop new (smart) functionalities to mitigate future risk
  • *Congestion management* given high priority
• Main tracks
  • Congestion management project (*GridOptions tool*)
  • Forecasting project
  • Dynamic line rating
  • Etc...
• Goal
  • Embed available *SOTA* tools and technologies within TenneT
  • Develop/maintain some (smart) *functionalities in-house*
  • Build *R&D environment* to tailor solutions to TenneT’s needs
GridOptions Tool

Problem Setting

- TenneT uses loadflow simulations to
  - Assess congestion related risks
  - Determine possible remedial actions
GridOptions Tool

Problem Setting

- TenneT uses loadflow simulations to
  - Assess congestion related risks
  - Determine possible remedial actions

Redispatch
- Baseline optimization tooling available
- Costly
GridOptions Tool

Problem Setting

- TenneT uses loadflow simulations to
  - Assess congestion related risks
  - Determine possible remedial actions

Redispatch
- Baseline optimization tooling available
- Costly

Topological actions
- Solutions are thought of and evaluated by humans
- Currently not fully exploited
- Support tooling only for running simulations
GridOptions Tool

Problem Setting

- TenneT uses loadflow simulations to
  - Assess congestion related risks
  - Determine possible remedial actions

- Several stages for each given day
  - Currently GridOptions is focusing on start of ID
GridOptions Tool

Problem Setting

- TenneT uses loadflow simulations to
  - Assess congestion related risks
  - Determine possible remedial actions

- Several stages for each given day
  - Currently GridOptions is focusing on start of ID
GridOptions Tool
Problem Setting

- TenneT uses loadflow simulations to
  - Assess congestion related risks
  - Determine possible remedial actions

- Several stages for each given day
  - Currently GridOptions is focusing on start of ID
  - Goal is to move expand in other time-frames
GridOptions Tool
Overview

- Developing on sub-net (Groningen-Drenthe)
GridOptions Tool
Overview

• Developing on sub-net (Groningen-Drenthe)
  • Challenging region due to shortages
  • Increasing requested connections
  • More generation of renewable energy resources
  • Dynamic flow patterns
GridOptions Tool
Overview

• Developing on sub-net (Groningen-Drenthe)
  • Challenging region due to shortages
  • Increasing requested connections
  • More generation of renewable energy resources
  • Dynamic flow patterns
GridOptions Tool

Overview

- Developing on sub-net (Groningen-Drenthe)
  - Challenging region due to shortages
  - Increasing requested connections
  - More generation of renewable energy resources
  - Dynamic flow patterns

- Meant to aid not automate
  - Need trust
  - Need to be understandable
  - Contrast between users and business case

GridOptions Tool
Comparison to L2RPN problem

- Fully **rolled-out** solutions for entire day
  - Provide topology for **each time-step** of the day
  - (Currently) **lower time resolution**
GridOptions Tool
Comparison to L2RPN problem

- Fully **rolled-out** solutions for entire day
  - Provide topology for each **time-step** of the day
  - (Currently) **lower time resolution**

- Dynamic environment
  - Grid model constantly changing
GridOptions Tool
Comparison to L2RPN problem

• Fully *rolled-out* solutions for entire day
  • Provide topology for *each time-step* of the day
  • (Currently) *lower time resolution*

• Dynamic environment
  • Grid model constantly changing

• Multi-Objective
  • *Safety* of the network is important
  • *Reduce* the number of *topological changes*
  • Ideally switch only bus-bar couplers (remote)
GridOptions Tool
Comparison to L2RPN problem

• Fully **rolled-out** solutions for entire day
  • Provide topology for **each time-step** of the day
  • (Currently) **lower time resolution**

• Dynamic environment
  • Grid model constantly changing

• Multi-Objective
  • **Safety** of the network is important
  • **Reduce** the number of **topological changes**
  • Ideally switch only bus-bar couplers (remote)
  • Solutions must be **trusted/understood** by operators
  • Set of solutions
    • Allowing operators to have options

GridOptions Tool
Comparison to L2RPN problem

- Fully **rolled-out** solutions for entire day
  - Provide topology for each **time-step** of the day
  - (Currently) **lower time resolution**

- Dynamic environment
  - Grid model constantly changing

- Multi-Objective
  - **Safety** of the network is important
  - **Reduce** the number of **topological changes**
  - Ideally switch only bus-bar couplers (remote)
  - Solutions must be **trusted/understood** by operators
  - Set of solutions
    - Allowing operators to have options

GridOptions Tool
Comparison to L2RPN problem

- Fully **rolled-out** solutions for entire day
  - Provide topology for **each time-step** of the day
  - (Currently) **lower time resolution**

- Dynamic environment
  - Grid model constantly changing

- Multi-Objective
  - **Safety** of the network is important
  - **Reduce** the number of **topological changes**
  - Ideally switch only bus-bar couplers (remote)
  - Solutions must be **trusted/understood** by operators
  - Set of solutions
    - Allowing operators to have options

GridOptions Tool
Comparison to L2RPN problem

• Fully **rolled-out** solutions for entire day
  • Provide topology for **each time-step** of the day
  • (Currently) **lower time resolution**

• Dynamic environment
  • Grid model constantly changing

• Multi-Objective
  • **Safety** of the network is important
  • **Reduce** the number of topological changes
  • Ideally switch only bus-bar couplers (remote)
  • Solutions must be **trusted/understood** by operators
  • Set of solutions
    • Allowing operators to have options

Where do we want to go?
Dot in the Horizon

Marot A. et al, Perspectives on Future Power System Control
Centers for Energy Transition, 2022
TenneT R&D (at Digital & Data department)

Establishing a R&D environment

- CROF development requires a well-defined environment and wow

Viebahn J. et al, Potential and challenges of AI-powered decision support for short-term system operations, 2022
TenneT R&D (at Digital & Data department)
Establishing a R&D environment

• CROF development **requires** a well-defined environment and **wow**

• Bring research and development closer
TenneT R&D (at Digital & Data department)
Establishing a R&D environment

- CROF development **requires** a well-defined **environment and wow**
- Bring research and development closer
  - Research focused on real world data
  - Close the gap between idealistic and realistic problem constraints

Viebahn J. et al, Potential and challenges of AI-powered decision support for short-term system operations, 2022
TenneT R&D (at Digital & Data department)

Establishing a R&D environment

- CROF development requires a well-defined environment and wow

- Bring research and development closer
  - Research focused on real world data
    - Close the gap between idealistic and realistic problem constraints
  - Development with flexibility and modularity in mind
    - Keep track of SOTA
    - Reuse solutions

Viebahn J. et al, Potential and challenges of AI-powered decision support for short-term system operations, 2022
TenneT R&D (at Digital & Data department)

Establishing a R&D environment

- CROF development requires a well-defined environment and wow

- Bring research and development closer
  - Research focused on real world data
    - Close the gap between idealistic and realistic problem constraints
  - Development with flexibility and modularity in mind
    - Keep track of SOTA
    - Reuse solutions

- Data at the center
  - Want to test/deploy on real world data as much as possible
  - Difficult to share data

Viebahn J. et al, Potential and challenges of AI-powered decision support for short-term system operations, 2022
TenneT R&D (at Digital & Data department)
Establishing a R&D environment

• CROF development requires a well-defined environment and wow

• Bring research and development closer
  • Research focused on real world data
    • Close the gap between idealistic and realistic problem constraints
  • Development with flexibility and modularity in mind
    • Keep track of SOTA
    • Reuse solutions

• Data at the center
  • Want to test/deploy on real world data as much as possible
  • Difficult to share data
  • SOLUTION: data (format) agnostic platform
    • Easy to share on open-source data
    • Easy to test/tailor on TenneT data

Viebahn J. et al, Potential and challenges of AI-powered decision support for short-term system operations, 2022
Research Track
Overview

• Ongoing research collaborations
Research Track
Overview

• Ongoing research collaborations
  • GNN for Grid Control (German Funded Project)
Research Track
Overview

• Ongoing research collaborations
  • GNN for Grid Control (German Funded Project)
  • AI4RealNet (Horizon Europe Project)
Research Track
Overview

• Ongoing research collaborations
  • GNN for Grid Control (German Funded Project)
  • AI4RealNet (Horizon Europe Project)
  • Several MSc/PhD students @ TenneT focusing on
    • GNNs
    • MARL
    • MORL
Research Track
Overview

• Ongoing research collaborations
  • GNN for Grid Control (German Funded Project)
  • AI4RealNet (Horizon Europe Project)
  • Several MSc/PhD students @ TenneT focusing on
    • GNNs
    • MARL
    • MORL

• Literature
  • Viebahn J. et al 2022: Potential and challenges of AI-powered decision support for short-term system operations, CIGRE Paris session
  • Viebahn J. et al 2024: GridOptions Tool: Real-World Day-Ahead Congestion Management using Topological Remedial Actions, CIGRE Paris session
Thank you for your attention.