Intelligent Electrical Power Grids

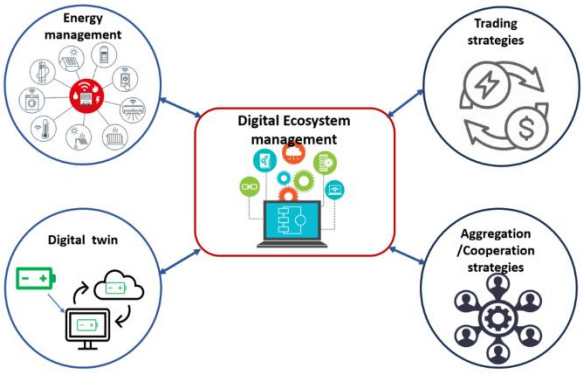
Collection of available MSc projects

April 2024

Areas covered:

- **Power system expansion**
- **Power system control**
- **Power system protection**
- **Power system transients**
- **Power system reliability**
- **Power electronics integration**
- **Integration of renewables**
- **Energy markets**
- **Multi-energy systems**
- **Co-simulations of energy systems**
- **Cyber-security of smart grids**
- **Big data analytics**

The Digital Ecosystem for Local Energy Communities



Scope: This project aims to develop the digital ecosystem for local energy communities (LECs). With the energy transition, the LECs represent a shift in energy management and distribution, promoting decentralized, sustainable, and community-centric approaches. The developing of the digital ecosystem for LECs can support the renewable energy integration, facilitate grater community engagement for the energy market and provide the flexibility for the future electricity grid. This topic covers broad aspects including Energy Management System (EMS) development, Digital Twin (DT) development, Aggregation/Cooperation strategies, and Trading strategies. This thesis will offer students the flexibility to choose and specialize in one of these key areas, analyzing its role, challenges, and potential within the context of LECs. Moreover, the students will have the opportunity to evaluate their system in the real-world setting at the ***24/7 Energy Hub at the Green Village.***

Problem definition and Objectives: The core problem addressed by this project is optimizing and advancing the digital ecosystem of LECs. This project seeks to understand how these diverse areas can individually and collectively contribute to the efficiency, sustainability, and resilience of LECs and how the system could be built to have the flexibility to hold all these diverse areas. The objectives of this topic include: 1) conducting a comprehensive analysis of the digital ecosystem for LECs. 2) exploring and proposing innovative solutions and strategies for enhancing effectiveness of LECs. 3) evaluating the potential impact of these solutions on the overall performance and sustainability of LECs.

Methodology: The research will be initiated with an extensive literature review to establish a foundational understanding of each aspect within LECs. The foundational protocol of the Digital ecosystem is already built and it can support further development. Following this, students can choose their focus area and adopt a methodology appropriate for their selected area (Energy Management System (EMS) development, Digital Twin (DT) development, Aggregation/Cooperation strategies, or Trading strategies). This will include quantitative methods such as data analysis, simulations and/or modeling. The project benefits from synthesizing insights from diverse fields such as energy management, computer science and energy markets. The approach will be designed to deeply investigate the chosen area while contributing to the broader understanding of LECs' digital ecosystems.

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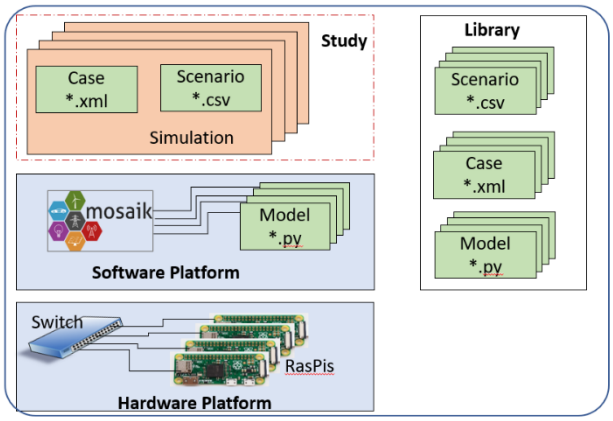
The Illuminator – energy system integration development kit

Scope: This project aims to demystify energy system operations and to improve energy system integration by creating an easy-to-use energy system integration development kit. This development kit is used to educate students on energy system integration questions, to illustrate challenges of the energy transition to a broader community, and to test new concepts, particularly real-time and non-real-time energy coordination algorithms.

The kit: The Illuminator kit emulates the energy system and the electricity grid. It is powered by Raspberry Pis that can be configured into a low to medium-fidelity scaled-down version of the real-world electricity grid. In our design, we have selected to interconnect RasPis with Ethernet cables via a switch. This approach was selected to ensure scaling to dozens of RasPis as it handles communication and power supply via the same cable. The Illuminator software platform is largely based on Mosaik that synchronizes the simulation process against a global time clock and manages the data exchange between the simulators.



Challenge: Your project would focus on the further *development* of the Illuminator 2.0 (version 1.0 already exists https://github.com/Illuminator-team/Illuminator). Possible additions and extensions to focus on could be the development of new case studies, the investigation of scalability, the design of the Graphical User Interface, the design of various algorithms on coordination in energy systems.

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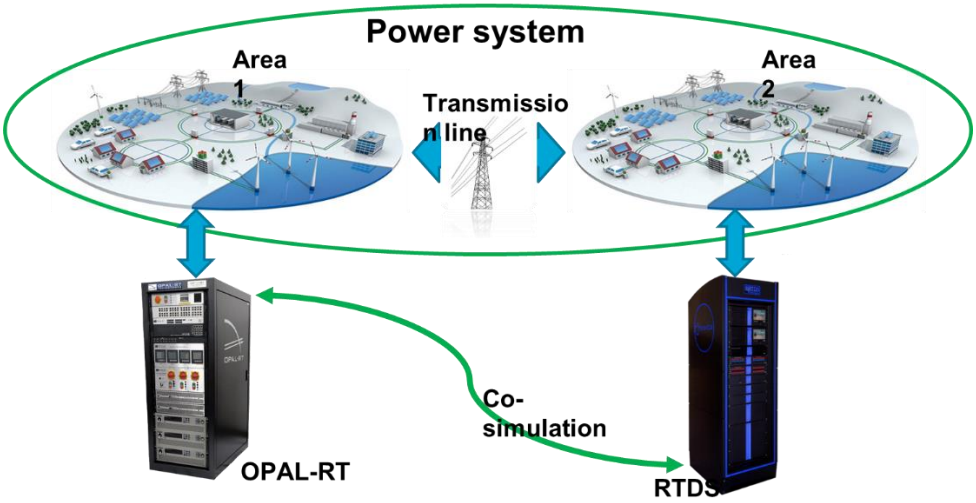
Power-hardware-in-the-loop control of the MMC



Scope: This thesis project will focus on the design of the power-hardware-in-the-loop setup for the control of the physical MMC. This work will connect the RTDS devices used for the emulation of the transmission network, with the physical MMC, controlled via OPAL-RT. The connection will be established using Aurora protocol, and amplifier.

Problem definition: The integration of renewables in power systems requires the extensive use of power electronics. To ensure the stable operation of the so-called hybrid power system, power converters should be properly tested for operation in a real-time simulation environment.

Methodology: You will analyze the literature and implement HIL connection for real-time EMT simulation. Then, you will develop a new control approach that interacts with the simulator and MMC. Subsequently, you will demonstrate the MTDC control approach for DC voltage and power to ensure stable operation of the MTDC power system that can actively and effectively respond to disturbances.

You will perform simulations in the real-time EMT simulation tool RSCAD, and OPAL-RT, and work on the physical connection between these two real-time simulation tools.

Research objectives:

- Design a physical connection between RTDS and OPAL-RT.
- Design of the control for the physical MMC.
- Test the developed algorithms using the PHIL setup including RTDS, amplifier, OPAL-RT, and MMC.

Industry relevance/partner: You will get experience in RTDS/RSCAD, and OPAL-RT/MATLAB.

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Learning for controller tuning of the Multi-terminal HVDC electrical grid

Scope: Your project will focus on the design of a stable control method for the multi-terminal HVDC-based (MTDC) power system. The control will be designed as a combination of linear approaches with artificial intelligence (AI) to improve reliability and robustness, e.g. combining reinforcement learning. Namely, the idea is to learn how to tune properly the classical proportional-integral (PI) controller.

Problem definition: The penetration of renewables in power systems requires the use of power electronics. There is a need for an Electro-Magnetic Transient (EMT) simulation tool that will be publicly available and suitable for the simulation of the power systems of the future.

Methodology: You will analyze the literature to then choose a suitable bipolar Multi-Terminal DC (MTDC) topology that you implement for real-time EMT simulation. Then, you will develop a new control approach that interacts with the simulator. Subsequently, you will analyze the literature for reinforcement learning in PI control. Finally, you will design the MTDC control approach for DC voltage and power to ensure stable operation of the MTDC power system that can actively and effectively respond to disturbances.

You will implement codes for AI in Python and perform simulations in the real-time EMT simulation tool RSCAD.

Research objectives:

- Design a bipolar MTDC using a real-time simulation tool.
- Design of the control for the hybrid power system using AI.
- Test the developed algorithms using the real-time simulation tool RTDS/RSCAD.

Industry relevance/partner: You will get experience in circuit theory, control, modeling, and simulation. You will get experience in RTDS/RSCAD and Python.

Contact details:

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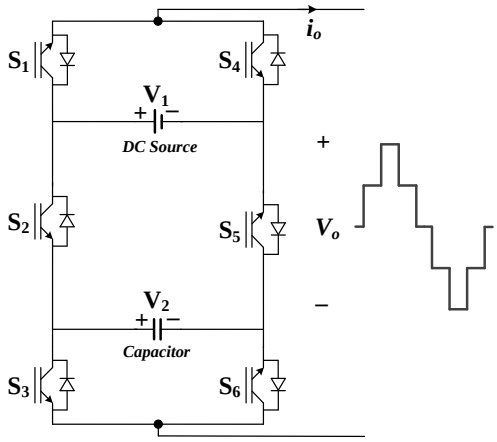
Advanced Control Design for PUC5 Converter



Scope: Multilevel inverters are widely used in industries for higher power applications due to low harmonic pollution and high efficiency. On the other hand, due to their complex structure and having more switches and DC links, their control is a matter of concern. Moreover, not too many advanced controllers have been yet designed on multilevel inverters due to complexity at a higher number of levels and difficulty in voltage balancing of those auxiliary capacitors. In this project, the 5-level Packed U-Cell inverter (PUC5) will be investigated to design and implement finite control set (FCS) model predictive control (MPC). The developed technique will be implemented on the real-time simulator and hardware setup.

Problem definition: Developing advanced controller FCS-MPC algorithms with integrated voltage balancing for the PUC5 inverter.

Methodology: A literature review will be done on multilevel inverters, especially PUC5. Afterward, different controllers with an integrated voltage balancing technique will be developed for the PUC5 inverter and rectifier modes of operation and simulated in MATLAB or PLECS. Hardware-in-the-loop (HIL) and rapid control prototyping (RCP) will be done using Plecs RT-Box or Opal-RT devices.

Research objectives:

- Performing a literature review on multilevel inverters and their applications in industry.
- Developing and applying advanced controller techniques with an integrated voltage balancing on the PUC5 inverter and rectifier.
- Simulation and experimental test of the developed algorithm in the lab.

Industry relevance/partner: You will get experience in working with PUC5 produced by dcbel (https://www.dcbel.energy/puc5/), OPAL-RT or Plecs RT-Box.

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Operation and control of the HVDC-HVDC converter in the Multi-terminal HVDC electrical grid

Scope: The multi-terminal HVDC electrical grid has no standardization up-to-date. Current predictions suggest the use of two HVDC levels ±320 kV and ±525 kV. To achieve the bidirectional power flow and connection between different rating HVDC electrical grids, the HVDC-HVDC converter will be necessary. This converter will ensure better controllability and higher robustness of the multi-terminal connection.

Problem definition: Analyze the operation of the HVDC-HVDC, examine its operation within the HVDC electrical grid, and design the control for the HVDC-HVDC converter.

Methodology: A literature review will be done on modular multilevel converters (MMCs) for the design of HVDC-HVDC converters. Furthermore, the converter will be implemented in the real-time simulation tool RSCAD/RTDS, and its operation within the HVDC electrical grid will be examined. Afterward, different controllers will be implemented for the HVDC-HVDC converter to achieve its robust and reliable operation.

Research objectives:

- Performing a literature review on HVDC-HVDC converters and their applications in industry.
- Developing and applying advanced controller techniques with an integrated voltage balancing on the PUC5 inverter and rectifier.
- Test the developed algorithms using the real-time simulation tool RTDS/RSCAD.

Industry relevance/partner: You will get experience in RTDS/RSCAD and Python.

Contact details:
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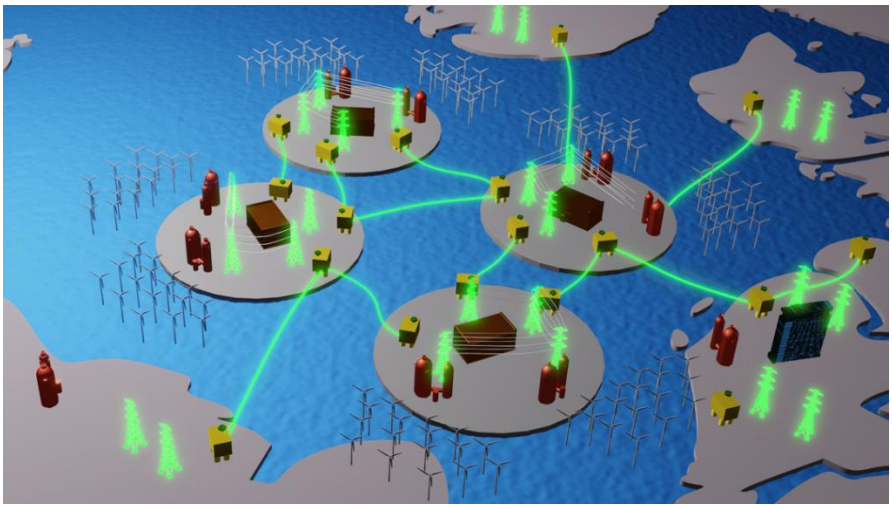
Application of AI in the control of multi-terminal HVDC power systems



Scope: Your project will focus on the design of a stable control method for the multi-terminal HVDC-based (MTDC) power system. The control will be designed as a combination of linear and nonlinear control approaches with artificial intelligence (AI) to improve reliability and robustness, e.g. combining reinforcement learning and fuzzy control.

Problem definition: The integration of renewables in power systems requires the extensive use of power electronics. To ensure the stable operation of the so-called hybrid power system, power converters should operate in a top-down configuration, where one converter ensures stable DC voltage and the other converters ensure stable active and reactive AC power.

Methodology: You will analyze the literature to then choose a suitable bipolar Multi-Terminal DC (MTDC) topology that you implement for real-time EMT simulation. Then, you will develop a new control approach that interacts with the simulator. Subsequently, you will analyze the literature for reinforcement learning in (model-predictive) control approaches and compare it with standard control approaches. Finally, you will design the MTDC control approach for DC voltage and power to ensure stable operation of the MTDC power system that can actively and effectively respond to disturbances.

You will implement codes for AI in Python and perform simulations in the real-time EMT simulation tool RSCAD.

Research objectives:

- Design a bipolar MTDC using a real-time simulation tool.
- Design of the control for the hybrid power system using AI.
- Test the developed algorithms using the real-time simulation tool RTDS/RSCAD.

Industry relevance/partner: You will get experience in RTDS/RSCAD and Python.

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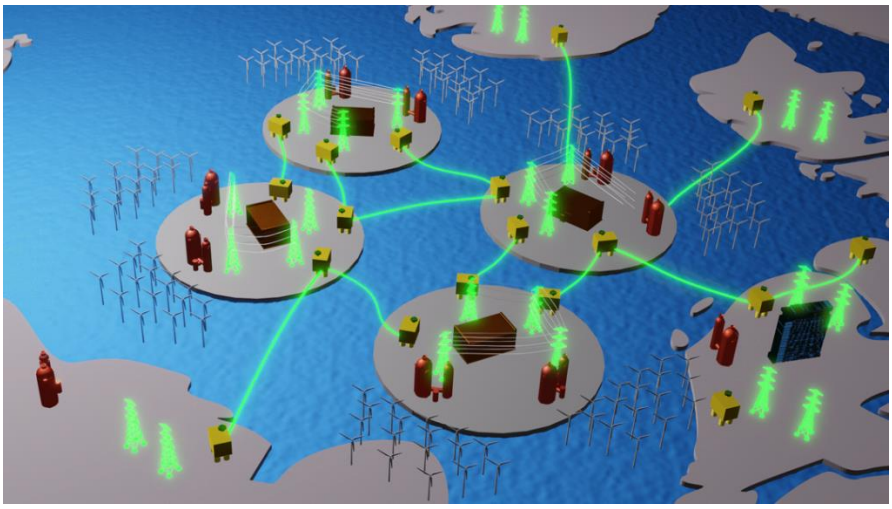
Leveraging AI to determine Grid Strength in Power Systems



Scope: Your project will focus on evaluating grid strength during the implementation of grid-following and grid-forming control methods for converter-interfaced generators providing ancillary support in power systems. Subsequently, artificial intelligence (AI) will be employed to analyze network data generated across various scenarios to derive the grid's strength.

Problem definition: The integration of renewables in power systems requires the extensive use of power electronics. To ensure the stable operation power converters should provide ancillary i.e. frequency and voltage support. There is a need to re-define the grid stability parameterization apart from the short circuit power. AI can play a significant role in deriving grid strength by analyzing vast amounts of data and thus predicting potential issues.

Methodology: You will analyze the literature to then determine grid strength parameterization in a network with converter interfaced generators with grid forming and following control. The network you will implement in real-time EMT simulator. You will develop ancillary control schemes for grid support for the converters. Finally, using this network you will generate data for different scenarios. This data will be used in deriving grid strength using AI techniques that will help the operator to effectively respond to the grid in response to disturbances or failures. You will implement codes for AI in Python and perform simulations in the real-time EMT simulation tool RSCAD.

Research objectives:

- Design of the Grid forming and Grid following control providing Ancillary support for the power system.
- Derive Grid strength parameterization to study the effect of converters using AI.
- Test the developed algorithms using the real-time simulation tool RTDS/RSCAD.

Industry relevance/partner: You will get experience in RTDS/RSCAD and Python.

Contact details: Supervisors: Aleksandra Lekić (A.Lekic@tudelft.nl),
Rashmi Prasad (R.Prasad@tudelft.nl).

Validation and compliance of grid-forming converters

Scope: It is of utmost importance to identify methods of integrating large portions of renewable sources without causing stability problems in the power system. To this date, most converter-based systems operate on a grid-following (GFL) principle where a phase-locked loop (PLL) is used to align with the grid voltage at the point of common coupling (PCC) of the converter. Thus, it "follows" the measured voltage by aligning and using the measured voltage as a reference. However, to be capable of supporting the operation of the AC power system under normal, disturbed, and emergency states without having to rely on services from synchronous generators, Grid forming (GFM) type converter-based systems are required.

Problem definition: Multiple grid operators and regulators have published their own set of requirements for the grid-forming capabilities. The objective of this master's thesis is to investigate the core capabilities of grid-forming converters and demonstrate compliance through simulation models.

Methodology: You will analyze the measured field data in control hardware-in-the-loop setting in different operation scenarios, and both for harmonic and time domain simulation. Depending on the chosen approach, the thesis can include clustering, ML, etc.

Research objectives:

- Extensive review of core capabilities required from a grid-forming converter-based resource in different regions like the US, UK, Australia, EU, etc.
- Development of metrics, methods, and simulation models to demonstrate compliance with the identified GFM capabilities. For example, quantification of contribution to system strength or system inertia, damping, etc. provided by the GFM unit.
- Benchmarking of converter models in RMS and EMT domains for different studies.

Industry relevance/partner: You will get experience working in the company DNV.

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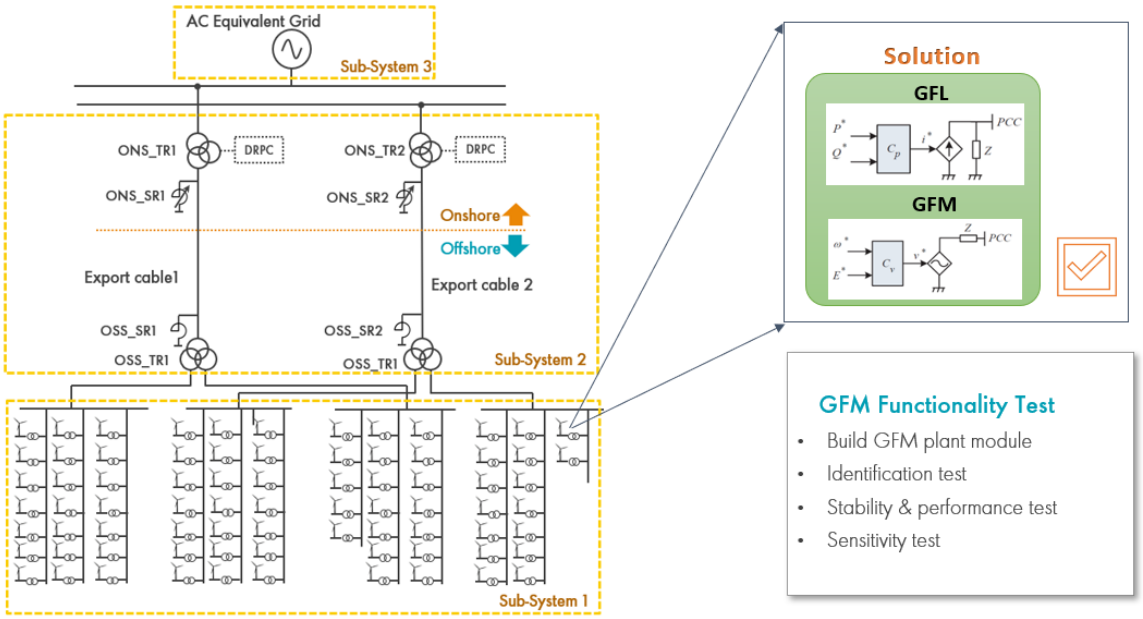
Stability analysis of offshore wind farm based on GFM technology



Scope: Grid-forming (GFM) technology has drawn much attention recently due to its supreme grid connection performance especially when connected to a weak grid – compared to its counterpart grid-following (GFL) technology. The stability performance evaluation plays a crucial role in the grid connection process. This project is a joint industry task with Shell that aims at conducting a stable performance of an offshore wind farm (OWF) based on GFM technology. It will include both time-domain and frequency-domain analysis and a sensitivity analysis based on different proportions of GFM and GFL will also be carried out.

Problem definition: Conduct stability analysis for GFM-based OWF including both time domain and frequency domain analysis, the study will be mainly conducted with PSCAD EMT study.

Methodology:

Step 1: Perform frequency sweep at the GFM converter level and power park level, and accordingly analyze its frequency domain difference to the GFL counterpart.

Step 2: Conduct time-domain stability analysis for GFM OWF, for example: various voltage dip at POI (point of inter-connection) of OWF; N-0 system intact, N-1 contingency scenarios.

Step 3: Conduct frequency domain stability analysis.

Step 4: Perform a sensitivity test with different proportions of GFL and GFM integration to OWF.

Research objectives: Conduct time domain and frequency domain stability analysis for GFM-based OWF.

Industry relevance/partner: You will get experience working in the company Shell.

Contact details: Supervisors: Aleksandra Lekić (A.Lekic@tudelft.nl),
Dan Wu (dan.d.wu@shell.com).

Modeling and analysis of battolyser electric power system

Scope: Affordable hydrogen from renewable sources is expected to account for 20% of Europe's energy system by 2050. Electricity is the dominant cost in the levelized cost of hydrogen. Trading power in volatile power markets and producing hydrogen using low-cost power at high efficiency reduces the overall electricity cost the most. The lower the cost of hydrogen, the more economical and faster the energy transition. Battolyser's innovative technology consists of an integrated battery and electrolyzer. It can be charged up to a certain level and then produce hydrogen. On the other side, it can be discharged as a battery and send energy back to the grid. Therefore, it can be considered a bidirectional battery/electrolyzer system. The electrical system is fed from a 400V AC grid and then connected to an AC/DC rectifier to supply DC voltage for the 1MW Battolyser unit, consisting of 4 250kW stacks. This project aims to model the electric power system of a 1MW Battolyser unit connected to the grid, considering its bidirectional power flow. Afterward, different analyses, such as grid reduction, harmonic performance, voltage/current ripple effect, etc., will be analyzed.

Methodology: A detailed study of the Battolyser technology will be done to learn how it works in connection with the grid. The company gives the electrical model of the Battolyser unit, and then its connection to the grid will be modeled in Matlab/Python. This includes the grid from a 1MW transformer, bidirectional converters, and the Battolyser stacks. Having the model ready, different analyses will be performed according to the company's needs, such as the voltage/current ripple effect of the Battolyser units, harmonic performance, grid fluctuations, etc. A digital twin of this system will also be created to run in real-time.

Research objectives:

- Understanding the Battolyser hydrogen production system.
- Modeling a whole Battolyser electric power system and studying the different conditions on that, such as grid fluctuations, voltage/current ripples, and harmonic performance.
- Delivering a digital twin model of the system with real-time operation.

Industry relevance/partner: You will get experience working in the company Battolyser Systems.

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Battolyser Systems

Development of an Impedance-Based Software Tool for Small-Signal Stability Modeling in HVDC Systems

Scope: This thesis aims to develop a dedicated software tool for small-signal stability screening in High Voltage Direct Current (HVDC) systems using an impedance-based approach implemented in C++. The tool will analyze the influence of active and passive components across a wide frequency range on the overall stability of the system.

Problem Definition: The rapid integration of power electronic-based active power components, especially Modular Multilevel Converters (MMCs), into HVDC systems poses challenges to system operation and stability. Existing stability analysis methods are insufficient to assess the interactions of converter controllers over an extended frequency range. Consequently, there's a demand for a specialized software tool capable of efficiently conducting small-signal stability screening while considering both active and passive network components.

Methodology: The methodology involves a careful examination of passive and active components in C++ to facilitate efficient small-signal stability screening in HVDC systems. The goal is an integrated cohesive code, creating a resilient software tool. Testing and refinement ensure the tool's accuracy and reliability. The overarching objective is to deliver a valuable solution for assessing stability in contemporary power systems.

Research Objectives: This thesis aims to:

- Translating mathematical models of passive and active components in C++, accounting for frequency-dependent behavior and converter controls.
- Designing algorithms and techniques to ensure efficient small-signal stability screening and swift system performance checks.
- Validating the software tool through simulation studies and benchmarking against existing methods and tools.

Industry Relevance/Partnership: This research has significant relevance to the power systems industry, especially in advancing HVDC technology. Collaboration with industry partners, TenneT and Swissgrid, and with open-source NGO Cresym, will provide valuable insights and validation opportunities.

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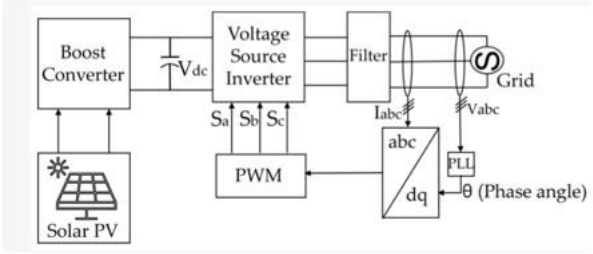
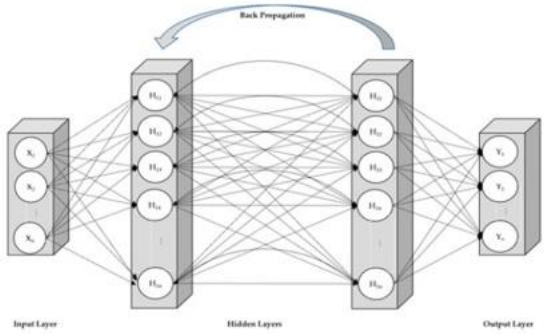
Impedance Identification in New Energy Grid-Tied Inverter Systems Using Long Short-Term Memory (LSTM) Networks





Scope: This thesis investigates the application of LSTM networks as an alternative method for impedance identification in new energy grid-tied inverter systems. The research aims to explore the capabilities of LSTM networks in capturing the complex dynamics of grid-tied inverters and accurately predicting impedance values based on voltage and current data.

Problem Definition: The interaction between grid-tied inverters and the power grid often leads to stability issues, necessitating accurate impedance identification for effective system analysis and control. Traditional impedance modeling methods may struggle to capture the dynamic behavior of grid-tied inverters, highlighting the need for alternative approaches like LSTM networks.

Methodology: The proposed methodology involves collecting time-series voltage and current data from new energy grid-tied inverter systems. LSTM networks will be designed and trained using this data to learn the underlying patterns and relationships between input signals and impedance values. The trained networks will then be utilized for impedance identification tasks, providing a novel approach to address stability issues in grid-tied inverter systems.

Research Objectives: Assess the feasibility and effectiveness of using LSTM networks for impedance identification in new energy grid-tied inverter systems.

- Design and implement LSTM network architectures tailored for capturing the complex dynamics of grid-tied inverters.
- Train LSTM networks using real-world voltage and current data to predict impedance values accurately.
- Evaluate the performance of LSTM-based impedance identification against traditional methods, such as analytical impedance modeling and neural network-based approaches.

Industry Relevance/Partnership: Collaboration with industry partners will ensure the relevance of the research to real-world challenges in power system stability analysis. By exploring LSTM networks as an alternative approach for impedance identification, this research aims to contribute to advancements in grid integration of renewable energy sources and enhance the stability of power systems.

Contact details:

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Optimal Meter Placement and Probabilistic State Estimation in Medium Voltage Distribution Networks for Control Room of the Future

Scope: This project will focus on the development of algorithms for (i) determining the optimal locations for placement of meters and (ii) using their data and pseudomeasurements for probabilistic state estimation in Medium Voltage (MV) distribution networks for Control Room of the Future (CRoF). This is a joint MSc thesis project run by TU Delft and Technolution & Phase to Phase.

Problem definition: In present medium voltage networks the electrical quantities are measured only at a limited number of points (typically transformer stations and some essential links). Due to the introduction of renewable energy sources the power flows in these networks become more volatile and the state estimation starts to form a significant problem. Algorithms must be developed in order to determine optimal locations for placement of meters and at the same time limit their number (related to the financial costs for distribution network operators). Traditional state estimation algorithms determine the network state which has the maximum likelihood. However, since significant amount of pseudomeasurements (fictive measurements) must be introduced to limit the number of metering devices, it is also important to determine the range, in which network variables (voltages, currents and powers) can potentially change, and probabilities related to potential under-/overvoltages and overloadings.

Research objectives:

- Develop an algorithm for optimal meter placement in MV distribution networks.
- Perform probabilistic state estimation for CRoF with a minimum number of available measurements, bad measurement data and false data injected by cyber attacks.
- Implement, test and validate the developed algorithms in CRoF using Vision Network Analysis and Gaia Low Voltage (LV) Design software and measurements available from distribution network operators.

Industry partner: This MSc thesis project is part of the Control Room of the Future research programme between TU Delft, Technolution and Phase to Phase. An internship with Phase to Phase on this topic might be possible beforehand. The results of this research will be applied in practice by Dutch distribution network operators.

Contact details: Daily supervisor Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl), Industry Supervisor: Dr. Anton Ishchenko (anton.ishchenko@phasetophase.nl), Chair: Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl)

Fault Localization for LV Network Management from Control Room of the Future

Scope: This project will focus on the development and implementation of a fault place localization algorithm for the management of low voltage networks from Control Room of the Future (CRoF). This is a joint MSc thesis project run by TU Delft and Technolution & Phase to Phase.

Problem definition: Technolution has developed an embedded sensor platform for analysis of the low-voltage networks. The sensor platform is called LV-Sensor and it contains a powerful microprocessor and 4 ADC channels, each with a sampling frequency of 20 kHz. On the LV-Sensor platform, Technolution & Phase to Phase implement various algorithms for the management of the low-voltage networks. In the context of this MSc thesis, the aim is to detect short circuits (faults) and calculate the exact location of the short circuit (fault place localization).

Research objectives:

- Develop an algorithm for detecting short circuits,
- Calculate the fault location from preloaded network information,
- Implement the algorithm and test it in the Control Room of the Future.

Industry partner: This MSc thesis project is part of the Control Room of the Future research programme between TU Delft, Technolution and Phase to Phase. An internship with Technolution and Phase to Phase on this topic might be possible beforehand. The results of this research will be applied in practice by Dutch distribution network operators.

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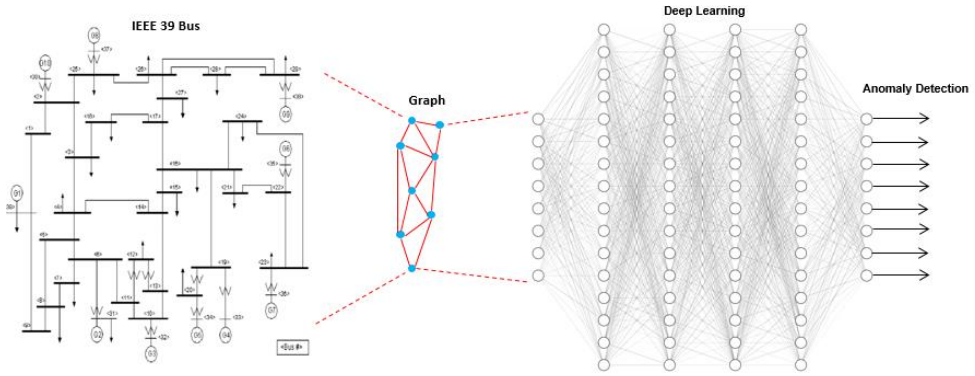
Power System Anomaly Detection and Correlation under Cyber Attack Scenarios



Scope: The scope of this MSc thesis project is to develop cyber-physical anomaly detection and correlation for power systems under cyber attack scenarios. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: Electrical power grids are critical infrastructures that are vulnerable to cyber attacks. The resilience and cyber security of the power grid have become recognized challenges for power system operation and the security of supply. Current research is mainly focused only on either cyber or physical anomalies, and not their combination. Hence, this thesis project aims to detect anomalies in power systems as spatio-temporal phenomena, correlated with cyber attacks.

Methodology: In this project, the main challenge is to detect anomalies in power grids caused by cyber attacks. Hence, you will simulate both power system and cyber IT-OT infrastructure. The physical power system is modeled in DIgSILENT PowerFactory, based on standard IEEE test systems, e.g., the IEEE 39-bus system. The cyber IT-OT infrastructure and communication within substations and to the control center run on Mininet. Simulated data from the power system is then observed as spatio-temporal data from a SCADA database. You will apply spatio-temporal analysis to this data to detect anomalies using artificial intelligence methods such as Graph Neural Network (GNN), Convolutional Neural Network (CNN), and Long Short-Term Memory (LSTM). The detected anomalies are then correlated with the simulated cyber attack scenarios.

Research objectives:

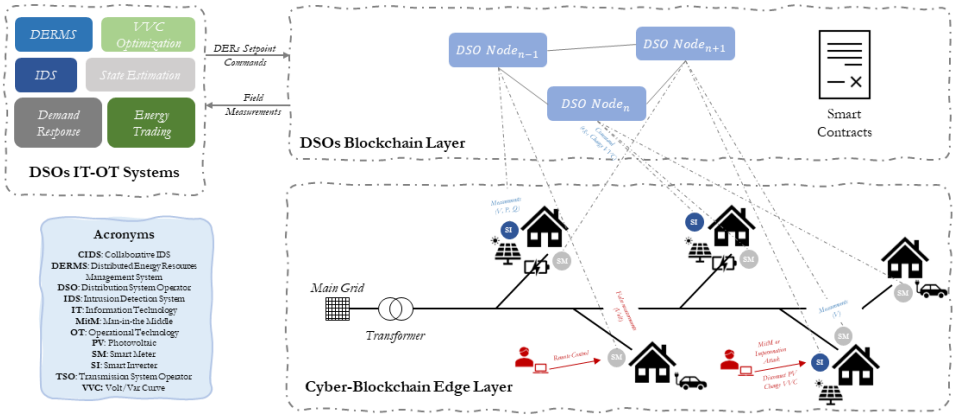
- Detect physical and cyber anomalies on the simulated power system.
- Develop a method to correlate cyber-physical anomalies.

Industry relevance/partner: Cyber security on power system is an emerging issue. Utilities and power grid vendors need people with knowledge of both power system, IT-OT, and cyber security. This project is an opportunity for you to learn about IT-OT power system operation, cyber security, artificial intelligence application and gain experience in one of the major industry tools PowerFactory. **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

Contact details:

- PhD supervisor: Alfan Presekal (A.Presekal@tudelft.nl)
- Supervisor: Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl)
- Thesis chair: Prof. Peter Palensky (P.Palensky@tudelft.nl)

Blockchain for a Cyber-Secure and Resilient Control of Distributed Energy Resources (DERs) at the Edge of the Smart Grid



Scope: The objective of this master thesis project is broadly twofold: (i) conduct a risk and vulnerability assessment of residential DERs (e.g., rooftop solar panels, electric vehicles, batteries, etc.) in order to evaluate the impact of various cyber attacks on these resources and quantify the extent to which they might affect the stability of the distribution networks, (ii) propose a blockchain-based monitoring and control framework to enhance the cyber-security and resilience of DERs which could be integrated with ML and AI techniques for attack/anomaly detection. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: The remarkable proliferation of DERs within residential areas, coupled with the digitalization of their interconnected devices (e.g., smart converters, charging points, etc.) has only increased the landscape of cyber attacks that could potentially destabilize the normal operation of distribution networks by causing voltage and/or frequency issues. This in fact, is the main concern behind this project, which aims at, first assessing the impact of certain cyber attacks targeting the primary control settings of the DERs' converters, or electric vehicles' charging behaviour. To then explore the potential of applying blockchain as an innovative distributed technology to enhance the cyber resilience of these resources due to its inherent security properties and fault-tolerance.

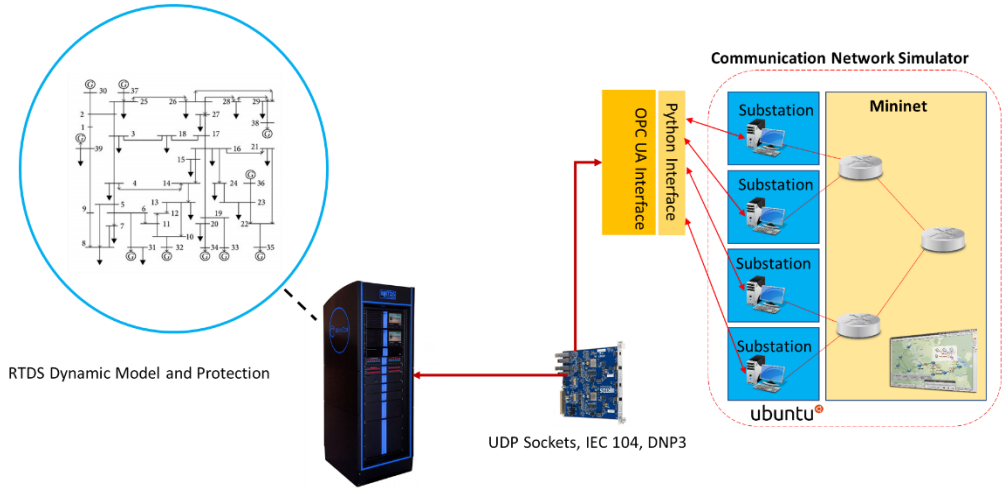
Methodology: You will contribute to prototyping a blockchain-based framework that would manage the overall workflow of DERs' control and monitoring (e.g., issued set-point commands from the DSOs). You will define the format and nature of the data to be recorded on the blockchain as well as the access rules within the whole ecosystem depending on the privileges of all stakeholders. You might also investigate the integration of an AI-based CIDS with the proposed blockchain framework to detect false data injection attacks or anomalies within the collected measurements from the various DERs.

Research objectives:

- Propose a proof-of-concept of a blockchain-based framework for DERs' control using smart contracts for intelligent automation and off-chain techniques for scalability.
- Test the integration of the framework with an AI-based CIDS and/or distributed energy management systems (e.g., DERs' reactive power optimal dispatch).

Collaboration: This thesis will be undertaken as part of the Control Room of the Future research program and offers you an opportunity to actively collaborate with various companies and researchers within/outside TU Delft.
Contact details: Daily supervisors: Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl), thesis chair: Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl).

Cyber Attacks on Power Grids: Cascading Failures and Impact Analysis



Scope: The scope of this MSc thesis project is to develop a detailed EMT power system model and its associated communication interface, to analyse large scale impact of cyber attacks on power grids – cascading failures and blackout. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: Cyber attacks on power grids are a real modern-day threat as evidenced by the cyber attacks on the power grid in Ukraine in 2015 and 2016 that resulted in power outages and disruptions. If the power system's observability and controllability are compromised due to communication and cyber security problems, it can be exposed to catastrophic cascading events that may even culminate in a blackout. As a result, there is an urgent need to model and investigate the impacts of cyber attacks on power grids. This thesis project will focus on investigating if and how cyber attacks may induce system-wide cascading failures that can lead to blackouts.

Methodology: For the standard IEEE 39-bus test system, you will develop an EMT network model on the Real-Time Digital Simulator (RTDS). A key aspect will be modelling of various protection schemes such as generator interface protection, line protection, etc. to simulate a cascading failure sequence. You will also develop a data exchange interface via UDP sockets or common power grid protocols such as IEC 104, DNP3 to exchange measurements and controls with the cyber system. The cyber system model incorporates the OT models of substations and control centres and is already developed using MININET communication network emulator. You will integrate the developed real-time power and cyber system models using our co-simulation framework. The main objective of this test-setup is to analyse the impact of simulated cyber attacks such as denial-of-service, man-in-the-middle on the power grid with regards to cascading failures and blackouts.

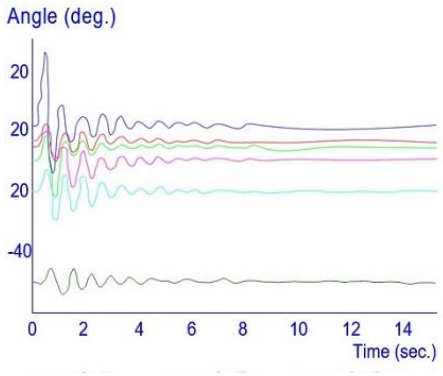
Research objectives:

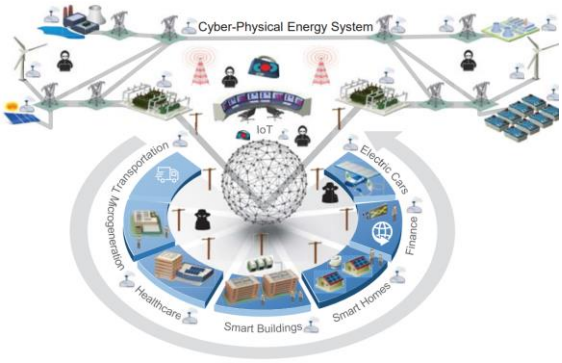
- Model the IEEE 39 bus test system with detailed protection functionality on the RTDS, and its communication interface using UDP/TCP sockets.
- Simulate cyber attacks and analyse their impact on power system, i.e., system dynamics, loss of load, cascading failures, etc.

Industry relevance/partner: Cyber security for power grids is an emerging issue. Utilities and equipment vendors require people with knowledge of both power systems and ICT. **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

Contact details: PhD supervisor: Vetrivel S.R (V.SubramaniamRajkumar@tudelft.nl), Daily supervisor: Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl), Chair: Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl).

Data-Driven Cyber-Physical System Security Assessment





Scope: This thesis project will focus on developing a data-driven tool which will utilize machine learning to evaluate the dynamic security of the Cyber-Physical System (CPS). **No prior knowledge of computer networking and cyber security are required.**

Problem definition: Despite the crucial importance of cyber security in the modern energy system, current studies suffer from significant gaps and neglect vital elements of the power system. Although there are different approaches to improving the IT-OT infrastructure security in power systems, including authentication, firewalls, and intrusion detection systems, it is inevitable to prevent cyber attacks in digitalized power systems with extensive IoT networks. The goal of this M.Sc. project is to develop a ML-based security assessment tool that can estimate power system security states regarding cyber-physical system vulnerabilities.

Methodology: In this project, a supervised learning algorithm for classification will be employed to develop a data-driven assessment tool for cyber-physical system security. As a result, the main challenge is achieving a high informational content database based on the cyber-physical power system model. In the database generation stage, various scenarios, including IT-OT system break down and cyber attacks will be investigated to maximize the information content of the training dataset. Next, the generated database will be utilized to train the ML algorithm and assess the security of CPS.

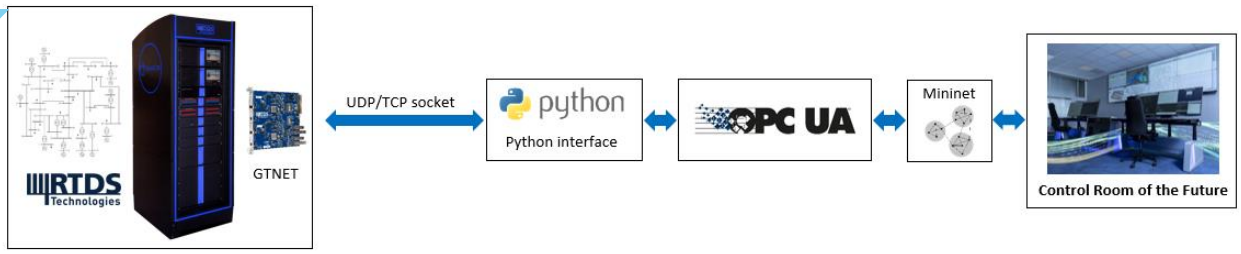
Research objectives:

- Devise a particular set of attack scenarios that have a direct impact on power system dynamics.
- Utilize machine/deep learning to obtain a deeper understanding of the dependency between stability and IT-OT infrastructure.
- Test the proposed method using power systems cyber-physical simulation tools for power systems.

Industry relevance/partner: This thesis will be undertaken as part of joint research activities within the scope of the H2020 funded eFORT project. This presents you with an opportunity to actively collaborate with leading universities and research institutions in Europe. Additionally, you will learn about practical considerations of power system dynamics and IT-OT systems and you also will get experience in one of the major industry tools in DIgSILENT PowerFactory or RSCAD. **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

Contact details: PhD supervisor: Ali Mollaiee (amollaiee@tudelft.nl). Daily supervisor: Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl). Thesis Chair: Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl).

Anomaly Detection using Real-Time Cyber Physical Co-Simulation



Scope: The scope of this MSc thesis project is to implement a data exchange method for cyber and physical co-simulation environment and develop a sampling data method to detect and mitigate cyber-physical power system anomalies. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: Electrical power grids are critical infrastructures that are vulnerable to cyber attacks. The resilience and cyber security of the power grid have become recognized challenges for power system operation and security of supply. In this regard, cyber-physical system co-simulation plays an important role in power grid cyber security research. This project will focus on the development of the Phasor Measurement Unit (PMU) data exchange method between power grid simulation on a Real-Time Digital Simulator (RTDS) and OPC Unified Architecture (OPC UA). The project will also focus on identifying and selecting representative data to observe cyber-physical power system anomalies.

Methodology: In this project, data exchange is implemented between RTDS and OPC UA through python socket interfaces. The main challenge is to develop detection and mitigation strategies based on PMU data from cosimulation. In this project, you are also required to propose power grid analytic methods to choose the most representative PMU data from RTDS based on power grid topology. The implementation will process the packet stream from the RTDS in real-time and integrate the proposed method with the Control Room of the Future facility at TU Delft.

Research objectives:

- Implement python-based PMU data exchange interface between RTDS and OPC UA Server.
- Identify representative PMU data samples based on power grid topology.
- Detect and mitigate anomalies in the power grid based on PMU data samples.

Industry relevance/partner: Cyber security on the power system is an emerging issue. Utilities and power grid vendors need people with knowledge of both power systems, IT-OT, and cyber security. This project is an opportunity for you to learn about IT-OT power system operation, cyber security, artificial intelligence application, and get experience in one of the major industry tools, i.e., RTDS. **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

Contact details:

- PhD supervisor: Alfan Presekal (A.Presekal@tudelft.nl) and Vetrivel S.R (V.SubramaniamRajkumar@tudelft.nl)
- Supervisor: Alex Stefanov (A.I.Stefanov@tudelft.nl)
- Thesis chair: Peter Palensky (P.Palensky@tudelft.nl)

Electrical Power Systems Security with Digital Twins

Scope: This thesis project will focus on developing near real-time impact assessment methods concerning cyber attacks for system operators, and courses of action in response to a security event.

Problem definition: Our society is becoming increasingly dependent on ICT including critical infrastructure which provides us with drinking water, energy chemical and manufacturing industries, transportation, etc. The continuous digitization of OT (operational technology) networks makes it harder to understand the complexity and extent of dependencies of IT/OT networks. This introduces new cyber security threats and vulnerabilities. With the advancements and continuously evolving cyber threat landscape and speed at which cyber-attacks occur, automation can aid human analysis and execution of response actions at machine speed.

Methodology: This master thesis project takes place in the context of the Horizon Europe eFORT project (https://efort-project.eu/) on Electric Power Energy Systems (EPES) Security. Within this project, you will work on the development of technology and tools for using a digital twin of the power grid to support the Security Operations Centre (SOC) and Control Room operators by analyzing the effects on the power grid due to cyber-attacks, including cascading effects. There have been increasing intrusions and cyber-attacks on power grids, which proves the importance of cyber security for EPES. Cyber-threats such as Stuxnet, BlackEnergy3 and Triton are some examples of cyber-attacks on OT systems when the IT network is penetrated through the OT network and causes great damage. Using a digital twin with a cyber range for real-time data analysis to create scenarios and possible cascading effects will help in securing OT networks. This will enable researchers to further implement better intrusion detection methods, (automated) incident response actions, etc.

Research objectives:

- Literature study on the use of Digital Twin for Security Operations Centre.
- Design a solution for real-time integration of the power grid Digital Twin in the Security Operations Centre.
- Set up experiments to evaluate the solution.

Industry relevance/partner: This MSc thesis project is part of the Control Room of the Future research programme between TU Delft and TNO. An internship with TNO on this topic is required. You will be supervised during your

work placement and be given the scope to get the best out of yourself. TNO will provide suitable work placement compensation.

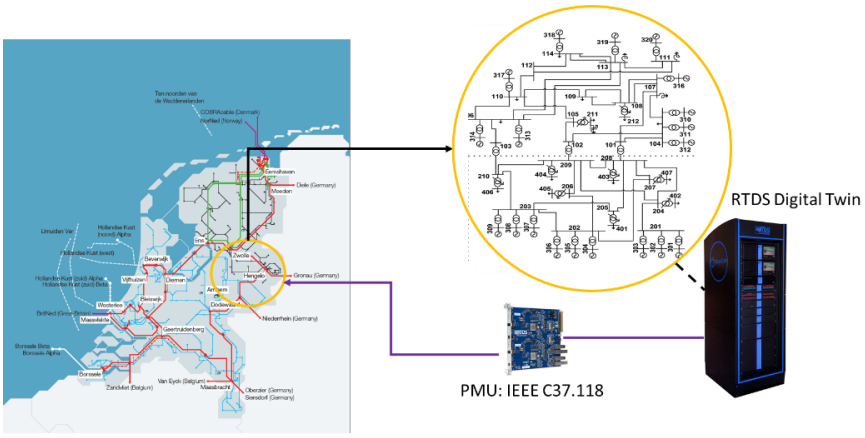
Application process: For this vacancy, it is required that a certificate of conduct (Verklaring Omtrent het Gedrag, VOG) is provided to TNO.

Contact details:

- PhD students:
  Ioannis Semertzis (i.semertzis@tudelft.nl)
  Yigu Liu (y.liu-18@tudelft.nl)
- Supervisor: Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl)
- Industry supervisors:
  Swarna Kumarswamy-Das
  Frank Fransen
- Thesis chair: Prof. Peter Palensky (P.Palensky@tudelft.nl)

Digital Twin of the Dutch High-Voltage Transmission Network

Scope: The objective of this master thesis project is to develop a digital twin of a section of the Dutch transmission system and its associated monitoring and synchronisation through Phasor Measurement Units (PMUs).



Dutch Transmission Network

Problem definition: The energy transition with integration of renewable energy sources and power electronics has resulted in increased complexity in the dynamic behaviour of the transmission systems. Hence, it is crucial to develop models and methods to accurately analyse this dynamic behaviour. A digital twin, as the name suggests is an exact digital replica of the actual real-world system. By creating a digital twin of a section of the Dutch transmission network, based on actual data and parameters, its behaviour can be comprehensively simulated and investigated. The digital twin can aid in the study of the dynamic behaviour of the transmission system when subject to events/disturbances, e.g., short circuits and outages, on the EMT timeframe. Furthermore, by interfacing PMUs with the developed digital twin, it becomes possible to interconnect it with the actual physical power grid.

Methodology: You will develop an EMT digital twin model of a section of the Dutch transmission network on the Real-Time Digital Simulator (RTDS). Grid data and parameters based on relevant scientific publications will be provided. A key aspect will be model/topology identification of the transmission system, and its associated protection functionality. You will also develop a PMU interface to exchange measurements and synchronise the developed digital twin with the actual power grid. The PMU measurements will be exchanged using the IEEE C37.118 standard that covers synchrophasors for power systems. You will then investigate various EMT related phenomena and analyse their impact using the developed digital twin. Programming skills in Python or similar languages are of advantage.

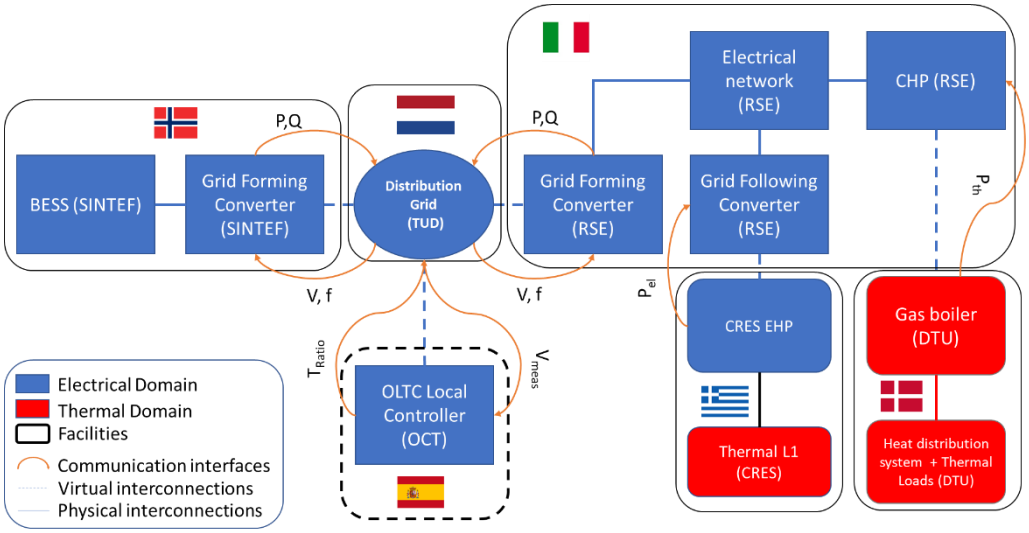
Research objectives:

- Model a detailed EMT digital twin of a section of the Dutch transmission network and its associated protection functionality on the RTDS, and interface and synchronise it to the actual grid, via PMUs.
- Perform real-time vulnerability assessment using the developed digital twin for various scenarios, e.g., disturbances, high share of renewables, etc.

Industry relevance/partner: You have the opportunity to work on a state-of-the-art topic in collaboration with the Dutch TSO, TenneT. Digital twins are gaining widespread prominence in industry.

Contact details: Daily supervisors: Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl) and Dr. Jose Rueda Torres (J.L.RuedaTorres@tudelft.nl). Thesis chair: Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl).

Multi-Energy District Flexibility: ERIGrid 2.0 Approach



Scope: The objective of this master thesis project is to investigate power-to-heat service provisions in a multi-energy district and analyse its impact on the electric and thermal networks. This will be achieved by multi-lab experiments with European project partners.

Problem definition: Power-to-X is an active, multi-domain topic of research. More specially, flexibility to distribution grids, provided by thermal and electric sources needs to be further investigated. The flexibility requested by the Distribution System Operator can be provided by a combination of electric and thermal storage systems as well as flexible controllable loads, such as Heat Pumps, Thermal Loads, Electric Boilers, etc. This master thesis project partially fulfils the objectives of the H2020 funded project ERIGrid 2.0 (https://erigrid2.eu/), Work Package (WP) 14, aimed at the demonstrating virtual interconnection of labs.

Methodology: You will undertake joint research experiments with partner institutions to study the multi-energy benchmark system. This will involve actual electrical networks in Norway and Italy, along with district heating systems, located in Denmark and thermal loads in Greece. Through this joint experiment, you will verify of the impact of local flexibility on available regulating power from a local district. You can also perform a comparison study of the geographically distributed experiment with a pure software simulation.

Research objectives:

- Couple a multi-energy system through a geographically distributed experiment.
- Verify of the impact of local flexibility on available regulating power from a local district.

Collaboration: This thesis will be undertaken as part of Joint Research Activity (JRA) 4 within the scope of the H2020 funded project ERIGrid 2.0 (https://erigrid2.eu/). This presents you an opportunity to actively collaborate with leading universities and researchers in Europe.

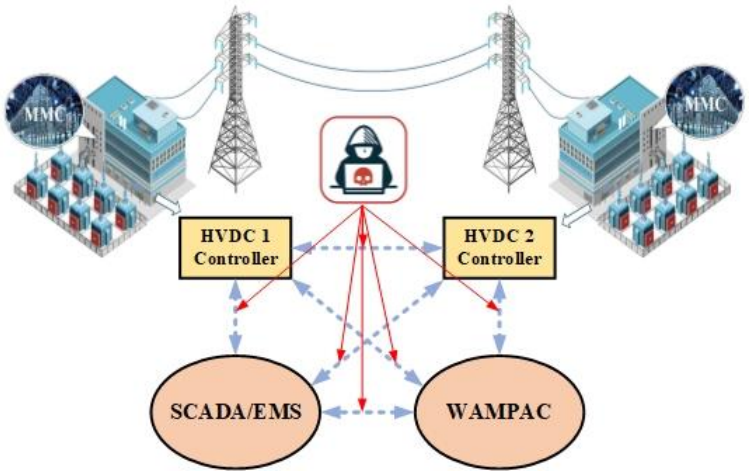
Contact details:

Postdoc supervisor: D. Gusain (D.Gusain@tudelft.nl).

PhD supervisor: Vetrivel S.R (V.SubramaniamRajkumar@tudelft.nl).

Thesis chair: Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl).

Cyber Attack Resilient Hybrid AC/DC Power Grids



Scope: This thesis will focus on identifying the vulnerabilities of HVDC systems against cyber events and making recommendations on how to properly face them and minimize their impact on the hybrid AC/DC power grids. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: Due to the increasing penetration of renewable energies into power grids, the use of HVDC technology is becoming more widespread. That's because of some special characteristics of this technology such as higher transmission capacity and lower losses over long distances. At the same time, Information Technology (IT) solutions are moving the electricity industry more and more towards digitalization. Therefore, today's hybrid AC/DC power grids can be considered a large Cyber-Physical System (CPS) that is vulnerable to cyber attacks. Therefore, one critical aspect of any protection and control strategy for the HVDC systems that need to be taken into account before deployment is its resilience against potential cyber attacks.

Methodology: In this project, you will first start by getting to know the HVDC-based grid architectures (topology, technological components, and operation algorithms for control and protection). Then you will develop an EMT HVDC grid model on the Real-Time Digital Simulator (RTDS). For this part, you can make use of some available HVDC grid benchmark models in the literature. You will then assess the cyber security of your developed model protection and control mechanism by doing Hardware-In-the-Loop (HIL) simulations in the next step. In the last step, you will develop approaches to minimize the impacts of cyber attacks on the implemented HVDC grid model.

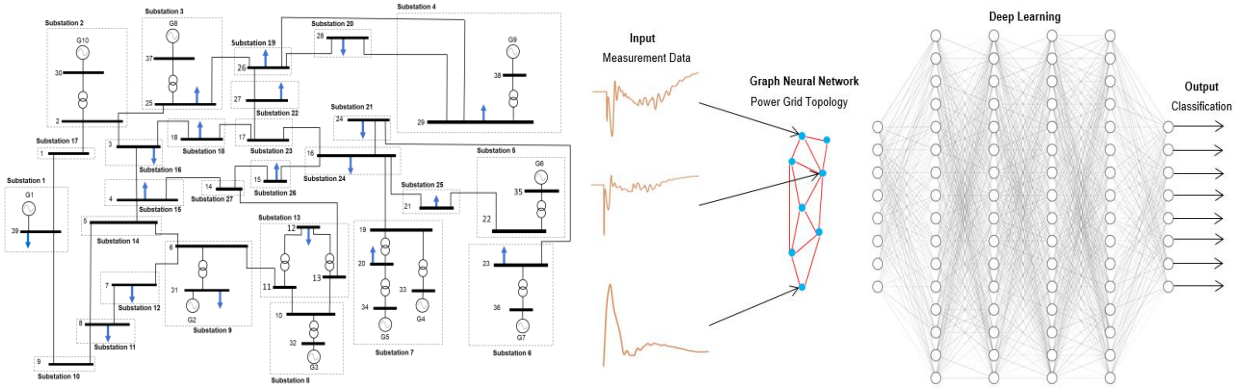
Research objectives:

- Investigating different HVDC-based grid architectures
- Developing an HVDC grid model in RTDS for conducting EMT simulation studies
- Assessing the impacts of potential cyber attacks on the developed HVDC grid model operation
- Making recommendations on how to reduce the impacts of cyber attacks on the hybrid AC/DC power grid

Industry relevance/partner: This master thesis project contributes to the objectives of the EU funded project HVDC-WISE. You will have the opportunity to collaborate with leading academic and industrial institutions in Europe which will help you to grow your professional network. **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

Contact details: Postdoc researcher Dr. Mohsen Jorjani Damghani (m.jorjanidamghani@tudelft.nl), Supervisor Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl), Thesis Chair Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl).

Classification of Power System Events for Detection of Cyber Attacks on Power Grids



Scope: The scope of this MSc thesis project is to generate datasets of power system events, including cyber attacks and classify them using a deep learning model. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: There are many types of power system anomalies that are triggered by various events including faults, disruptions, loss of generation, etc. Machine learning algorithms have been proposed for power system event classification. However, the majority of existing research does not consider cyber attack-based events. One of the challenges for this research is the availability of power system datasets that incorporate cyber attacks. Such datasets can be used for training machine learning models for cyber attack detection and classification using new datasets.

Methodology: Develop scenarios that cover various power system events, including cyber attacks. The scenarios will be tested on DIgSILENT PowerFactory using Python scripting to generate datasets from the power system measurement, i.e., voltage magnitude, phase angle, frequency, etc. The datasets are then used to implement deep learning-based time series classification.

Research objectives:

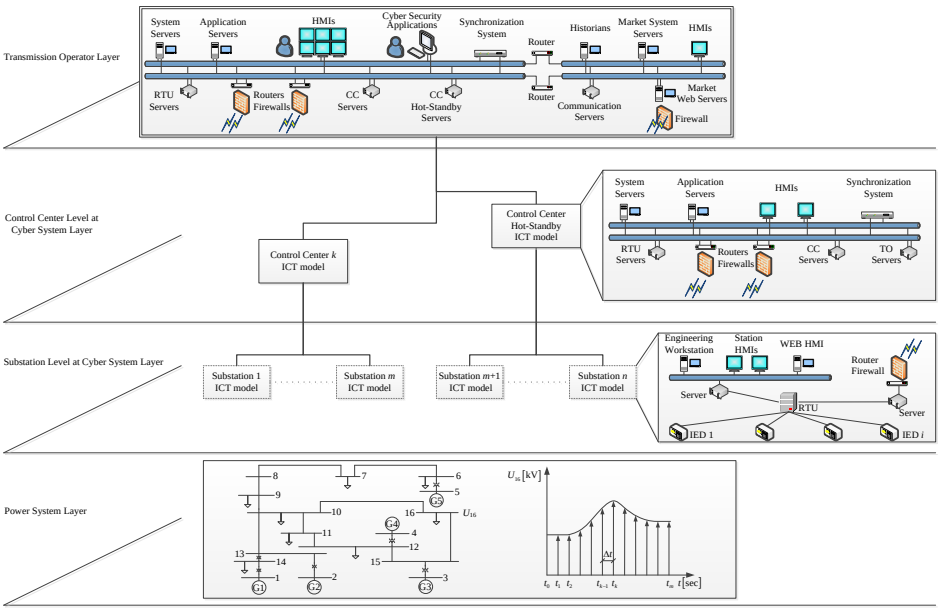
- Develop scenarios of a wide variety of power system events including cyber attacks.
- Generate the dataset based on the proposed scenario using DIgSILENT PowerFactory.
- Utilize deep learning to classify the time series datasets.

Industry relevance/partner: Energy utilities and industrial vendors seek electrical engineers with knowledge of cyber security for power grids. This project is an opportunity for you to learn about (1) communication networks/protocols used for monitoring and controlling the physical power grid, (2) cyber security basics of power systems, and (3) artificial intelligence application. Finally, you will be able to get experience in one of the major software tools used in the industry, i.e., DIgSILENT PowerFactory, as well as to develop your skills in Python. **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

Contact details:

- PhD supervisors: Ioannis Semertzis (I.Semertzis@tudelft.nl) and Alfan Presekal (A.Presekal@tudelft.nl)
- Supervisor: Alex Stefanov (A.I.Stefanov@tudelft.nl)
- Thesis chair: Peter Palensky (P.Palensky@tudelft.nl)

Impact of Cyber Attacks on Power System Dynamics



Scope: The scope of this MSc thesis project is to develop an integrated model of a test power system and its operational technologies and assess the impact of cyber attacks on power system dynamics.

Problem definition: On top of the power infrastructure reside operational technology (OT) layers for monitoring and control of the grid. The cyber and power systems together form a complex structure, which is referred to as a cyber–physical system (CPS). If the power system's observability and controllability are compromised due to communication and cyber security problems, the grid can be exposed to catastrophic events. As a result, there is a great need to model the power grid and OTs for cyber security investigations. CPS models are needed to simulate cyber attacks, analyse their impact on power system dynamics, and develop mitigation techniques.

Methodology: For the standard IEEE 39-bus test system, you will develop the dynamic model of the power grid using an industrial-grade power system simulation tool (DIgSILENT PowerFactory). The cyber system model incorporates essential OT functionalities for real-time communication between the power grid and transmission system operator. The OT models of substations and control centres will be developed using communication network simulators such as MININET. You will integrate the power and cyber system models using our co-simulation framework. To conclude, you will simulate cyber attacks at the cyber system layer (unauthorized access and control of remote terminal units, man-in-the-middle and distributed denial of service) and analyse their impact on power system dynamics at the physical system layer in an integrated environment. You will make recommendations for transmission system operators to mitigate the impact of cyber attacks on power grids.

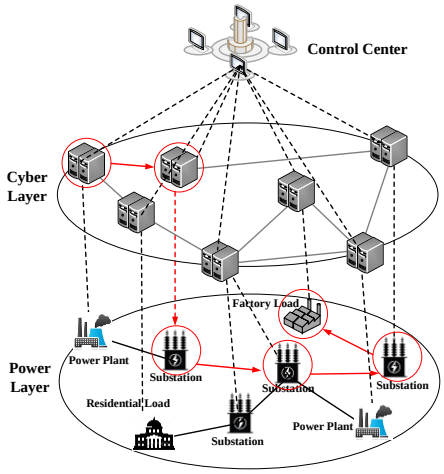
Research objectives:

- Model an integrated CPS that incorporates both the power grid and its OT infrastructure.
- Simulate cyber attacks and analyse their impact on power system dynamics.

Industry relevance/partner: Cyber security for power grids is an emerging issue. Utilities and power grid vendors need people with knowledge of both power system and IT. This project is an opportunity for you to learn about cyber-physical systems and cyber security for power grids.

Contact details: Supervisor Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl), Promotor Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl)

Interdependency Analysis of Cyber-Physical Power Systems



Scope: The scope of this MSc thesis project is to systematically analyze the complex interdependency of cyber-physical power systems from both structural and operational perspectives. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: With the rapid development of Information and Communication Technologies (ICTs) and Operational Technologies (OTs), the power grids are now tightly coupled with communication infrastructures in an unprecedented way, which forms a complex, interdependent Cyber-Physical System (CPS). The newly introduced complex interdependency between cyber and physical layers brings new challenges to the operation of power grids. The goal of this MSc project is to develop an effective and feasible framework to analyze the impact of the complex interdependency to modern power grids.

Methodology: In this project, the main challenge is to model the CPS from both structural and operational perspectives. For structural interdependency, you will model the cyber topology based on standard IEEE systems, e.g., IEEE 39-bus system, and then you will form reasonable structural interdependency of cyber and physical layer based on the industrial design standard of digital substations. During this process, graph theory, complex network theory, or other effective tools may be utilized to tackle the modeling problems. Based on the formed CPS structure, you will consider the operational complexity (e.g., power flow, power dynamics) of CPS and develop an interaction model to capture the cascading failure mechanism of CPS. You will develop power layer model in DIgSILENT PowerFactory and use Python to model the cyber layer. At last, you need to design a series of indices or develop a framework to quantify the impact of interdependency to CPS operation and then reveal the detailed mechanisms of cascading failures in CPS.

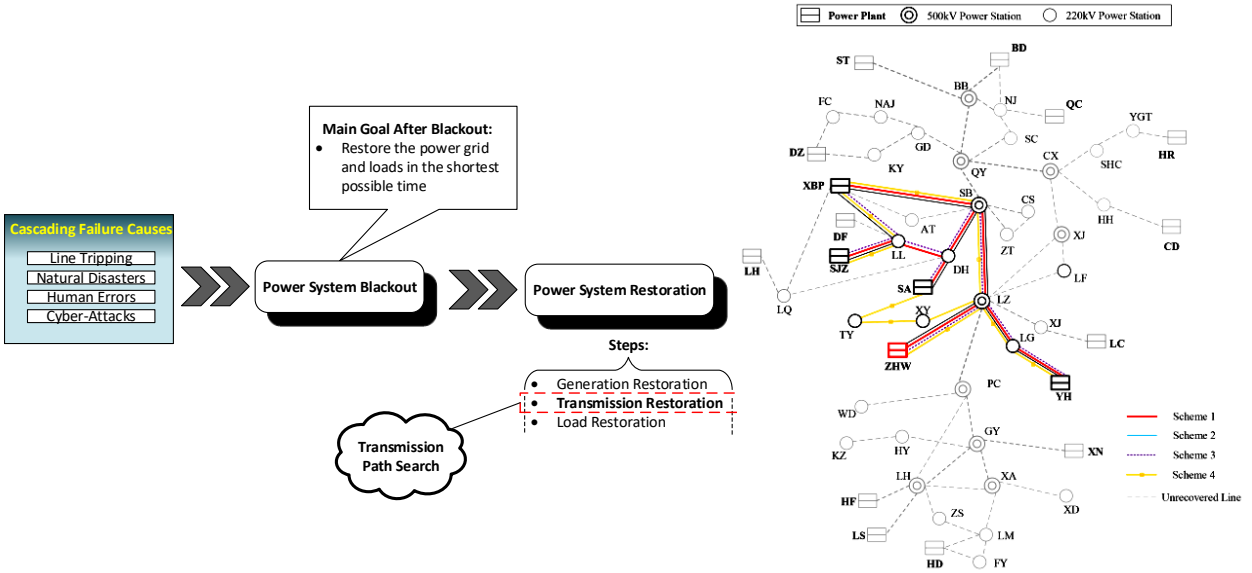
Research objectives:

- Model CPS from both structural and operational perspectives considering the complex interdependency between cyber and physical layers.
- Develop an effective framework to analyze the impact of interdependency to modern power grids.

Industry relevance/partner: **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

Contact details: PhD student Yigu Liu (y.liu-18@tudelft.nl), Supervisor Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl), Thesis Chair Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl).

Decision Support for Power System Restoration Path Selection After Cyber Attacks



Scope: This project will focus on developing decision-making systems to provide alternative path schemes for system restoration from a blackout caused by cyber-attacks. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: Considering the growth in frequency and strength of cyber attacks on power grids, a power system blackout is an unavoidable event around the world. In this regard, performing fast and reliable power system restoration after a major blackout is a vital task for system operation and planning. Generally, the whole restoration process can be divided into three stages: generation restoration, transmission restoration, and load restoration. During the transmission network restoration process, energizing paths need to be optimized and identified to transfer the cranking power and energize the transmission network.

Methodology: The energizing path scheme made beforehand may not be executed successfully due to the possible unavailability of data or incorrect information under the cyber attack condition, so it is necessary to provide alternative energizing path schemes with priority ordering for system restoration. In doing so, first, you will work on the mathematical expression of energizing path optimization problem. Then, several path schemes will search and determine to compose the alternative path set. Next, an evaluation index set will be established and a multiple attribute decision-making method will be introduced to make a comprehensive evaluation of the path schemes.

Research objectives:

- Analyzing the effect of cyber attacks on transmission line restoration step.
- Providing decision support systems to help power system operators.

Industry relevance/partner: As a power system blackout has far-reaching consequences, it is important for operators to be prepared. So, this project is an opportunity for you to learn about the power system restoration steps. **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

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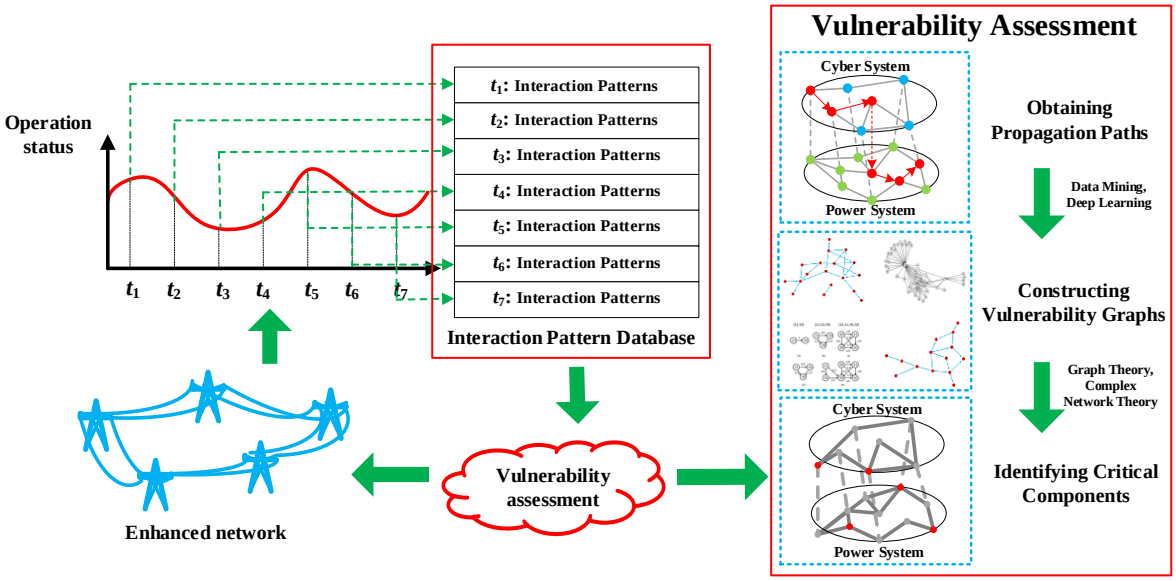
Data-Driven Vulnerability Assessment for Cyber-Physical Power System



Scope: The scope of this MSc project is to assess the vulnerability of cyber-physical power systems under different cyber attack scenarios from a data-driven perspective. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: The power system operation is increasingly dependent on ICTs and Operational Technologies (OTs). It can be envisioned that on top of the power system infrastructure reside integrated layers of ICTs and OTs. Together they form an interdependent and complex Cyber-Physical power System (CPS). However, cyber-related vulnerabilities are inevitably introduced in the cyber-physical system, which can be exploited by adversaries and thus weaken power grid robustness and security of supply. The goal of this project is to develop effective algorithms to assess the vulnerabilities of CPS under different cyber attack scenarios.

Methodology: In this project, the first challenge is to model the cyber attack scenarios. For each attack scenario, you will formulate the corresponding attack models and then investigate their impact on CPS. You will develop a power system model in DIgSILENT PowerFactory and use Python to model the cyber layer. The purpose of attack modeling is to capture the interaction patterns (e.g., cascading failure paths, failure correlations) of components in both cyber and physical layers. Based on the identified interaction patterns, you will use machine learning algorithms to analyze the patterns and extract valuable information of CPS operation. During this step, you need to construct vulnerability graph based on different research goals. At last, you will use graph theory or complex network theory to analyze and quantify the system vulnerability and identify critical components for CPS.

Research objectives:

- Model cyber attack scenarios and investigate the interaction patterns of CPS under attacks.
- Develop an effective vulnerability assessment framework and identify critical components for CPS.

Industry relevance/partner: **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

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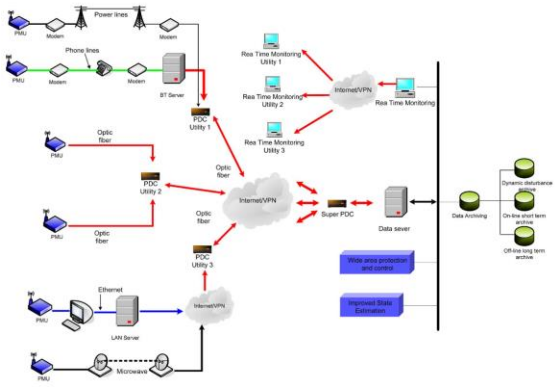
Cyber Attack Detection in WAMPAC Systems



Source: V. Terzija et al., "Wide-Area Monitoring, Protection, and Control of Future Electric Power Networks," Proceedings of the IEEE, 2011.

Scope: The scope of this thesis project is to design a cyber attack detection method for Wide-Area Monitoring, Protection, and Control (WAMPAC) applications in the power grid. **No prior knowledge of computer networking and cyber security is required.**

Problem definition: Phasor Measurement Units (PMUs) are devices that produce time-synchronized measurements. These devices enable Wide-Area Monitoring, Protection and control applications in the power grid. Improved state estimation, real-time visualization of power system, early event detection, and real-time stability analysis are some of the benefits of PMU-enabled WAMPAC systems. However, one serious problem regarding the WAMPAC systems is its cyber security. A security breach in the WAMPAC system may have a system-wide impact.

Methodology: The main challenge in this project is to first determine the vulnerable points and attack surfaces of a WAMPAC system, considering certain applications. Exploiting the vulnerable points, then a number of attack scenarios will be carried on to produce a dataset. Finally, using the obtained dataset, attack detection methodologies (mostly machine learning-based) will be investigated.

Research objectives:

- Reviewing WAMPAC applications in the literature and their possible attack surfaces.
- Build a testbed for WAMPAC applications based on PMU measurements.
- Simulate cyber attack scenarios and observe the impact on the power grid.
- Investigate possible attack detection mechanisms for the simulated scenarios.

Industry relevance/partner: This thesis is a part of InnoCyPES project with industrial partners including EDF (FR), Typhool HIL (CS), and Siemens Gamesa (DK). In addition, you will learn about tools such as PowerFactory and machine learning libraries that are widely used in industry. **This MSc project offers industry collaboration and networking opportunities in Control Room of the Future.**

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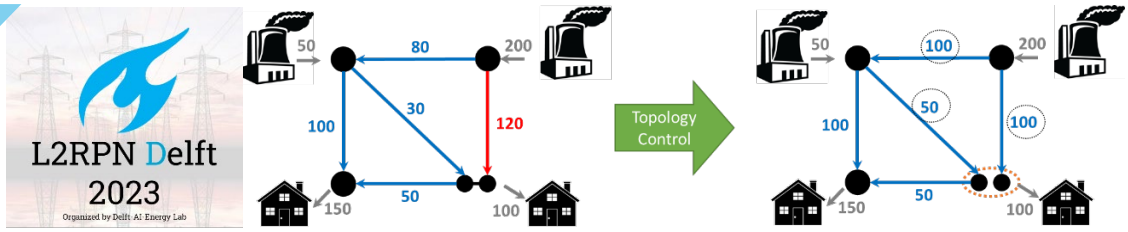
Optimization-based Agent for Topology Control of Power Systems



Scope: This thesis project will investigate optimization algorithms to perform topology control of electric power systems.

Problem definition: Electric power systems are undergoing a fundamental transition to become more sustainable and intelligent. Uncertain renewable sources (e.g., wind and solar) with limited flexibility are replacing flexible (dispatchable) conventional generators (e.g., diesel, coal, gas, etc.). In this context, many researchers in recent years have demonstrated the under-exploited flexibility of transmission network topology to reduce operational cost and improve system security. Transmission network topology control refers to the switching on/off of the transmission networks elements (e.g., branches) to re-direct active and reactive power flows in the network. Currently system operators rely on their experience, predetermined look-up table and heuristic methods to perform corrective switching (topology) actions. However, these approaches could lead to sub-optimal and/or insecure solutions. To overcome this problem, the French system operator (RTE) has launched a series of competitions called the ***Learning to Run a Power Network (2RPN)*** to train artificial intelligence agents to perform topology control actions The latest version of L2RPN was hosted in TU Delf last year. You can watch the award ceremony of L2RPN Delft 2023 here.

Methodology: You will investigate an optimization-based agent in the L2RPN competition environment. To this end, you will implement the transmission network topology optimization problem and integrate it in the L2RPN competition environment.

Research objectives

- Review literature of topology control of power systems.
- Investigate the L2RPN challenge and the developed winning agents of the competition.
- Implement the transmission network topology optimization in Python (some code available).
- Implement a topology-based agent in the L2RPN environment in Python (Grid2Op).
- Investigate the sensitivity of the implemented agent with respect to renewable uncertainty, security, economics, and scalability.
- [Extra] The developed agent could be enhanced by AI algorithms such as reinforcement learning.

Industry relevance/partner:

You will learn technical skills on mathematical optimization, AI, and operation of transmission systems. The developed approach could be used by transmission system operators to securely operate power networks. The transmission network topology control is a hot topic under investigation of RTE (French system operator), Tennet (Dutch system operator), and other major transmission system operators.

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Active Control of Reactive Power in Productive Energy System

Scope: At System Operations we are responsible for system safety. One of the variables that plays a role in this is reactive power. We want to develop a control mechanism for detecting and affecting reactive power in our energy system.

Problem definition: With the growth of renewables in our energy system we are also adding increasingly reactive power in volume and dynamics. Reactive power is a vital component in managing congestion and balance. Not only at DSO level but also at TSO level. Therefore, need to understand how we can control reactive power at de medium voltage level related to the connection points with the TSO.

Methodology: You will work with real time measurement data to build insight into the behavior of reactive power at the connection point with TSO and in the medium voltage grid. Apply ruling policy to the insight to determine if we are out of bounds. Based of that propose, with the insight from the data analysis, policy to manage system safety at the medium voltage grid. And implement this into the the dynamic safety assessment module in our congestion management system.

Research objectives:

- Understand the dynamics of system operations at DSO level
- Understand the role of reactive power in these dynamics
- Understand how reactive power is covered in the netcode, internal policy and customer contracts
- Understand the main sources of reactive power in distribution grids
- Develop algorithms to analyze and forecast reactive power in medium voltage grid and at TSO connection points
- Visualize the reactive powers dynamics for operational purposes
    - Develop policy for managing reactive power in medium voltage gridIncluding difference reactive power control mechanism, such as capacitor/reactor banks, STATCOMs, etc.
- Develop algorithm for managing reactive power in Alliander IT system
- Operationalize this in a production environment

Industry relevance: Currently problems of reactive power are developing especially at the connection point with TSO. At this point in time there is insufficient insight in the dynamics of reactive power to make decisive choices of how to control this. This research contributes to getting this in place.

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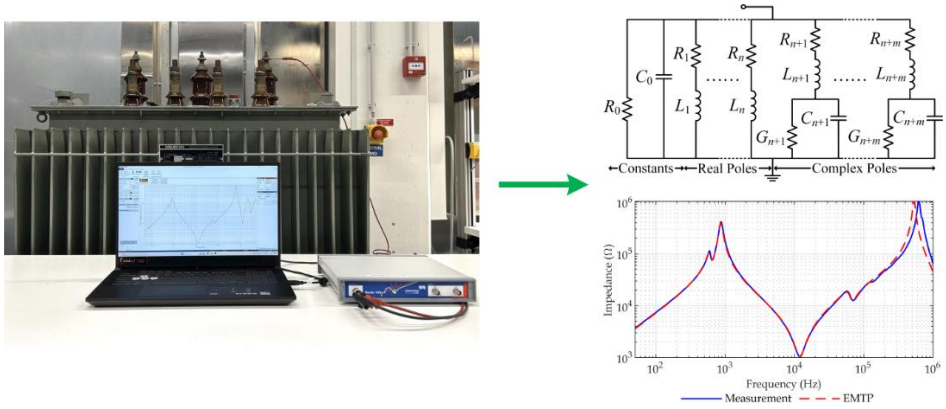
Developing Stable and Passive Equivalent Circuits for Frequency-Dependent Transient Modeling of Power System Components



Scope: The objective of this project is to develop stable and passive equivalent circuits for power system components such as power transformers or transmission lines/cables to reproduce their frequency-domain response over the desired range of frequency.

Problem definition: To investigate the effects of electromagnetic transient phenomena such as lightning and switching on power system components, including transformers and transmission lines/cables, proper models are required. Since transient phenomena typically consist of various frequencies, these models must be valid in a wide frequency range. An important necessity for the developed equivalent models is to ensure that they are physically correct (passive and stable). Available modelling approaches sometimes fail to do so and produce equivalent circuits with negative element values (resistances, inductances, or capacitances).

Methodology: So far, several methods have been proposed to derive all-positive equivalent circuits with the help of optimization methods. Nevertheless, this process can be enhanced by i) applying alternative methods with superior characteristics (possibly using machine learning algorithms) and ii) introducing additional constraints to improve the characteristics of the derived equivalent circuits in terms of complexity order and/or bulkiness. You will implement algorithms of your choice by programming in MATLAB or Python to enforce positive element values for the equivalent circuits and perform simulations using one of the common power system tools (EMTP, PowerFactory, RSCAD) to validate the derived models.

Research objectives:

- Becoming familiar with the development of frequency-dependent models for power system equipment.
- Ensuring the physical correctness of developed models by enforcing positive element values based on the method of your choice (possibly using evolutionary algorithms or machine learning algorithms).
- Improving the characteristics of the developed models in terms of complexity, order, and bulkiness.
- Testing and validating the developed improved model using one of the common power system tools.

Industry relevance/partner: In this project, you will learn about the modelling of frequency-dependent responses in power systems, offering a wide range of possible applications in electromagnetic transients, dynamics and stability, protection, and real-time simulation analyses. You will gain experience with programming using MATLAB or Python and also in power system simulation tools applied in the industry, including EMTP, PowerFactory, and RSCAD.

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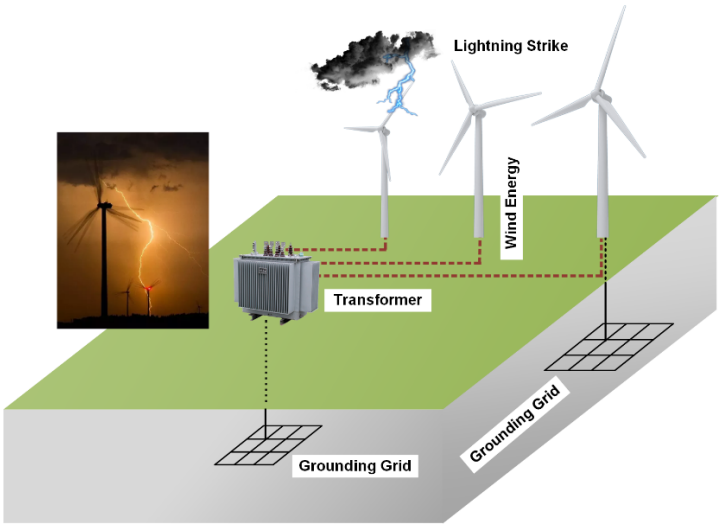
Overvoltage Protection of Wind Energy Systems Against Lightning Strikes Considering High-Frequency Behavior of the Ground



Abstract:

Wind power is crucial for transitioning from fossil fuels to renewable energy sources. However, wind turbines are often hit by lightning. When lightning strikes without proper protection, the damage can be severe. On the one hand, the increased height of modern wind turbines makes them more susceptible to lightning strikes; on the other hand, they are made up of more complex and sensitive control and processing electronics, making them vulnerable to lightning-induced transients. In addition, a direct lightning strike on a wind turbine triggers a traveling wave within the components of the turbine, including the tower, cable connections, wind turbine transformer, and the earthing system. The propagation and reflection of the current and voltage waves between the cables and the units of the system can lead to the elevation of overvoltages that can pose a danger to the insulation of the main cable and the transformer LV winding. Therefore, designing lightning protection schemes for wind turbines is essential for their continued operation. Numerical simulations on computer models are the most efficient and cost-effective method to evaluate and implement effective lightning protection designs.

Methodology:

In this project, detailed models of the blade, dynamic contact part, tower body, and grounding system will be developed in EMTP software. Numerical analyses in EMTP will be conducted based on the probabilistic nature of the lightning phenomenon, and a comprehensive overvoltage protection scheme against lightning strikes on wind turbines will be developed based on the obtained results.

Research objectives:

- Literature review on overvoltage protection and insulation coordination studies with emphasis on wind generation units.
- Implementing detailed models of system components in EMTP software, including tower, cables, transformer, and grounding system.
- Conducting probabilistic studies on the EMTP model of the system considering various lightning parameters.

- Defining suitable protection for overvoltage protection for the system against adverse effects of lightning-induced components.

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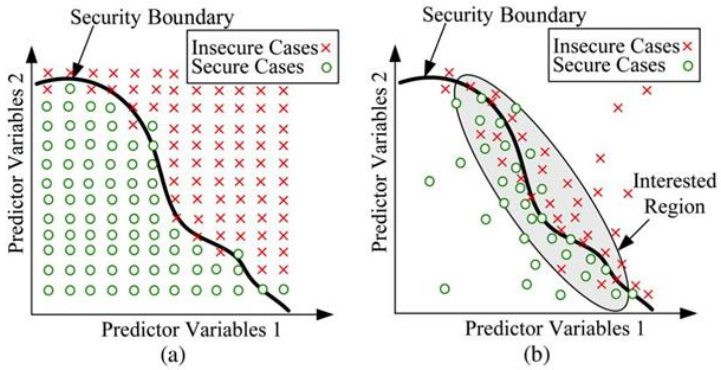
Active Learning for Power System Security Assessment



Scope: This thesis project will investigate an active learning approach for security assessment with a focus on balancing missed alarms and false alarms, considering their different consequences.

Problem definition: The system operator must ensure that the power system is secure against faults. Machine learning is promising to train classifiers that can predict security of many possible operating scenarios. Common practice is to train the classifiers in a passive way using all operating scenarios and analyse them with time-domain stability analysis to figure out whether the faults would be secure. However, active learning allows to assess only the scenarios that are likely to improve the classifiers. But even such active approaches do not consider different impacts, or probabilities of faults, and various costs for missed and false alarms of the predicting classifiers.

Methodology: You will investigate and extend a recently developed framework for active learning in dynamic security assessment. For one or more model systems, you will investigate the implicit risk preference of the trained classifiers and identify ways to improve the risk trade-offs inherent in the active learning procedure. You will use sampling algorithms (statistics), information theory and risk concepts to analyse and improve the methodology, and test it in a Python-based environment.

Research objectives:

- Review literature on active learning and risk-based security assessment
- Identify ways to quantify risks using contingency probabilities, expected impacts of misclassification, and misclassification metrics (ROC-curves, F1 scores, etc.)
- Extend the existing active learning algorithm (in Python) to incorporate risk-aware enhancements.
- Test the final framework against passive learning, and deterministic quantification of security assessments

Industry relevance/partner: This work is of high relevance for several transmission system operators (TSOs), which have ongoing R&D efforts on security assessment. There are opportunities to present the thesis work to our collaborating TSOs.

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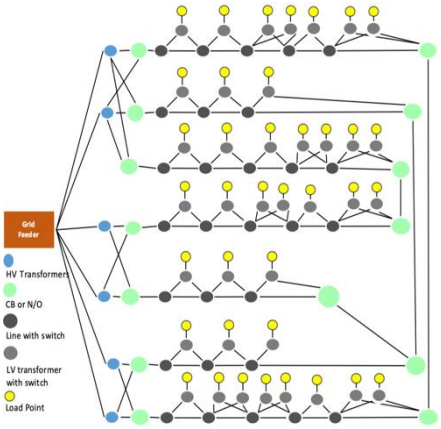
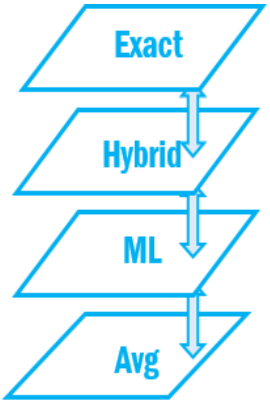
Efficient distribution network reliability estimation using MLMC

Scope: In this project you will investigate efficient methods to estimate the reliability of distribution networks.

Problem definition: Over half of the power interruptions experienced by end users occur due to faults in the distribution network. Distribution system operators (DSOs) are incentivized by the regulator to reduce the impact of faults, which are commonly summarised using metrics such as SAIFI, SAIDI and CAIDI.





The complex restoration process is a barrier for modelling distribution network reliability: after a permanent fault occurs, automatic or manual switching of breakers is used to reconnect many customers while the original fault is being repaired. Full restoration happens in multiple steps, according to the fault, the repair process and the network conditions. Estimating the average impact of all possible faults is therefore a time-consuming process. Multilevel Monte Carlo sampling is a method that can be used to speed up this process if a suitable simplified model is available for joint sampling of both models.

Methodology and objectives:

- Developing a suitable test model starting from the literature or in-house models.
- Implementing a reference model for failures and repairs, based on realistic heuristics or a MILP (mixed-integer linear program) optimization model. Performing a reliability estimation based on conventional Monte Carlo sampling.
- Developing one or more simplified models for failure and repair processes. Implementing these in a multilevel Monte Carlo framework (a Python module for doing so is available).
- Comparison of approaches in terms of computational efficiency and accuracy.

Requirements: This approach will require basic knowledge of optimization, programming skills (Python preferred), probability and statistics, and the knowledge from EE4665 Uncertainty Modelling and Risk Assessment.

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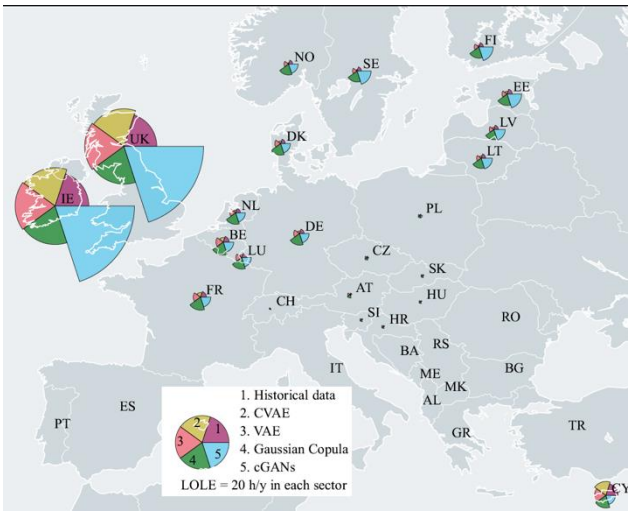
Managing resource adequacy risks in large interconnected systems



Scope: This project investigates computational methods to quantify security of supply in multi-area systems (e.g. the European continent).

Problem definition: For system planning, it is critical to calculate the risk that the generation and transmission system cannot supply all demand, for example due to extended low-wind conditions during peak demand hours. To reduce such risks, some countries have introduced incentives to build new generators. For large interconnected systems (such as the European system), there is a need for accurate large-scale simulations to estimate the impact of such capacity mechanisms (and design them). Depending on the interests and skills of the student, this project may focus on one or a combination of the following:

- Literature study of capacity mechanism implementations in Europe, with supporting simulations.
- Efficient computational methods for efficient risk estimation, e.g. importance sampling Monte Carlo schemes, multilevel Monte Carlo schemes or Polynomial Chaos Expansion methods.
- Embedding operational complexity (storage dispatch, unit commitment, etc.) into resource adequacy assessment models. A basic dispatch model is available.
- Defining and calculating the contributions of individual network elements (generators, transmission corridors, storage units) to the system adequacy metrics.
  It may be possible to execute this as a **company project with ENTSO-E's Resource Adequacy team** in Brussels (subject to further discussion and approval)

Requirements: This approach will require basic knowledge of optimization, programming skills (Python preferred), and the knowledge from EE4665 Uncertainty Modelling and Risk Assessment. Useful electives include Energy System Optimization, Applied Convex Optimization, Monte Carlo Simulation of Stochastic Processes, Scientific Programming for Engineers.

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Machine Learning-Driven Transformer Diagnosis using Sweep Frequency Response Analysis

Figure 1. Inter-turn fault [electricaltechnology.org].

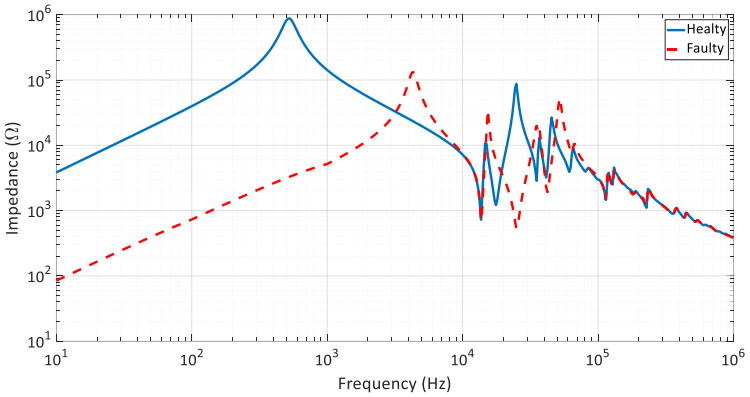

Figure 2. Transformer impedance characteristics.

Scope: This thesis project will focus on developing a machine learning-based algorithm to assess the condition of power transformers and detect specific fault types using Sweep Frequency Response Analysis (SFRA) data. The goal is to create a robust diagnostic tool that can reliably identify transformer issues such as radial deformation, axial displacement, and short turns, enabling proactive maintenance and improved grid reliability.

Problem definition: SFRA is a powerful tool for evaluating the mechanical and electrical integrity of transformers, nevertheless interpreting the complex SFRA signatures requires significant expertise. Developing a machine learning-based approach to analyze SFRA data can enable more efficient and accurate transformer diagnostics.

Methodology: The proposed thesis project will involve the following key steps:

1. Dataset Generation: Utilize the detailed high-frequency transformer model to generate a comprehensive dataset of SFRA characteristics, covering a wide range of transformer geometries and fault conditions, including radial deformation, axial displacement, and short turns.
2. Machine Learning Model Development: Design and implement a machine learning-based algorithm to accurately assess the transformer condition and identify fault types based on the SFRA data. Train the machine learning model using the generated dataset, and thoroughly validate its performance through extensive simulations and testing.
3. Algorithm Integration: Explore the integration of the developed machine learning-based diagnostic algorithm into a user-friendly software tool or interface, enabling practical application by transformer maintenance teams.

Research objectives:

- Develop a comprehensive SFRA dataset for both healthy and faulty transformer conditions.
- Design and implement a machine learning-based algorithm capable of accurately assessing the condition of the transformer and identifying the type of fault based on SFRA data.

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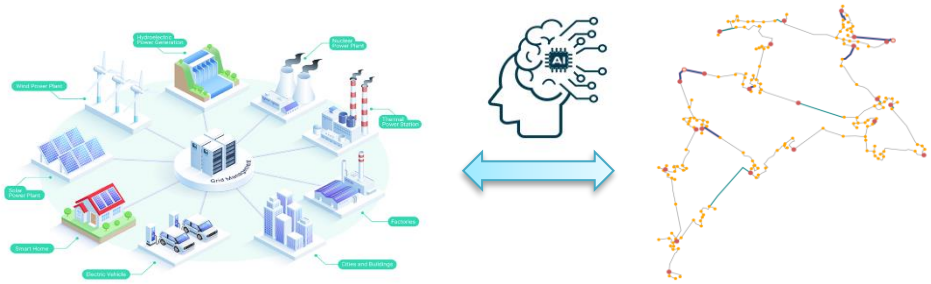
Physic-Informed Deep Learning for Situational Awareness in the Distribution System



Scope: This MSc thesis project focuses on enhancing a deep learning method based on physic-aware graph neural networks to enable real-time monitoring of the complex and uncertain distribution grid.

Problem definition: Distribution systems are taking a more active role in the energy transition. These active distribution systems require more extensive monitoring and control, which is possible by developing Distribution System State Estimation (DSSE). Conventional SE algorithms are challenging to implement due to the size and shape of the distribution grid and the lack of real-time measurements. A novel approach based on Graph Neural Network (GNN) has been proposed to use the topology and the physics of the grid to improve the estimation accuracy, showing promising results [1]. However, multiple improvements are still needed to allow for a practical implementation of this approach.

Methodology: The objective of this project is to add functionalities to a deep learning architecture developed internally. The current model, a physic-aware graph neural network (PIGNN), shows promising results to perform state estimation in the distribution network with limited measurements available. Multiple improvements are needed to reach a functional state estimator, including topology identification, parameter estimation, bad data detection, or cyberattack detection. The choice of improvement to investigate is up to the student.

Research objectives

- Literature review on distribution system state estimation;
- Investigate DSSE optimization problem in Python on a test system with current methods (code ready);
- Develop a module to enhance the model;
- Develop a training workflow with data generation in PandaPower;
- Test the developed approach against state-of-the-art optimization methods and ML-based approaches.

Industry relevance/partner:

DSSE is an active research field for Distribution System Operators (DSOs). This monitoring tool is perceived as the future backbone of the intelligent grid to gain situational awareness in the active distribution system. This research will involve learning key methods of industrial need, such as state-of-the-art ML methods and GNNs, power system modelling, mathematical optimization, and operation of power systems.

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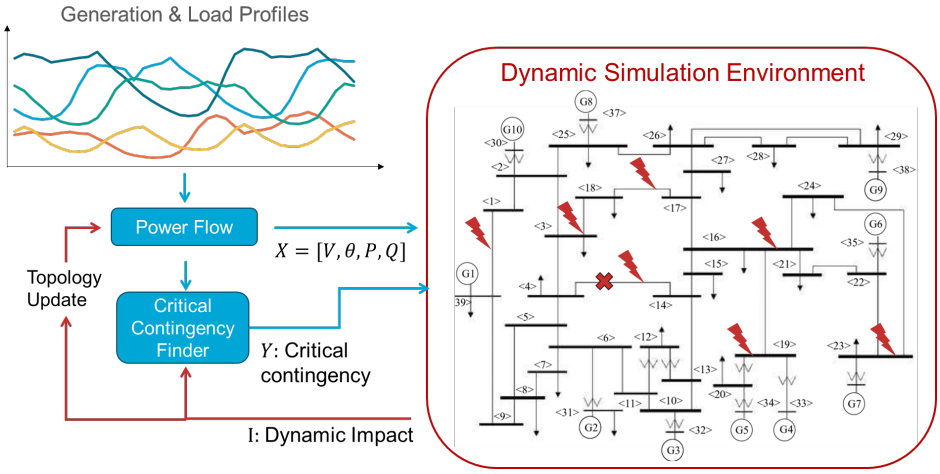
- Supervisor: Dr. Jochen Cremer (j.l.cremer@tudelft.nl)

References

[1] B. Habib, E. Isufi, W. v. Breda, A. Jongepier and J. L. Cremer, "Deep Statistical Solver for Distribution System State Estimation," in IEEE Transactions on Power Systems

Identification of critical disturbances for power system dynamic security



Scope: This project focuses on developing a novel algorithm to identify the most critical contingency against sequential dynamic failures. The identified contingency causes the highest disruption in the system for the selected component and the future failures of the neighboring connected elements. The algorithm uses the static power flow results as an input to select the contingency to be simulated in the dynamic simulation environment.

Problem definition: Decarbonization of the energy supply alters the power systems' operation with more inverter-connected generation. Higher variability in generation combined with new complex dynamics introduced by inverter controllers increases the requirements for dynamic security analysis to avoid power blackouts. Power system operators secure against the possible loss of a single component, but do not carry out dynamic simulations for consecutive failures because of the high computational costs. Intelligent selection of the simulation scenarios can reduce the number of required simulations where the system operators can take necessary planning for the operation.

Methodology: This thesis investigates novel algorithms making a tangible contribution to securing the energy supply in the future. First, you will design the experimental environment for your investigations using DigSilent PowerFactory. In the experimental environment, you will impelemnt the dynamic impact index (*your milestone 1*). This index evaluates the power system dynamic trajectories where the higher magnitude of oscillations and longer settlement time of generator dynamic states increase the impact. Subsequently, you will analyse the literature about algorithm choices, including grid search, reinforcement learning and others (*your milestone 2*). You make a systematic choice on the algorithm, and implement the identification algorithm (*your milestone 3*). Your algorithm will use power flows as input to output the contingency with the maximized cumulative impact after "k" cascading failures

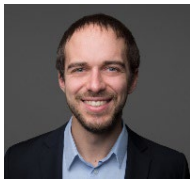
Research objectives:

- Literature review on power system dynamic
- Design of experimental environment with dynamic impact index (with advice from experts by TenneT)
- Literature review on algorithms (optimization, evolutional algorithms, tree search, machine learning, etc.)
- Select algorithm (with support from Delft AI Energy Lab team)
- Analyse the algorithm for various operating conditions

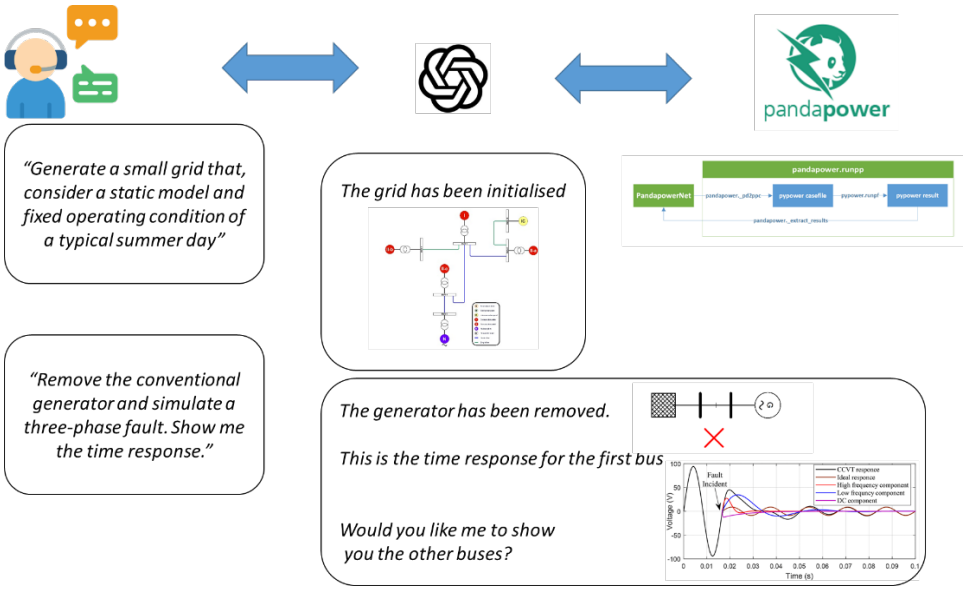
Industry relevance/partner: Security of the operation is a challenging task for transmission system operators like RTE (France), National Grid (UK), or Tennet (NL, DE) in Europe. You are expected to proactively engage with our industry contacts from TenneT.

Contact details:

- PhD supervisor: Mert Karacelebi (m.karacelebi@tudelft.nl)
- Supervisor: Dr. Jochen Cremer (J.L.Cremer@tudelft.nl



Generative Pre-trained Transformer for Sustainable Energy Systems



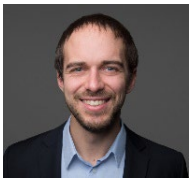
Scope: This thesis project will investigate Large Language Models interfacing with Software to Sustainable Systems

Problem definition: Engineers currently study renewables-based power systems to improve design, feasibility or stability. In conventional power system studies, the electrical power engineer modifies a grid model, simulates the model, analyses the result, and iterates until the study's objective is met. These manual steps, simulation, analysis and conclusion, take time, are subject to the engineer's interpretation and do not scale well with the grid size, the number of analyses and study objectives, etc.

Methodology: ChatGPT has been shown to support programming tasks interestingly well having increased the development speed of Python code and other programming languages. Programmers can now code significantly faster than before by providing *"pseudo"* instructions to a Generative Pre-trained Transformer (GPT). Your investigated methodology will be based on GPT. You will develop Power System Generative Pre-Trained Transformer (PSGPT), the first Application Programming Interface (API) connecting power system software (such as panda power) with ChatGPT.

Research objectives:

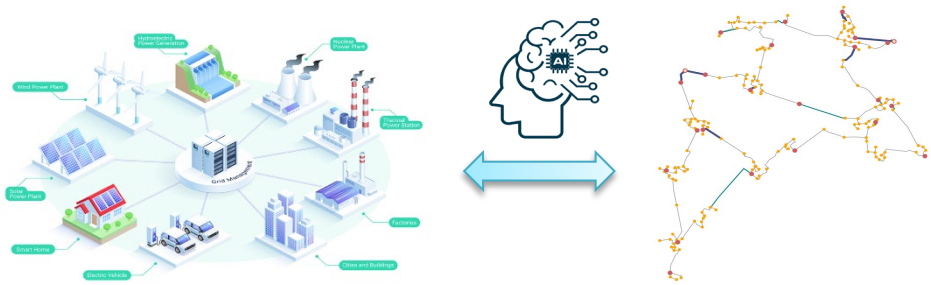
- Create a testbed of a static power grid
- Develop a concept for an API that connects interactive interaction through a GUI with the GPT
- Develop the API to process instruction-based prompts by the user to the power system software. The prompts can be simple modifications of model parameters
- Develop the API further to process information-seeking prompts so the simplified presentation of study results back to the user
- Analyse the accuracy of the user input/output prompts, and develop advice on prompt engineering based on studies where the API fails



Contact details:

- Supervisor: Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)

Measurements in Graph Neural Networks for State Estimation



Scope: This MSc thesis project focuses on one fundamental question: Can Graph Neural Networks reduce the number of measurements needed for an accurate estimation of the power system state?

Problem definition: Distribution systems are taking a more active role in the energy transition. The situational awareness using state estimation is utmost important but not realised yet at all in distribution systems, so a lot of opportunities to develop your own tooling for Distribution System State Estimation (DSSE). Conventional SE algorithms are not suitable for distribution systems as there are only very little measurements. A novel approach [1] based on Graph Neural Network (GNN) learns using the topology and the physics of the grid to improve the estimation accuracy. Yet, it's unclear whether this approach reduces the number of required measurements.

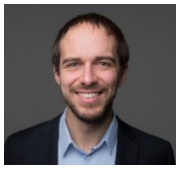
Methodology: You will investigate this model and compare with several baselines. Then, you will develop this method further to rely on a very low number of measurements. You will consider the probability distribution of measurement noise, and aggregated household smart meter data as input to the model. You will investigate message passing and attention-based mechanisms that may enhance the training of the graph neural networks. You then develop a tailored approach that propagates the information from little measurements effectively over the graph neural networks to maximize its learning.

Research objectives

- Literature review on distribution system state estimation, graph neural network architectures, message-passing and attention mechanisms and other novel developed mechanisms
- Develop experimenting environment with varying measurement numbers (based on existing code [2])
- Develop your own module to enhance the GNN model either using advanced information on the measurement distribution and/or on the GNN mechanisms
- Implement 1-2 baseline approaches such as weighted least square method to compare your method
- Analyze your model with experiments comparing against these baselines, and summarise findings in a scientific publication (if results allow)

Industry relevance/partner:

You will be part of the Innovation Center for AI: AI For Energy Grids Lab with Alliander and Stedin as industrial partners. Therefore, your work is directly visible to industry and a group of industrial-PhD researchers. DSSE is a key priority of the lab.



Contact detail:

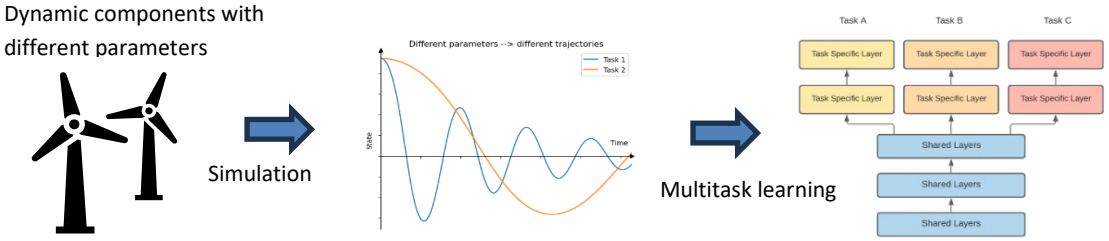
- PhD supervisor: Benjamin Habib (b.habib@tudelft.nl)
- Supervisor: Dr. Jochen Cremer (j.l.cremer@tudelft.nl)

References

[1] B. Habib, E. Isufi, W. v. Breda, A. Jongepier and J. L. Cremer, "Deep Statistical Solver for Distribution System State Estimation," in IEEE Transactions on Power Systems

[2] Starting code https://github.com/TU-Delft-AI-Energy-Lab/Deep-Statistical-Solver-for-Distribution-System-State-Estimation

Multitask Learning of Power System Dynamics with Physics-Informed Neural Networks (PINNs)



Scope & relevance: This thesis project focuses on how the numerical simulation of power system dynamics can be aided and accelerated using Machine Learning (ML) and in particular by multitask learning. The simulation of power system dynamics is a key part of power system operations. The energy transition complicates these simulations and increases their computational cost. Therefore, approaches to accelerate the simulations are of high importance to grid operators to enable the integration of the renewable energy sources.

Problem definition: The simulation of power system dynamics is computationally expensive as it requires the solution of a large number of differential equations. We investigate ML methods, such as PINNs, to accelerate these simulations but it is currently challenging to apply them to large power system. PINNSim, a recent approach, addresses this challenge by training a separate PINN for each dynamic component (usually generators or inverters) in the power grid. However, this might require the training of a large number of PINNs to include all the connected components and for all relevant operating conditions. Conventional numerical methods for differential equations are flexible enough to handle parameter changes but PINNs require retraining the entire model. This leads to the two research questions for this thesis: Which ML methods can we use to exploit the common structure of the physical equations in the training of PINNs? What is the trade-off between accuracy, training time, and evaluation time of the potential methods?

Methodology: You will develop a learning framework that allows the training of PINNs of a power system component type with a range of component parameters. The baseline approach will be to include all relevant parameters in the input to a standard PINN. You will consider alternative approaches that alter the PINN architecture to exploit the shared structure in the differential equations. Potential candidates for such methods are operator, transfer, and multitask learning. You will implement at least one approach and compare the results against the baseline with respect to the achieved accuracy, the required training time, and the evaluation time of the trained model.

Research and learning objectives:

- Develop a deep understanding of PINNs and multitask learning. Formulate the learning tasks.
- Establish a credible benchmark and a standardised ML pipeline in Python or Julia.
- Score advanced methods against the benchmark.
- Analyse conceptual benefits and limitations of the different methods.
- Disseminate results to a scientific article if results allow.

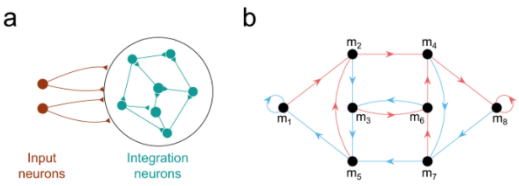
Industry relevance : You will gain hands-on experience in numerical methods and training of PINNs. Your research will be part of the NWO VENI Project #19161 with industrial partners TenneT, Stedin and TNEI Energy Consultancy. You will present your thesis findings to representatives from the project consortium.

Who should apply?: This research lies at the intersection of power systems, numerical methods and ML. We aim to combine the best of each, hence, the question "Why does this method work or not work?" will occur regularly. Does this question excite you? If the answer is yes and you are familiar with either ML, dynamical systems, or differential equations, this thesis might be for you.

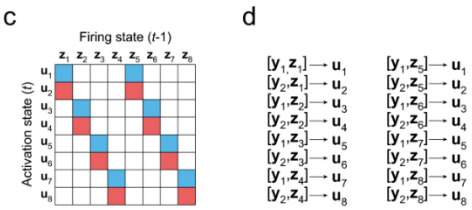
Contact & Supervision:
Ola Arawolo (o.a.arowolo@tudelft.nl)
Jochen Stiasny (J.B.Stiasny@tudelft.nl)
Jochen Cremer (J.L.Cremer@tudelft.nl)

Neural Network for N-k Security Constrained AC Optimal Power Flow

Scope: This thesis project will focus on developing a neural network that is trained for a N-k Security Constrained AC Optimal Power Flow. You will combine linear algebra and end-to-end learning to train a neural network that predicts the N-k security constrained AC optimal power flow (SCOPF).



Problem definition: With conventional methods the N-k SCOPF can only be solved for small k. The objective of the SCOPF is to compute a secure operating condition for a grid where k equipment failures. The number of equipment's like generators will drastically increase due to decentralization of energy resources which is why the combinatorial challenge to consider N-k equipment outages increases raising an additional serious threat to systems: cascades.



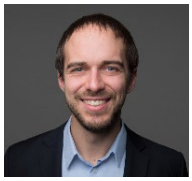
Methodology: You will develop a neural network that exploits the structure of the power system using linear algebra. There, you will investigate suitable neural networks structures, and decide for one structure based on thorough analysis. Then you will invent a tailored loss function for training your Neural Network structure that predicts solutions for the N-k SC AC OPF by just considering N-1 failures. You will then maximize the capability to generalize to N-2, N-3,… N-k faults of this trained Neural network that you have trained with your developed structure-exploding loss function considering only N-1 failures. You will implement your developed method in standard packages from Python using CVXPY, Numpy, Pytorch, and other packages.

Research objectives

- Literature review on neural networks, backpropagation algorithms, linear algebra, linear, convex, and graph-based formulations of optimization problems
- Study about AC Optimal Power Flow formulations, select a convex relaxation or distributed approach to solve the AC OPF, then, design a method that generates N-1 Secure Optimal AC solutions. Sele
- Design a supervised learning workflow training to predict N-1 secure solutions substituting SC ACOPFs
- Developing a neural network structure exploiting the structure of N-k SCACOPFs to predict for N-k solutions
- Develop a training workflow for N-k SC ACOPF predictions combining concepts from linear algebra, mathematical optimization and neural networks
- Test the method on its generalizability from N-1 to N-k faults. Test on different power system networks.
- Disseminate results to scientific article if results allow.

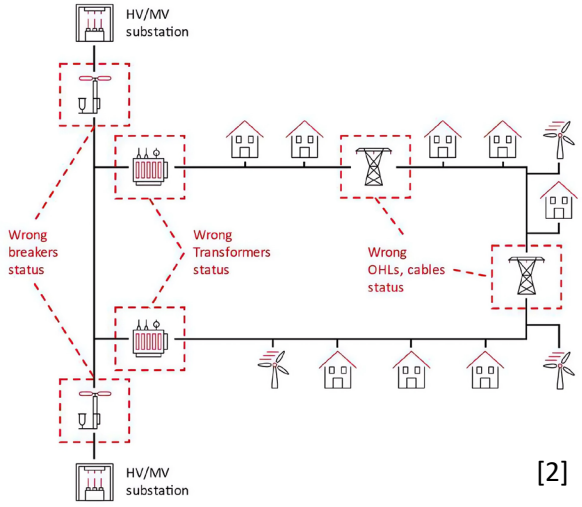
Additional note: This thesis topic is thought through, ambitious, challenging and likely leads to a scientific publication. This project is recommended if you consider to pursue a PhD afterwards. Hence, please only apply as an outstanding individual demonstrated with high-performing grades, strong scientific interest, critical thinking and independence. **Starting code:** https://github.com/TU-Delft-AI-Energy-Lab/Constraint-Driven-SCOPF

Industrial relevance: Assessing the power system for N-k faults is of utmost importance for system operators like TenneT. If you develop a novel methodology that can solve this ambitious and challenging problem you are in a very good position to enter the job market being qualified: with relevant skills (ML/AI) and important engineering skills to address key issues of energy transition.



Contact details: Supervisor Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)

Predicting tap-changer positions with imperfect machine-learning



[2]

Scope: This thesis project will investigate weakly-supervised learning with imperfect models for predicting active tap changer positions within distribution grids

Problem definition: Distribution system operators often have incorrect information about their grid topology, most importantly the position of tap-changing transformers. Distribution system state estimation and topology identification are arguably the most profound functions of the distribution system, but they are not available yet as distribution grids are low-observable as few measurements are placed. The problem is to learn a model with machines that can identify the topology from the few noisy measurements available.

Methodology: The investigated methodology adopts calibration and regularization, considering the availability of imperfect state estimation models. You will develop your method for a weakly supervised learned graph neural network trained for state estimation. You then will investigate your method on real distribution system data provided by Alliander and integrate it with the Power Grid Model Alliander and Linux Energy Foundation developed.

Research objectives:

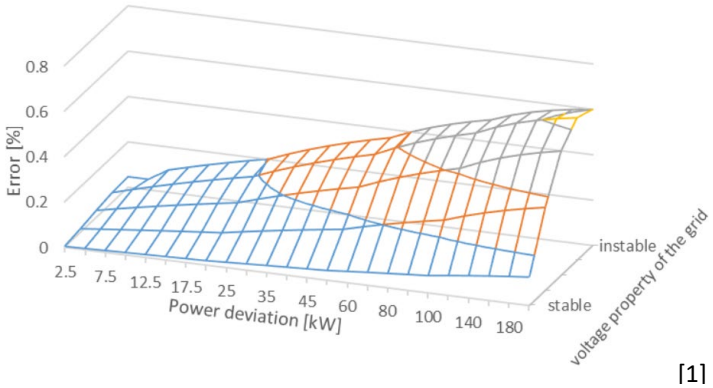
- Creating a testbed with imperfect models of tap changes within the distribution grid state estimation
- Develop an algorithm for identifying tap changer location based on measurements
- Develop an algorithm that learns state estimation with imperfect forward models of the grid topology
- Test the approach on Alliander grid data and publically available IEEE test systems
- Disseminate your method in a scientific publication

Industry relevance/partner: You will be part of the Innovation Center for AI: AI For Energy Grids Lab with Alliander and Stedin as industrial partners. Therefore, your work is directly visible to industry and a group of industrial-PhD researchers.

Contact details:

- Supervisor: Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)
- Company supervisor: Dr. Tony Xiang (tony.xiang@alliander.com


Machine Learning to predict Flexibility from Energy Storage



[1]

Scope: This thesis project develops an Machine Learning (ML)-based algorithm to estimate the nodal voltage and line loading sensitivity to nodal power injections in distribution networks, purposed for flexibility estimation of for example energy storage and distributed energy resources (DERs).

Problem definition: The massive increase of renewables and distributed generation in power systems led to higher variability and unpredictability, which is where energy storage is handy to mitigate the variability. Distributed generation and active storage prosumers can offer their flexibility to mitigate issues arising from this unpredictability. Therefore, the distribution network's sensitivity to their power injection/consumption can be estimated to accurately anticipate the impacts of energy storage and other flexibiliry resources. In addition, analyzing the sensitivity of nodal voltage to the nodal power injection is a significant part of voltage prediction and control in power networks [2]. Estimating the nodal voltage and line loading sensitivity to power injections can be slow and inaccurate, especially when the capacity of energy storage is fully used. ML-based algorithms can estimate the nodal voltage and line loading sensitivities with limited knowledge of the network. ML-based algorithms can be faster, less prone to the number of measurements available, adaptable to new network conditions, and less prone to uncertainties from renewables.

Methodology: You will initially study the problem of nodal voltage and line loading sensitivity to changing energy storage power curves. Then, you will study graph neural networks (GNNs), one type of ML model, and apply them to the sensitivity estimation problem with varying storage capacity. Finally, you will report the findings on the accuracy, speed, and adaptability of the algorithm compared to existing approaches. You will also report how much more renewable energy can be implemented when the sensitivity is accurately estimated.

Research objectives:

- Learn about nodal voltage sensitivity to nodal power injections, energy storage power curves,
- Learn about line loading sensitivity to nodal power injections, and the impact of energy storage,
- Learn and apply ML algorithms such as GNN,
- Develop an algorithm estimating the sensitivity for any network topology,
- Communicate findings to energy system modelers and AI experts in a publication

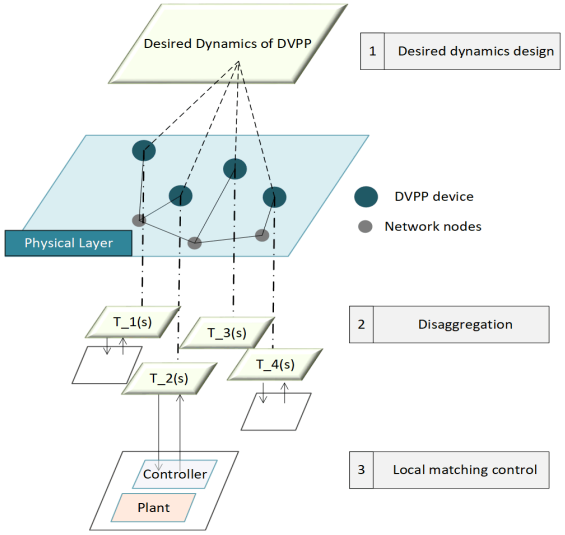
Industry relevance/partner: This research is part of the MEGAMIND project (https://megamind.energy/).

Contact details:

- Demetris Chrysostomou (D.Chrysostomou@tudelft.nl),
- Dr. Jochen Cremer (J.L.Cremer@tudelft.nl),
- Dr. Jose Rueda Torres (J.L.RuedaTorres@tudelft.nl)



Dynamic Electric Vehicle Virtual Power Plants



Scope: This thesis project develops the concept of Dynamic Electric Vehicle Virtual Power Plants (DEVVPP) for the first time. You will develop a control strategy for converter-based charging stations of EVs in a virtual power plant to track a given grid dynamic accurately. This interdisciplinary project bridges advanced control theory with low-inertia grids and with charging stations of Electric Vehicles (EVs) providing flexibility to the grid, and the results are expected to be validated on the RTDS simulator such that the effectiveness of the developed framework can be guaranteed.

Problem definition: Dynamic Electric Vehicle Virtual Power Plants (DEVVPP) coordinate groups of EV charging stations and individual EVs to offer dynamic ancillary services and thus enter the ancillary market. To form the desired dynamics required from transmission system operators, the owner/operator of DVPPs needs to coordinate and send (control-) signals to each EV-charging station with disaggregated grid dynamics. The local controllers of the participators should be designed to accurately track their disaggregated dynamic and adapt to the changes in the dynamic caused by the uncertainty of the EV driver behaviors, the charging station schedulers, and the renewable energy uncertainty.

Project deliverables:

- Literature review and study of modelling renewable energy sources, EV charging control approaches, and adaptive control theory.
- Develop a test system including a model of transmission system considering frequency dynamics, and charging station modelled as inverter based resources
- Implement an adaptive control method (e.g. H_∞ control, robust model predictive control) for the DEVVPP.
- Theoretical analysis and simulation validation on Real Time Dynamic Simulator *(optional for high grade)*

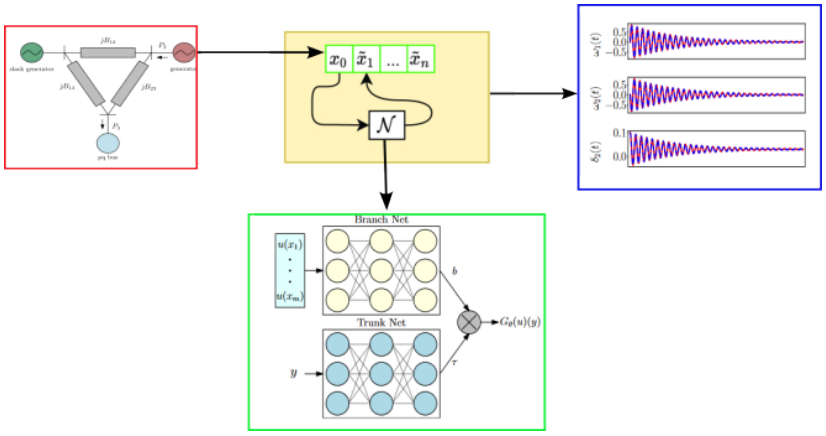
Requirements:

- You have a strong interest in electric vehicles, energy system modelling and simulation
- You have a solid background in control theory, power system analysis, and electric vehicles (eg track/profile)
- You are good at communication and easily interact with the team.

Contact details:

- PhD student: Haiwei Xie (H.Xie-2@tudelft.nl)
- Supervisor: Jochen Cremer <J.L.Cremer@tudelft.nl>

Deep operator neural network for power system simulations



Scope: This thesis project will investigate Deep Operator Neural Network (DeepONet) for learning the solutions of differential-algebraic equations describing a power system's dynamics.

Problem definition: Transient stability analysis in power systems is usually performed by time-domain simulations in which the non-linear differential-algebraic equations of the system are solved using numerical integration techniques. However, the set of differential equations which describe the system is stiff, which means they have widely differing time scales. As the complexity of the dynamics of the power system increases with more renewable energy sources, the modelling detail required for time domain simulation also increases. Also, stiffness increases with modelling details [1]. Stiff differential equations are challenging to solve and require integrating with a very small time step to avoid numerical instabilities. This makes solving computationally expensive and real-time time domain simulations difficult [2].

Methodology: The proposed methodology uses deep operator neural networks to approximate the solution operator of the differential-algebraic equations describing the power system dynamics. Deep Operator Networks can approximate any solution operator similar to how deep neural networks can approximate any function. Deep operator networks have already been used to approximate the dynamic response of a synchronous generator[3]. In this project, we would adopt the DeepONet method to approximate the response of a power network which contains renewable energy sources such as wind or solar. The DeepONet model would be integrated into a time domain simulation tool which can be used to predict the response of the power network to a disturbance.

Research objectives:

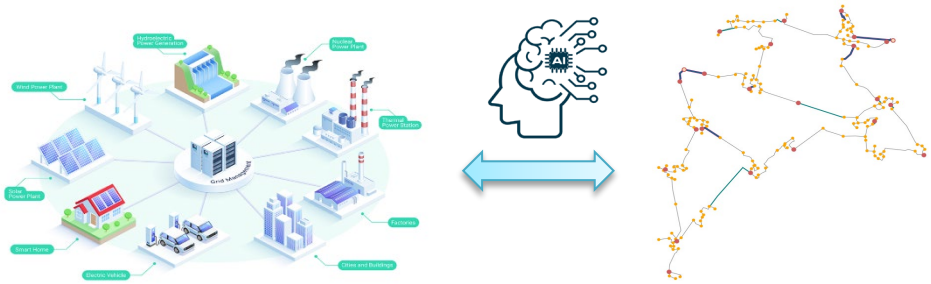
- Perform literature review on solving differential algebraic equations for time domain simulation in power systems
- Develop DeepONet model for solving the differential algebraic equations of the test power system
- Integrate the DeepONet model into a time domain simulation framework
- Verify the performance of the simulation approach on transient stability study cases

Industry relevance/partner: This project is directly sponsored by TenneT and is directly relevant to the industry.

Contact details:

- PhD Supervisor: Ola Arowolo (O.A.Arowolo@tudelft.nl)
- Supervisor: Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)
- Company sup.: Dr. Jan Viebahn (jan.viebahn@tennet.eu)

Improvement of Physic-Informed Deep Learning model for Situational Awareness in the Distribution System



Scope: This MSc thesis project focuses on enhancing a deep learning method based on physic-aware graph neural networks to enable real-time monitoring of the complex and uncertain distribution grid.

Problem definition: Distribution systems are taking a more active role in the energy transition. These active distribution systems require more extensive monitoring and control, which is possible by developing Distribution System State Estimation (DSSE). Conventional SE algorithms are challenging to adopt in distribution systems due to the size and shape of the distribution grid and the lack of real-time measurements. A novel approach based on Graph Neural Network (GNN) has been proposed to use the topology and the physics of the grid to improve the estimation accuracy, showing promising results [1]. However, multiple improvements are still needed to allow for a practical implementation of this approach.

Methodology: The objective is to add functionalities to a deep learning architecture developed internally. The current model, a physic-aware graph neural network, show promising results to perform state estimation in the distribution network with limited measurements available. Multiple improvements are needed to reach a functional state estimator, including topology identification/robustness, parameter estimation, bad data detection, or cyberattack detection. The choice of improvement to investigate is up to the student.

Research objectives

- Literature review on distribution system state estimation;
- Investigate DSSE optimization problem in Python on a test system with current methods (code ready);
- Develop a module to enhance the model;
- Develop a training workflow with data generation in PandaPower;
- Test the developed approach against state-of-the-art optimization methods and ML-based approaches.

Industry relevance/partner:

DSSE is an active research field for Distribution System Operators (DSOs). This monitoring tool is perceived as the future backbone of the intelligent grid to gain situational awareness in the active distribution system. This research will involve learning key methods of industrial need, such as state-of-the-art ML methods and GNNs, power system modelling, mathematical optimization, and operation of power systems.

Contact detail:

- PhD supervisor: Benjamin Habib (b.habib@tudelft.nl)
- Supervisor: Dr. Jochen Cremer (j.l.cremer@tudelft.nl)

References

[1] B. Habib, E. Isufi, W. v. Breda, A. Jongepier and J. L. Cremer, "Deep Statistical Solver for Distribution System State Estimation," in IEEE Transactions on Power Systems

OPTIMAL POWER SUPPLY MIX FOR RELIABLE OPERATION OF A 500 MW ELECTRIFIED INDUSTRIAL LOAD

Scope – This thesis project will focus on identifying optimal mix of power sources to reliably supply an electrified industrial load of 500 MW capacity in the Netherlands, Botlek area.

Problem Definition – Electrification of industry is an important strategy in reaching net zero emissions. However, there are many challenges associated with electrifying industrial sites, both in the short and long term. The primary challenge is reliability of continuous supply.

In the near future, by 2035, renewable power generation growth can outstrip the pace of development in grid infrastructure leading to congestion issues affecting reliability of supply to industrial electric loads. The first problem is identifying issues that threaten supply reliability – examples may be grid congestion, network component outages. and quantify their impact in size and duration.

The second problem is to identify the measures which will enhance the supply reliability such as storage, hydrogen power generation and methane gas turbine, and assess viability of the solution based on cost, carbon intensity and, reliability of supply.

Thirdly, assess this mix power generating fleet based on distinctive characteristics of the industrial load such as ramp rate, energy capacity, and other constraints based on the load type.

Methodology – The first step is to conduct a relevant literature study on power system challenges that impact reliability of supply to large industrial electrical loads in 2035 and beyond. For identifying congestion related issues, a representative grid model of Botlek industrial area will be developed. The next step would be to identify the set of resources that can address this reliability of supply challenge. Finally, using dispatch simulation, identify an optimal mix of resources for various levels of reliability of supply based on their costs, carbon intensity, etc.

Research Objectives – This research project's objective is to develop detailed insight into the challenges facing electrification of industrial loads from a reliability of supply perspective in 2035 and beyond. The thesis project will investigate these questions and propose solutions to overcome these challenges.

Expected Outcomes – Listing of reliable supply strategies along with their cost of implementation, their reliability contributions, and their carbon intensity based on load characteristic for an industrial site looking to decarbonize.

Industry partner – Shell (Student will be expected to spend 1 day a week at Shell office in Amsterdam)

Contact details:

- José Rueda Torres (j.l.ruedatorres@tudelft.nl)

ASSESSING THE ROLE OF DEMAND SIDE RESPONSE FROM INDUSTRIAL LOADS IN FUTURE POWER SYSTEMS

Scope – This project will focus on researching challenges arising from developments in power grid infrastructure and markets within NL and Europe and understanding the role of flex from electrified industrial loads in addressing those challenges.

Problem Definition – Growth in renewables and the push for electrification impacts grid infrastructure expansion plans as well as impact markets for electricity. Increased variability and unpredictability in the far horizon, coupled with insufficient grid infrastructure to transport generated green electrons to load centers leads to unfavorable prices in the power market. For an industrial load, assumed to run continuously, high price prices can be detrimental to economics. The first challenge is to understand power price peaks and assess their development in 2035 scenario with current grid infrastructure, known grid expansion plans (such as interconnections), and expected European load and generation developments in mind. To protect against these price peaks, flexibility is a key asset. Therefore, the second challenge is to evaluate various flex options to protect against high power prices.

Methodology – Using spatial information on expected new generation (wind, solar, and nuclear), demand (increased demand from industry, residential and commercial.), interconnectors, and grid capacity in 2035 (in accordance with expansion plans), develop insight into factors that will impact power prices in the Netherlands. Next, assess storage (both long and short term), and industrial flex (from curtailing own process) as a potential solution to mitigate the impacts of high power prices using a dispatch simulation. To enable different strategies, economic parameters, such as CAPEX (Capital Expenditure), OPEX (Operating Expenditure) (for enabling flex) and product value (for curtailing), need to be developed. Sensitivity analysis will be conducted with variations of parameters that characterize the flex industrial load to evaluate different strategies.

Research Objectives – The key research objectives are:

1. Conduct a literature search from past reports such as from TNO, TenneT, Elia, RTE, VITO, Klimaatplan etc. and create a base for further study
2. Develop insights on power price developments in electrical power markets in 2035
3. Develop economic parameters, such as CAPEX, OPEX and product value for two industrial processes. Shell experts will help to achieve this objective.
4. Investigate the role of flexibility in protection against high power prices
5. Evaluating flexibility in industrial process and storage (long and short duration) in lowering costs

Expected Outcomes – A better understanding of the impact of developments in electrical power generation, demand, and grid on power price peaks, and strategies to reduce price peak for industrial loads.

Industry partner – Shell (Student will be expected to spend 1 day a week at Shell office in Hague)

Contact details:

- José Rueda Torres (j.l.ruedatorres@tudelft.nl)

Method for rotational inertia metering and forecasting in low-inertia power system

Scope: The main objective of the proposal to be developed is to measure and forecast rotational inertia in low inertia power systems due to the high penetration of electronic power converters, through innovative artificial intelligence techniques.

Problem definition: The increasing penetration of power-electronic interfaces, such as wind and photovoltaic generation plants, devices is expected to have a significant effect on the overall system rotational inertia. This has led to a massive displacement of system inertia, with networks now requiring enhanced system visibility and understanding to deliver fast acting response services. Currently, the reduction of inertia is having drastic consequences on protection and real-time control and will play a crucial role in the system operation. The inertia of European electricity grids is estimated to continuously decrease next year. In the United Kingdom and Germany patterns of inertia decrease are emerging in their electricity grids. For this reason, on 2nd of August 2017, the European Commission approved a regulation for Transmission System Operators (TSOs) to approach the decreasing levels of inertia (*Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation*). In Chile (Splight[1] case study), according to studies by the national electrical coordinator (CEN) carried out in 2020, for an accelerated decarbonisation scenario (2026), there would be a problem with the levels of systemic inertia, especially in the northern region *(Análisis de la Operación y Abastecimiento del Sistema Eléctrico Nacional de Chile en un escenario de retiro total de centrales a carbón al año 2025, septiembre 2020, Coordinador Eléctrico Nacional.*) The study describes that the lack of inertia levels will occur during the day, due to a high penetration of Variable Renewable Energy (VRE). From Splight[1] we observe it is mandatory to introduce real time tools able to monitor and forecast the system inertia through methods based in artificial intelligence and data driven by means of PMUs (phasor measurement unit). The solution to be developed consists of calculating/estimating and forecasting the critical rotational inertia in real time of the Northern Chile system of the SEN (model in DigSilent Power Factory), in order to be able to adequately integrate VRE, reduce operating costs (inertia reserve) and mitigate formation risks of islands or blackouts.

Tasks:

The work methodology to achieve the proposed objectives is summarized by the following activities/taks:

- A review and analysis of the state-of-the-art of the different methods for the estimation and measurement of inertia and rotation.

- Study and implement mathematical models of a power system (generators, converters, dynamics loads, controllers, etc.) for the generation of exhaustive data in DIgSILENT PowerFactory.

- Study and methodologies for the generation, processing and acquisition of data based on synchrophasor measurements (PMU) IEEE Standard for Synchrophasor Measurements for Power Systems (IEEE Std C37.118.1) and development of a cloud-based in Amazon Web Services (AWS) or others.

- Study and development of innovative algorithms based on data analysis, forecasting, machine learning, neural networks, data driven, for calculation / estimation of total inertia of the system.

- Analysis of results and comparison of the proposed methods for the proposed rotational inertia calculation considered region power electronic convert and load impact.

· Simulation and validation techniques propose physical and virtual model systems in laboratory (in-side and remote platforms).

1: SPLIGHT ARTIFICIAL ENERGY (https://www.splight-ae.com/)

The Splight Lab is an open environment where our resources and expertise are made available to external developers (whether clients, partners, corporates, universities, NGOs, government agencies or independent individuals) who are willing to explore, co-create or co-develop with us innovative ideas and solutions for the energy industry using our digital and business platforms as a sandbox. This collaborative setting is the cornerstone of the Splight platform, where a diverse ecosystem of players come together to change the energy paradigm and deliver a cleaner, more equitable and sustainable world. We are the bridge between the worlds of energy and digitalization. Our business model is based on a constant dialog among our team of energy experts, who work closely with our clients to identify opportunities for technological improvement, our team of data scientists, machine learning engineers and cloud architects, who develop and implement tailor-made digital solutions for our clients, and our team of technological translators, who operate as the interface between business and technical stakeholders.

Proposal:

With the aim of creating an incentive for the student (s) of the project. Splight offers to carry out a month of research tasks at its facilities, in the provinces of Mendoza and Cordoba of the Argentine Republic. This incentive includes roundtrip tickets, accommodation and vouchers for lunch and dinner.

The space that Splight offers for the research project on systemic inertia is up to two people.

Knowledge of the Spanish language is valued, but this is not an exclusive requirement.

Contact details:

Supervisors:

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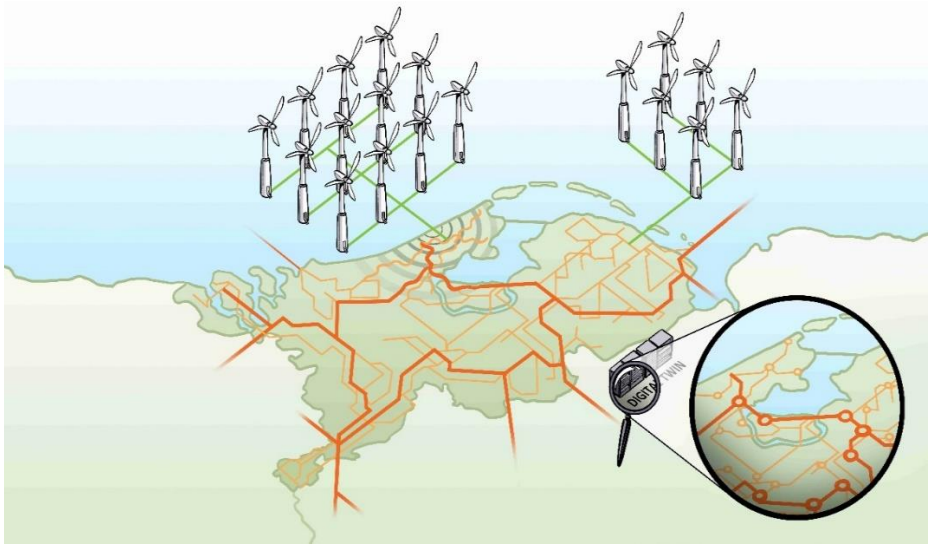
RMS Digital Twin of the 380 kV Dutch Transmission System



Scope: Definition, implementation, and testing of an RMS model of the Dutch high voltage transmission system in order to perform dynamic security assessment in future operational scenarios and topologies.

Problem definition: The Dutch power system will experience a major technological upgrade by year 2050. In such future situation, it is expected that at least 50% of the power supply is done by power electronic interfaced renewable generation plants, and that these plants and multi-GW scale responsive demand provide support in primary controls tasks to safeguard the overall system stability. Due to high variability of operating conditions, it is expected that new forms of dynamic phenomena occur, which will have special and unprecedented properties (e.g. time varying frequency and damping of oscillations in the range 0-100 Hz). The overall goal of this thesis work is to develop a RMS Digital Twin of the future 380 kV Dutch Transmission system, which can facilitate: i) Deep understanding of the main factors behind new forms of dynamic phenomena (i.e. frequency stability, rotor angle stability, and voltage stability); ii) Developing tools to ensure proper initialization and continuous tuning of different components of the Digital Twin. The whole work will be conducted by using DIgSILENT PowerFactory.

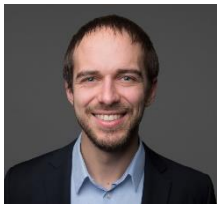
Tasks:

- Literature review of the different techniques used for RMS modelling and simulation of power electronic dominated power systems.
- Develop a RMS Digital Twin by using RMS generic models and parameters defined in IEEE and CIGRE standards. The Digital Twin shall have different operating points, topologies, and dispatch conditions including:
    - Different amount of conventional and renewable generators with their control systems
    - Different models of transmission lines (HVAC and HVDC) and controllable loads (e.g. electrolysers).
    - Dynamic equivalents of neighboring countries and subsystems in lower voltage levels (e.g. 200 kV, 150 kV, 110 kV).

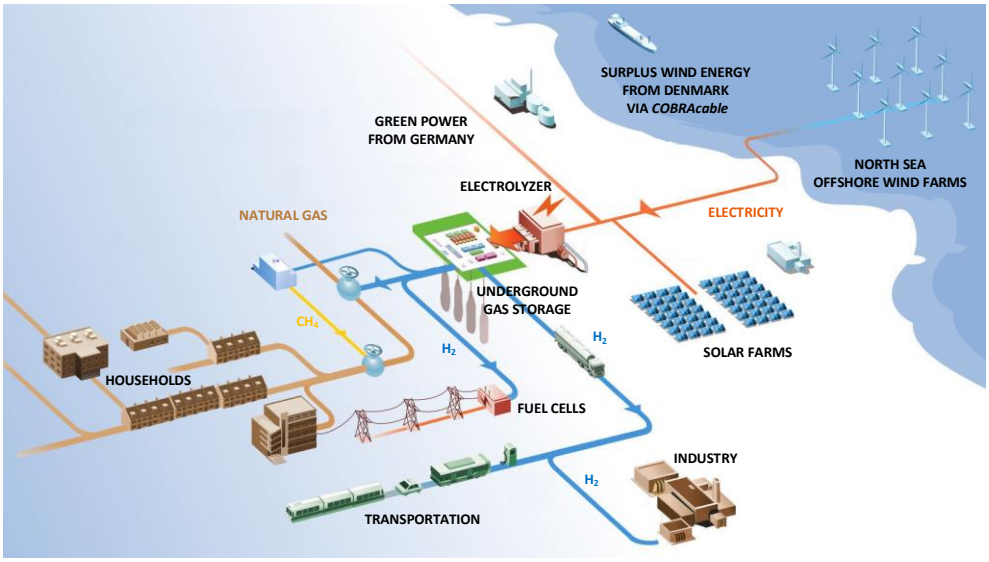
- Identify and test different perturbations in the system with the goal of performing dynamic security assessment and sensitivity analysis based on signal processing techniques.
- Development of a method to ensure optimal initialization in each simulated condition
- Development of a data-driven feature method that analysis the features of simulated conditions and adjust the initialization for maximized exploration
- Train a machine learning classifier for real-time dynamic security assessment.

Contact details:

- Supervisors: José Rueda Torres (j.l.ruedatorres@tudelft.nl) and Jochen Cremer (J.L.Cremer@tudelft.nl)



Modular converter topology for accurate modeling of large scale elecltrolyser



Scope: This thesis project will focus on developing modular converter topology for large scale electrolyser application in the range of hundreds of MW.

Problem definition: The scale of pilot Power-to-Gas projects built to date range from 100 kW to 10MW. The maximum rated power of one electrolyser module, that is already available in the market is about 2 MW to 3 MW. On the other hand, the capacity required for commercial projects in future will likely be large scale with capacities in the range of tens to hundreds of MW. Therefore a proper modular topology should be proposed in order to fulfill the needs of future power system industry. In addition, the understanding of interactions of large scale electrolysers within the power system, can be facilitated with practical models.

Methodology: The challenge is to model the proper topology for accurate modeling of large scale elctrolyser system. To achieve this purpose, one electrolyser module with the maximum rated power will be implemented in PowerFactory, and then modular topology of electrolyser modules will be formed to represent the real layout of large scale electrolyser.

Research objectives:

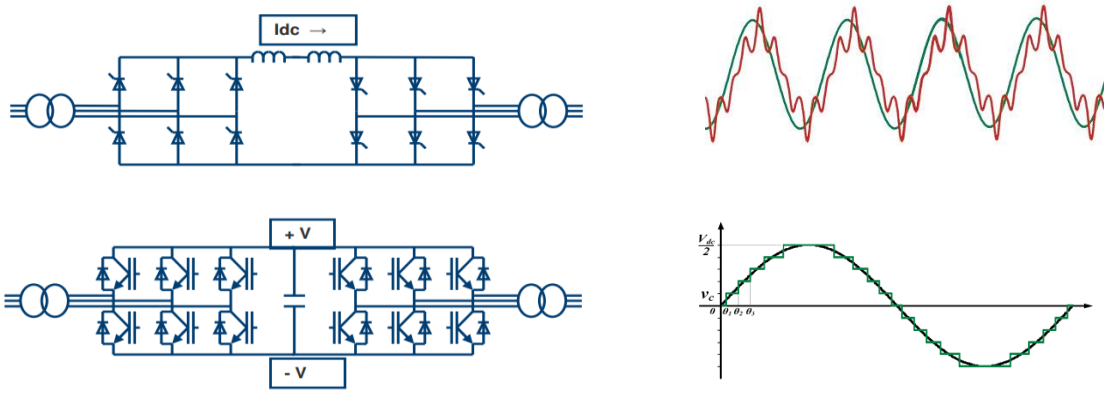
- Presenting the modular converter topology for accurate modeling of real large scale electrolyser.
- Investigating the reduction of total harmonic distortion (THD) in large scale electrolyser.
- Proposing the control scheme, required to extend the capabilities of electrolysers for ancillary service applications.
- Testing the robustness of controllers, when disturbances occur in power system.

Industry relevance/partner: You will learn about advanced modeling of modular converter topology for large scale electrolyser and you will get experience in one of the major industry tools in PowerFactory.

Contact details:

- Supervisor: Jose Rueda Torres (J.L.RuedaTorres@tudelft.nl)

Fundamental harmonic study of systems with LCC+VSC technologies



Scope: This thesis project is focused on developing a simulation study in order to analyze the harmonic generation produced by Line Commutated Converter (LCC) and Voltage Source Converters (VSC).

Problem definition: The progressive increment in the integration of renewable energy sources into the power systems is directly influencing the amount of Power Electronics (PE) devices connected to the electricity grid even at transmission levels. For that reason a fundamental study at harmonic frequencies will result interesting in order to contribute with solutions for avoiding polluted harmonic grids in the future.

Methodology: You will analyze and compare the harmonics generation produced by Line Commutated Converter (LCC) and Voltage Source Converters (VSC) close each other, as a direct consequence of the control structures present in these two types of HVDC technologies. After that, you will recommend (or propose) relevant actions in order to contribute to reduce the total harmonic distortion (THD) in the system if there is a violation detected in the grid.

Research objectives:

- Review and definition of technical specifications for VSC and LCC systems.
- Partial modelling of the LCC+VSC systems.
- Perform sensitivity analysis of the control functions associated.

Industry partner: No

Contact details:

- Supervisor: José Rueda Torres (j.l.ruedatorres@tudelft.nl)

HVDC based rotating synchronous inertia online estimation

Scope: Definition, implementation, and testing of HVDC functionality in order to accurately measure AC network's system rotating synchronous inertia.

Problem definition: Large scale deployment of Renewable Energy Sources (RES) in particular inverter connected wind turbines and photovoltaics (PV) which do not provide rotational inertia, are effectively displacing conventional generators and their rotating machinery. This trend has the potential to considerably reduce the power system's rotational inertia, which has implications for frequency dynamics and power system stability. Since frequency dynamics are faster in power systems with low rotational inertia, this makes the frequency control and power system operation more challenging [2].

Transmission system operators (TSO) typically rely on offline estimation of the system inertia, however an on-demand online measurement of the system inertia can be performed by injecting a perturbation from the HVDC converter into the grid and by analyzing the grid's response.

With an on-demand inertia measurement available, TSOs can better plan their dispatch and spinning reserves. Such measures would improve system stability and avoid load shedding due to frequency deviations as occurred in the UK on August 2019 [5].

This work will test the use of Artificial Neural Networks (ANN) for the task of the network inertia estimation and compare results with more conventional methods of inertia estimation [1][2][3][4].

Tasks:

- Literature review of the different techniques used to measure inertia
- Develop a Test system in PSCAD EMTDC (e.g. 39-bus, 10 generators, New England Test System) including an HVDC converter where the inertia will be measured at the point of connection during simulations. The test system shall have different operating points and dispatch conditions including:
    - Different amount of generators/governor controls
    - Big fault level range and the point of connection of the HVDC.
    - Different status of transmission lines and loads
- Identify and test different perturbations in the system (Active power ramp/step or others) and measure frequency deviations and RoCOF, with the goal of using the measurements of the AC network's reaction to estimate the system inertia in [GVA·s].
- Evaluate different methods of using the measurements obtained in simulations to estimate the system inertia.

References:

1] O. Beltran "*Inertia Estimation of Wind power Plants based on the swing equation and phasor measurement units*" November 2018. Journal of applied Sciences.

[2] A.Ulbig "*Impact of low rotational inertia on power system stability and operation*". Elsevier IFAC proceedings Voume 47, Issue 3. 2014.

[3] Mengran Yu "*Effects on swing equation-based inertial response control on penertraion limits of non synchronous generation in the GB power system*". IEEE International Conference on Renewable Power Generation (RPG 2015)

[4] Thongchart. K. "*Robust virtual inertia control of a low inertia microgrid considering frequency measurement effects*" 'IEEE Access April 2019.

[5] Interim Report into the Low Frequency Demand Disconnection (LFDD) following Generator Trips and Frequency Excursion on 9 Aug 2019. National Grid August 2019.

Industry partner: Siemens AG, Erlangen Germany :Alvaro Hernandez

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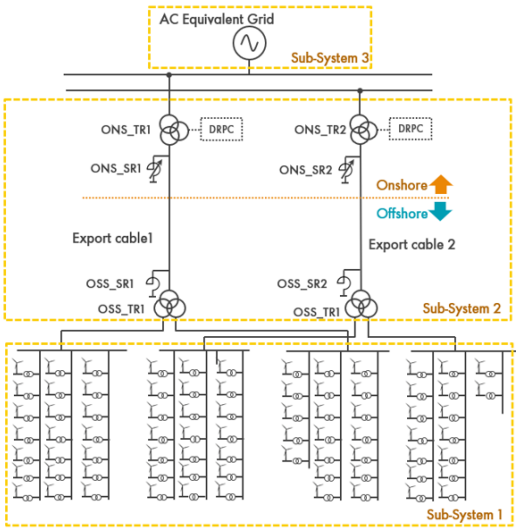
Contact details:

- Supervisor: José Rueda Torres (j.l.ruedatorres@tudelft.nl)
- Co-supervisor: (alvaro.hernandez_manchola@siemens.com)

Development of grid code compliance tool for gfm technology



Based on the grid compliance and test procedure in offshore wind farm development (ION interim operation notice)

Compliance Simulations

- Test of 3,2 and 1-phase faults, for various voltage dips.
- Test of LVRT Curve.
- Test of P Control, FSM, and LFSM-O/U
- Test of Q Control, voltage and PF control
- Test of df/dt (RoCoF)
- Test of Phase Jumps
- Test of Reactive Power Capabilities

Scope: In recent years, as grid-forming (GFM) technology emerging as one of the key technology enablers for renewable energy source integration, many developers, OEMs together with TSOs are releasing out guidelines regarding how to proper define the grid codes and efficiently test the GFM power park modules. This work is a joint industry project with Shell, focused on developing an automatic test tool for the GFM grid code compliance test which will be based on the practical ION process (interim operation notice) adopted by many system operators. The project will be initially based on offshore wind farm (OWF) application, but has potential to extend to other scenarios e.g. PV and ESS applications.

Problem definition: Developing grid compliance tool for test GFM grid connection performance, using Python together with power system study tools, e.g. PSCAD and PowerFactory (master of PSSE is considered as plus).

Methodology:

- Step 1: Get familiar with grid code requirement for GFM and ION process, as well as offshore wind farm modelling.
- Step 2: Build up the automatic test tool with Python to fulfill the grid compliance test cases, starting with EMT study based on PSCAD. For example, the test cases include: various fault dips scenarios, active power and frequency control test, reactive power and voltage control test, phase jump test etc.
- Step 3: For the frequency and voltage requirement, build up the automatic test cases with Python and RMS tool as PowerFactory.

Research objectives:

- Get familiar with grid code requirement especially for the GFM technology.
- Develop automatic grid compliance test tool for GFM based power park module.
- Conduct the automatic test and validate the dynamic and static performance of GFM based OWF.

Industry partner – Shell (Student will be expected to spend 1 day a week/month at a Shell office in The Hague/Amsterdam)

Contact details:

- José Rueda Torres (j.l.ruedatorres@tudelft.nl)
- Dan Wu (dan.d.wu@shell.com)

Analysis and Enhancement of VSC-HVDC Power Oscillation Damping

Scope: Analysis of the damping behavior of the VSC-HVDC systems with different operation/control modes in the low frequency range of around 0.1Hz to 2.0Hz. Evaluating existing control schemes in literature and propose enhancements to mitigate any instabilities in this frequency range.

Problem definition:

According to the ENTSO-E HVDC network connection rules [1], *the HVDC system should be capable of contributing on the damping of power oscillations in the interconnected AC network. In case no contribution is possible, the control system of the HVDC shall not reduce the available power oscillation damping behavior of the ac network*. The latter requirement could be considered as a minimum or base requirement. This means, that the HVDC system should not cause by itself or even amplify power oscillations in the low frequency range (typically 0.1Hz to 2Hz). Thus, a positive damping of power oscillation could be considered as an extra requirement for the HVDC.

Tasks:

- Select or define a suitable methodology for identifying the damping behavior for the VSC-HVDC in the proposed frequency range
- Analysis of the damping behavior of a generic VSC-HVDC without extra damping controllers. The impact of the control parameter should be considered
- Literature review of existing damping control schemes which can be applied for the VSC-HVDC
- Implementation of most appropriate control schemes and evaluate the damping behavior of the HVDC system
- Propose of possible enhancements to the selected control schemes

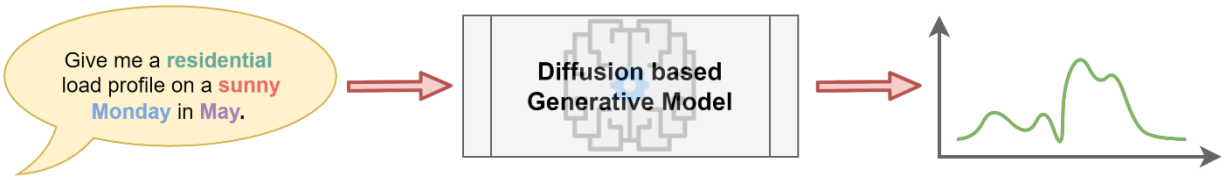
Industry partner: Company Siemens AG represented by Dr. M. Suwan, Dr. S. Al-Areqi

[1] COMMISSION REGULATION (EU) 2016/1447of 26 August 2016, establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules.

Contact details:

- Supervisor: José Rueda Torres (j.l.ruedatorres@tudelft.nl)
- Co-supervisor: Dr …. (....@....)

Smart Meter Data Scenario Generation with Diffusion-based Generative Models



Scope: This thesis project will focus on developing scenario generation algorithms for smart meter data utilizing state-of-the-art diffusion-based generative models (DBGMs).

Problem definition: Smart meter data holds great potential for future energy systems applications such as forecasting, reliability analysis, and flexibility assessment. For these, it is crucial to have representative scenarios in your smart meter dataset. Unfortunately, most of the available datasets lack these and result in a bias toward usual scenarios. Therefore, the amount of data belonging to under-represented scenarios should be increased.

Methodology: In the world of AI, DBGMs have proven their power in the fields of natural language and image processing (DALL-E 2, Stable Diffusion). In this project, this power will be channeled to the smart meters and novel methods for integrating energy systems related constraints and scenarios into the generation mechanism will be developed.

Research objectives:

- In-depth literature review on DBGMs and their variations as well as scenario generation.
- Building a framework for training, testing, and visualizations of DGBMs designated to smart meter data.
- Proposing method(s) to control the scenario generation mechanism.
- Performance checking of the methodology by various energy systems related applications like forecasting.
- Releasing the developed framework and the proposed methodology to GitHub.

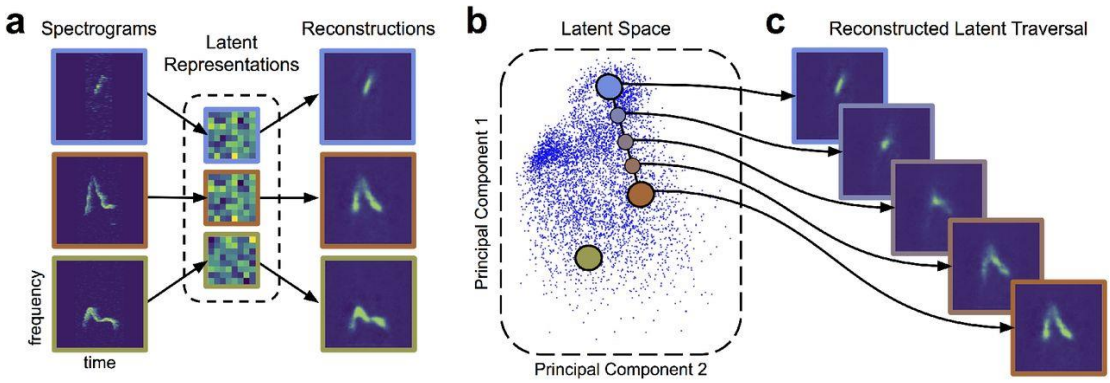
Requirements: Fluency in Python and a deep learning framework (PyTorch/Tensorflow); affinity for probability theory.

Industry relevance/partner: This project will be done within the IEPG group. Scenario generation is an important topic for large-scale machine learning and future energy systems applications. A collaboration with Alliander (large Dutch DSO) may be possible.

Contact details:

- PhD student: Kutay Bölat (K.Bolat@tudelft.nl)
- Supervisor: Simon Tindemans (S.H.Tindemans@tudelft.nl)

Interpretable Grid Data Generation with Variational Autoencoders



Source: Goffinet, J., Mooney, R., & Pearson, J. (2019). Inferring low-dimensional latent descriptions of animal vocalizations. bioRxiv, 811661.

Scope: This thesis project will focus on the exploitation of the disentanglement power of variational autoencoders (VAEs) for generating synthetic grid data with high-level interpretation.

Problem definition: Synthetic data generation has become very popular in the last decade. However, quantifying the plausibility of the generated data is often fairly subjective and applied mostly on image and audio data. On the other hand, the data from electrical grids are mostly in the form of multi-dimensional time-series. Thus, we require a systematical way to investigate the plausibility of the automatically generated grid-data.

Methodology: The disentanglement power of VAEs (a type of deep neural networks) will be exploited in this project. You will develop a VAE framework where you can train a VAE with grid-data and inspect the disentangled generative power of this network with various visualization methods such as t-SNE.

Research objectives:

- In depth literature review on VAEs and their variations (β-VAEs, CVAEs, etc.) as well as disentanglement
- Building a framework for training, testing and visualizations of VAEs designated to grid-data
- Proposing a method to qualify and/or quantify the plausibility of the generated grid-data samples
- Releasing the developed framework and the proposed method to GitHub

Requirements: Fluency in Python and a deep learning framework (PyTorch/Tensorflow); affinity for probability theory.

Industry relevance/partner: This project will be done within the IEPG group. Synthetic data generation is an important tool for large-scale machine learning, and to address privacy concerns. A collaboration with Alliander (large Dutch DSO) may be possible.

Contact details:

- PhD student: Kutay Bölat (K.Bolat@tudelft.nl)
- Supervisor: Simon Tindemans (S.H.Tindemans@tudelft.nl)

Conditional EV Charging Demand Synthesis using Diffusion Model

Scope: This research focuses on applying the state-of-the-art diffusion model to generate electric vehicle charging demand data based on given conditions.

Problem definition: This research falls under the NWO funded project ALIGN4Energy, which aims at accelerating the heat transition. Residential electric vehicle (EV) charging demand profiles are of vital importance for the planning and operation of both electrical distribution networks. Due to privacy issues, it is difficult to collect real demand profile data from smart meter measurements. Therefore, we turn to synthesize such data using machine learning models. The challenge here is how to incorporate conditions such as weather, vehicle characteristics, behavior traits into the generation process. Fortunately, similar problems have already been solved in the computer vision field, that is, generating images conditioned on prompts. This research aims to transfer the state-of-the-art generative model, conditional diffusion models, to synthesize high-resolution time-series data with encoded the input conditions.

Methodology: The primary methodology in this research is the new state-of-the-art denoising diffusion probabilistic models in the deep generative AI category. You also compare with baselines such as GAN, VAE, diffusion models, and Copula. The model-free nature of machine learning algorithms will facilitate modeling the dependency between cross-sector conditions and charging demand data.

Research objectives:

- Identify and quantify the influence of relevant conditions on the EV charging demand profiles.
- Develop a diffusion model to synthesize EV charging demand data which incorporates multiple cross-sector conditions.
- Test the developed algorithm and compare it with related baselines.

Industry relevance/partner: You will learn about electric vehicles and its interaction with the electricity system. By developing your algorithm, you will learn state-of-the-art generative AI models while gaining practical experience with Python and PyTorch, which is the mainstream frameworks for machine learning in the industry.

Contact details:

- PhD student: Nan Lin (n.lin@tudelft.nl)
- Supervisor: Pedro Vergara Barrios (p.p.vergarabarrios@tudelft.nl))

From Gas to Electricity: Predicting the Future Heating Demand

Scope: This research focuses on optimization approaches to convert historical gas-based heat consumption data into future-proof heat pump-based or district heating-based data.

Problem definition: This research falls under the NWO-funded project ALIGN4Energy, which aims at accelerating the heat transition. In the foreseeable future, heat pumps and district heating will take the place of gas boilers, which will bring an unprecedentedly heavy burden onto the distribution networks. But what exactly will the demand curve look like? The question lies in how to predict future heating demand based on the heating demand today, from gas consumption to electricity consumption.

Methodology: The primary method is foreseen to be a combination of machine learning and optimization. The student can also choose to explore physics-informed neural networks to transform gas-based data into future heating data.

Research objectives:

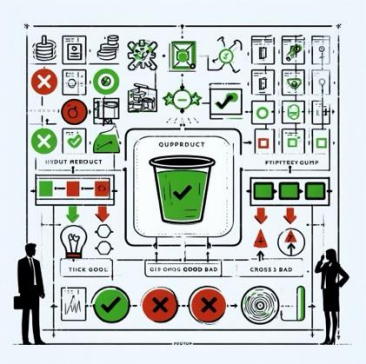
- Identify the different natures of the present and future-proof heating systems.
- Develop a machine learning algorithm to predict future heat pump or district heating load profiles based on current gas consumption data.
- Test the developed algorithm and compare it with existing methods.

Industry relevance/partner: You will learn about heating system and its interaction with the electricity system. By developing your algorithm, you will learn about advanced probabilistic machine learning while gaining practical experience with Python and PyTorch, which is the mainstream frameworks for deep learning in the industry.

Contact details:

- PhD student: Nan Lin (n.lin@tudelft.nl)
- Supervisor: Pedro Vergara Barrios (p.p.vergarabarrios@tudelft.nl)

Re-assessing the Evaluation of Synthesized Energy Data



Scope: This research focuses on an extensive review of the existing literature on evaluating the quality of synthesized energy data and developing an effective new way of performing such evaluation.

Problem definition: This research falls under the NWO-funded project ALIGN4Energy, which aims at accelerating the heat transition. Because of privacy issues and cost concerns, energy data are often synthesized for analysis in the energy community. However, how much can we really trust these "fake" data? How to evaluate the quality and how much do they help with downstream tasks? This research aims to answer these questions with a thorough review of existing metrics and propose new ways to evaluate synthesized energy data.

Methodology: Solving this research question includes a detailed investigation of existing synthetic data evaluation methods in the energy field and in other fields such as image and audio. Proposing either a new mathematical or a pragmatic approach to evaluate synthetic data (possibly transferred from other fields) is the primary objective of this research.

Research objectives:

- Review the current synthetic data quality evaluation methods in different fields.
- Propose new evaluation methods based on mathematics and by transferring from other fields.
- Implement reviewed evaluation methods and proposed ones and compare in experiments.

Industry relevance/partner: You will learn about advanced mathematics and their application in the power system. By investigating generative models in different fields, you will get a deep understanding of such models. By developing your algorithm, you will deepen your knowledge of probabilistic machine learning while getting practical experience with Python and PyTorch, which is the mainstream frameworks for deep learning in the industry.

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Analysis of switching transients with transmission cables

This note proposes the high level technical objective for a technical paper to verify the measurement results that were carried out in 2012 in National Grid's 275 kV network.

The IPST 2013 paper [1] investigated failure of sheath voltage limiters (SVLs) in a 275 kV cable. The failures were attributed to trapped charges on the cable. The paper showed that if trapped charges resulted in high enough residual voltage on the cable, the next switching of the cable would cause high enough induced surges on the sheath that would cause chain failure of the SVLs.

At the time, it was argued by some cable engineers that the trapped charges would usually be dissipated within a short time and by the next switching in the network which was usually six hours later there would not be any significant residual voltage on the cable.

A paper published in IPST 2017 [2] presented the results of measurement of the residual voltage on the same cable. The measurement was non-intrusive, i.e. with no physical contact with the cable, and set up to measure only the dc residual voltage.

The measurement showed that at the point of switching out the cable, the initial residual voltage on the cable can be as high as 2 pu [2]. Although it is known that in circuits with high capacitance, the voltage may become higher than the nominal voltage when a circuit or network section is switched out from the rest of the system, but the voltage as high as 2 pu have been challenged.

It is therefore proposed that the system is investigated to confirm the measurement and to find the root cause of the residual overvoltages with magnitudes as high as 2 pu. The investigation will also attempt to show whether higher residual voltages would be possible and if yes under what circumstances.

The overvoltages are attributed to switching of capacitive current and the ability of circuit breakers to successfully break the current.

[1] "Effect of Trapped Charges on Cable SVL Failure", IPST 2013.

[2] "275 kV Cable Discharge Field Measurement and Analysis of SVLs Chain Failure Using ATP", IPST 2017.

Industry relevance/partner: National Grid, UK

Contact details:

- Supervisor: M. Popov (m.popov@tudelft.nl)
- Dr. F. Gassemi, National Grid, United Kingdom

Transformer differential protection testing by RTDS

Scope: Within the grid of TenneT TSO BV power transformers are used to couple subnets to the national grid. Transformer differential protection relays are put in place to protect power transformers against potential damage due to short circuit currents. This relay monitors all currents which flow to- and from the power transformer's windings. When the distance between current/instrument transformers of the primary and secondary windings is too large (f.ex 300 meters), overhead line/cable differential protection relays are put in place to ensure the protection of the segment between the current transformers. These relays contain a transformer protection module in addition to a distance protection module. In order to quickly recognize a fault in the protected segment and send/receive inter-trip signals communication between the relays is necessary and is facilitated by a glass fiber connection. Figure 1 provides an overview of a circuit containing a 2-winding power transformer and the described protection scheme.

Methodology: The network presented in Figure 1, will be modeled in the RTDS environment. The relays which are available in the IEPG lab will be connected in parallel and the testing will be realized

Problem definition / Research objectives: In practice, the differential protection scheme did not perform as expected which caused short-circuit currents to persist longer than desired. A specific case concerns a phase-to-earth fault in the differentially protected segment directly after switching on the 220 kV circuit breaker. This fault was cleared by the distance protection module instead of the differential protection because inrush detection blocked the function. The following types of protection relays are to be tested: Siemens Siprotec 4 7SD5 (or Siprotec 5 7SL8) and GE MiCOM p545.

The objective of the tests is to answer the following research questions with respect to the different types of relays:

- What are viable protection schemes regarding the application or exclusion of inline transformer modules?
- What are the limitations of using protection schemes involving inline transformer modules in contrary to using a transformer differential protection relay (a single application-specific relay).
- Which settings are crucial and why (theoretically)? F.ex differential I>; I>>; 2nd and 5th harmonics.
- Which settings should NOT be configured (or could result in conflicting behaviour)?
- What are the response times regarding starting, trip, responses, and blocking signals?

Industry relevance/partner: TSO TenneT

Contact details:
Supervisors: Marjan Popov (M.Popov@tudelft.nl)

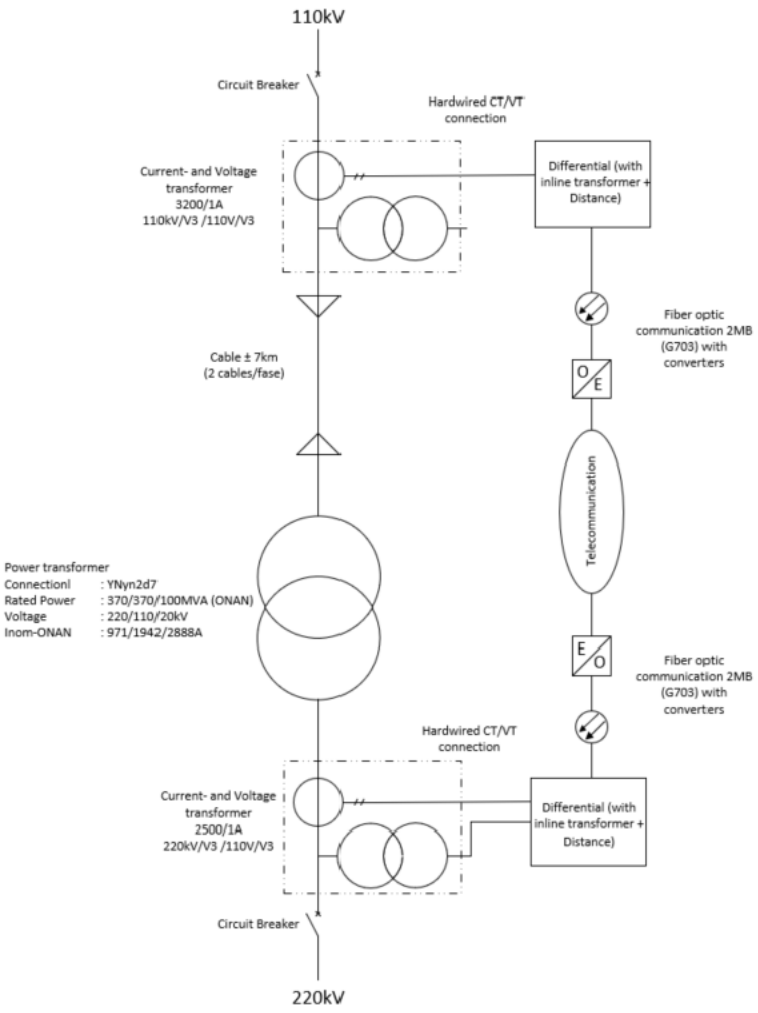


Fig. 1. Transformer differential protection

Investigation of HV cable switching transients and verification with field measurements

Scope: In this work, the high level technical objective should be performed to verify the measurement results that were carried out in in National Grid's 275 kV network.

Problem definition: In the past [1], the failure of sheath voltage limiters (SVLs) in a 275 kV cable was investigated. The failures were attributed to trapped charges on the cable. It was shown that if trapped charges resulted in high enough residual voltage on the cable, the next switching of the cable would cause high enough induced surges on the sheath that would cause chain failure of the SVLs. At the time, it was argued by some cable engineers that the trapped charges would usually be dissipated within a short time and by the next switching in the network which was usually six hours later there would not be any significant residual voltage on the cable.

Additional research was performed [2] and presented the results of measurement of the residual voltage on the same cable. The measurement was non-intrusive, i.e. with no physical contact with the cable, and set up to measure only the dc residual voltage. The measurement showed that at the point of switching out the cable, the initial residual voltage on the cable can be as high as 2 pu [2]. Although it is known that in circuits with high capacitance, the voltage may become higher than the nominal voltage when a circuit or network section is switched out from the rest of the system, but the voltage as high as 2 pu have been challenged.

Methodology: The modeling will be realized in ATP-EMTP environment. The data will be provided by National Grid, UK. Once the modeling is realized, the measurements will be provided and comparative analysis will be realized. The starting point of the project are references [1] and [2] for which modeled topology in ATP-EMTP will be available.

Research objectives: In this thesis, it is needed that the system is investigated to confirm the measurement and to find the root cause of the residual overvoltages with magnitudes as high as 2 pu. The investigation will also attempt to show whether higher residual voltages would be possible and if yes under what circumstances. he overvoltages are attributed to switching of capacitive current and the ability of circuit breakers to successfully break the current.

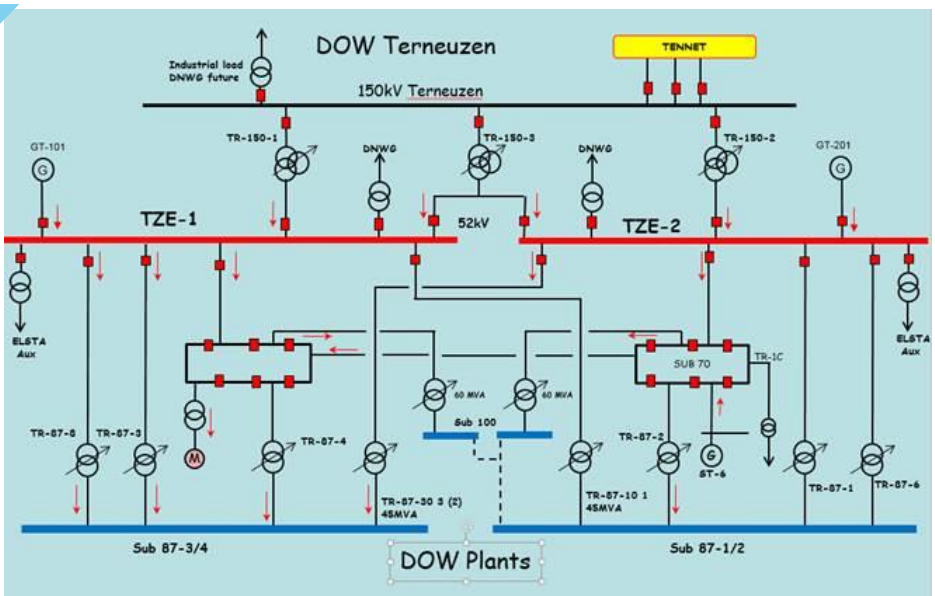
Industry relevance/partner: This is an actual industrial project which by comparing and developing the correct model will be used in practice to investigate mysterious failures during different topologies. The main partner in this is National Grid, UK. TSO TenneT will also take part because of heavy relevance concerning the Dutch grid.

We offer: Pleasant working environment and excellent supervision.
We require: Highly motivated candidate with excellent communication skills who attended and passed the subject Electrical Transients in Power Systems.

[1] "Effect of Trapped Charges on Cable SVL Failure", IPST 2013.
[2] "275 kV Cable Discharge Field Measurement and Analysis of SVLs Chain Failure Using ATP", IPST 2017.

Contact details:
Marjan Popov (M.Popov@tudelft.nl)

Generator protection Siemens 7UM 85 and new frequency relays



Scope: The project is focused on testing new Siemens 7UM 85 relay by making use of Omicron Test system

Problem definition: The gas-turbines at the DOW power plant are providing steam and electricity for the production plants. The DOW wants to apply this protective relaying on the existing 125MW gas-turbines. The protection scheme should fulfil specific requirements. A typical testing of the relay should be done on different cases (scenario's).

Methodology: Modeling in ATP-EMTP and testing by making use of Omicron

Research objectives:

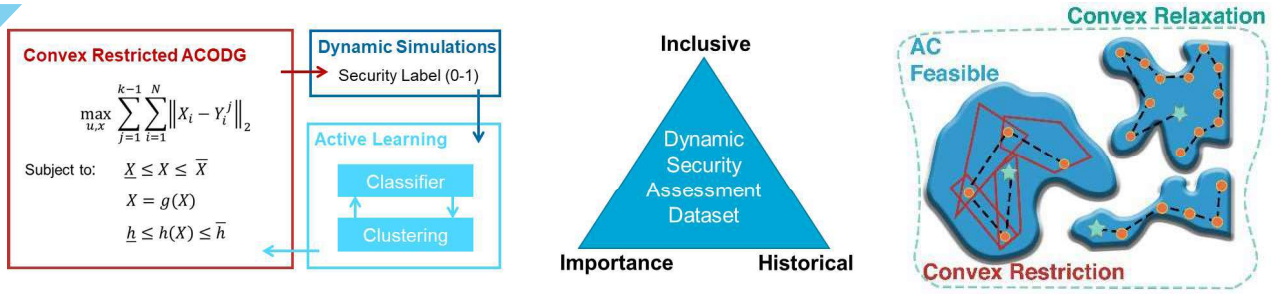
- Modeling of the generators with governors and excitation;
- Modeling the electrical load on the production site by the use of the aggregated induction motor and static models;
- Model the df/dt and voltage decay in different island scenario's, predict the network behavior;
- Do sensitivity test on some important parameters;
- Define cases for the testing the relay, the relay should trip or stay stable during different network upsets;
- Define islanding detection system at the 50 kV;
- Define islanding load shedding system based on gas turbine operation mode;
- Test new Siemens df/dt and frequency detection relay for islanding detection and load shedding non critical loads.

Industry relevance/partner: DOW Terneuzen

Contact details:

- Supervisor: M. Popov (m.popov@tudelft.nl)

AC Optimal Data Generation (ACODG) for Power System Security



Scope: This thesis project will focus on developing a novel data generation method for the dynamic security assessment (DSA) classifier. Convex restriction of the AC power flow optimization enables the generation of feasible possible operating conditions based on historical observations. Active learning framework further improves the quality of the dataset.

Problem definition: Machine learning (ML) based DSA requires a rich dataset for successive prediction. Training data must cover past observations, possible future operations, and samples around the security boundary. Sampling strategies from historical data cannot anticipate unseen possible conditions. Greedy search algorithms suffer from the nonconvex feasibility space of the power flow. ML labels require costly dynamic simulations for the predefined contingency cases. Label generation costs can be reduced extensively with an efficient, effective, and automatic data generator.

Methodology: You will develop a sequential optimization problem called AC optimal data generation (ACODG) that explores nonconvex AC optimal feasible space with convex constrained envelopes around the historical feasible operating points. The objective is to maximize dissimilarity between discovered points and control variables. You will conduct dynamic simulations with generated feasible conditions to calculate security labels against the disturbance. The database is used to train support vector classifier (SVC) and artificial neural network (ANN) models. Furthermore, you will aggregate operating conditions with the agglomerative hierarchical clustering method to identify the highest ratio of misclassified samples. These samples can be used as new initial samples for the ACODG.

Research objectives:

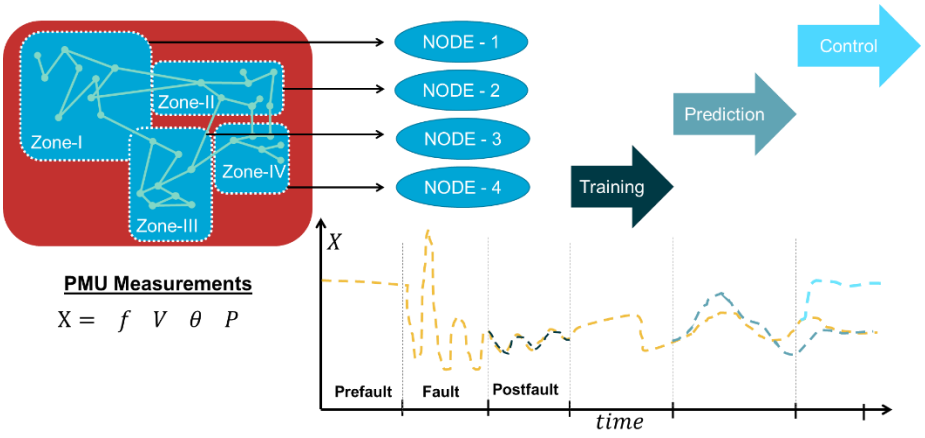
- Literature review on AC OPF, quadratic optimization, supervised learning algorithms, clustering algorithms, DSA.
- Development of the modified convex restricted AC OPF.
- Conducting dynamic root mean square (RMS) simulations on the test system.
- Development of the ML pipeline: Preprocessing, feature selection, model construction, training, and tuning.
- Design of high scale high dimensional unsupervised clustering algorithm.

Industry relevance/partner: This MSc thesis is part of the PAIBET industrial project with Tennet (NL, DE), TNEI (UK), and Stedin (NL). There, security of the operation is an essential and challenging task for transmission system operators like RTE (France), National Grid (UK), or Tennet (NL, DE) in Europe. This thesis combines the ML and power system dynamics which is highly valuable in both academia and system operation.

Contact details:

- PhD supervisor: Mert Karacelebi (m.karacelebi@tudelft.nl)
- Supervisor: Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)

Neural Ordinary Differential Equations for Power System Dynamics



Scope: This thesis project will focus on using machine learning (ML) to predict power system dynamic trajectories after system disturbances. You will use the ML method of Neural Ordinary Differential Equations (NODE) to train efficiently known power system dynamics.

Problem definition: The structure and operation of the power systems are evolving while our society must move toward a sustainable and carbon free future. Power grids become more vulnerable to large disturbances that can cause power outages. Dynamic simulations reveal the system performance for a specific disturbance scenario but simulation of real operation is highly challenging due to the unpredictable nature of the blackouts and the large number of scenarios to consider. Alternatively, ML models can be trained in near real time by using high-resolution post fault measurements. NODE models are promising to mimic dynamical systems efficiently and accurately.

Methodology: You will develop a NODE algorithm for the prediction of power system dynamics. You will review the literature about dynamical systems, numerical integration, neural networks, and time-series models, and NODEs. Then, you will conduct dynamic simulations of a test system in a simulation environment (e.g., DIgSILENT PowerFactory). You will generate data by simulating a disturbance, analyze the data. Subsequently, you will investigate efficient training methods using your own neural network architecture that utilizes NODEs. Finally, you will analyses the NODE performance in terms of accurately approximating dynamics and training time requirements.

Research objectives:

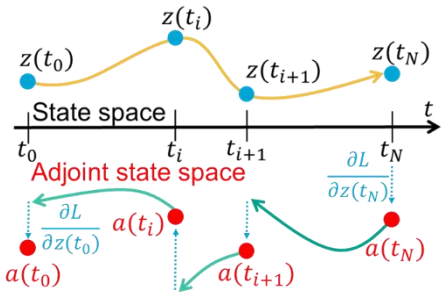
- Literature review on dynamical systems, numerical integration, neural networks, time-series models, NODEs
- Conducting dynamical simulations of a power system to investigate blackout events.
- NODE modeling, training, and prediction of simulated power system events.
- Performance testing of NODEs with unseen dynamics using real time training approaches.

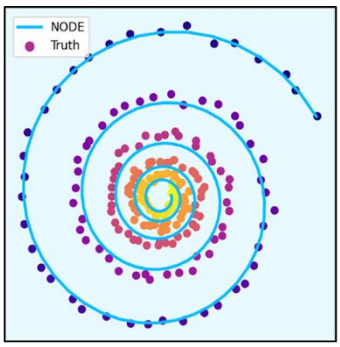
Industry relevance/partner: The security of the operation is one of the most important and challenging tasks of a transmission system operator. This thesis combines the ML and power system dynamics which is highly valuable in both academia and system operation.

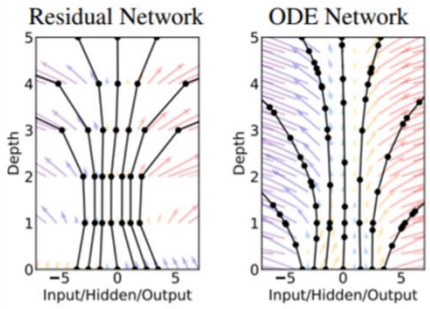
Contact details:

- PhD supervisor: Mert Karacelebi (m.karacelebi@tudelft.nl)
- Supervisor: Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)

Understanding NODEs for time-critical applications







Scope: This thesis focuses on the analysis of novel supervised machine learning method neural ordinary differential equations (NODE) for time-critical applications such as power system dynamic monitoring or dynamic security assessment. NODE models utilize both ordinary differential equation (ODE) solvers to approximate a continuous dynamic system, and neural networks to learn hidden feature dynamics [1]. Analysis of model complexity, memory, and time requirements can identify bottlenecks in training where new solutions can improve training efficiency without a significant drop in performance.

Problem definition: Complex, nonlinear, and large scale power systems' dynamic response to a disturbance can be computed with mathematical models. Although simulation models accurately solves differential algebraic equations, they are not feasible to solve in real time. NODEs are highly suitable for learning unknown dynamics of nonlinear and complex systems under partial observations [2]. Unfortunately, training is a challenging task in real-time. Regularization helps NODE to generate simpler dynamics that are easier to solve by the ODE solver but the overall training time is increased due to the computation of the regularization function [3]. Other studies identify efficient methods but average training times are still infeasible for large-scale systems [4-5]. The time requirements grow in parallel with the system size (number of states), the duration of the data (data size) and the complexity of the solution (solver requires more time).

Methodology: Power system dynamics can be predicted by training NODEs in real-time with a small amount of training data, using shallower networks, adaptive loss functions and faster training algorithms. You will construct the NODE model with the given power system data from the dynamic simulations. You will study the impact of training data size, network architecture, loss function, learning rate, regularization and training algorithms. Identified bottlenecks will be solved by novel methods to improve efficiency. You will compare the performance, required training memory, and time of the proposed solution against the base NODE model.

Research objectives:

- Literature review on neural networks, ordinary differential equations, algorithm complexity, and training algorithms.
- Analysis of different NODE models, parameters, and training strategies regarding training efficiency.
- Development of new methods to improve training efficiency for accurate prediction of dynamics from the small amount of data.
- Comparison of solutions with the base model.

Requirements: High motivation, interest and knowledge of artificial intelligence algorithms, and differential equations. Decent knowledge of programming languages (Julia is preferred but not mandatory). Interest in learning algorithm analysis is a plus.

Contact details:

- PhD student: Mert Karacelebi (m.karacelebi@tudelft.nl)
- Supervisor: Jochen Cremer (J.L.Cremer@tudelft.nl)

References:

[1] Chen, R. T. Q., Rubanova, Y., Bettencourt, J., & Duvenaud, D. (2018). *Neural Ordinary Differential Equations*. *NeurIPS*.

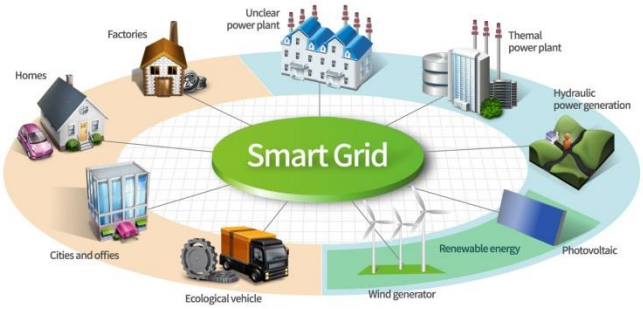
[2] Ayed, I., de Bézenac, E., Pajot, A., Brajard, J., & Gallinari, P. (2019). *Learning Dynamical Systems from Partial Observations*. http://arxiv.org/abs/1902.11136

[3] Kelly, J., Bettencourt, J., Johnson, M. J., & Duvenaud, D. (2020). Learning differential equations that are easy to solve. *Advances in Neural Information Processing Systems*, *2020-December*.

[4] Finlay, C., Jacobsen, J. H., Nurbekyan, L., & Oberman, A. M. (2020). How to train your neural ODE: The world of Jacobian and kinetic regularization. *37th International Conference on Machine Learning, ICML 2020*, *PartF16814*, 3135–3145.

[5] Xia, H., Suliafu, V., Ji, H., Nguyen, T. M., Bertozzi, A. L., Osher, S. J., & Wang, B. (2021). Heavy Ball Neural Ordinary Differential Equations. *Advances in Neural Information Processing Systems*, *23*(NeurIPS), 18646–18659.

Future smart grid scenarios: Modeling and simulation



Scope: This is a set of several MSc thesis/extra projects that focuses on developing models and simulations for future smart grids. Smart grid emerges as a combination of many technologies, including power systems, communication grids, renewable energy, storage and electric vehicles, controls and optimization, flexible consumption, etc. Since the future technological developments are uncertain, it is important to create and model multiple scenarios to realistically represent potential outlook of the future electricity grid including developments towards 100% renewable generation and business as usual case.

Problem definition: The main challenge is to develop 1) case scenarios, 2) models, and/or 3) simulators that represent more than one domain of smart grids. This can be done in many different ways, by combining already existing models of sustainable technologies, or models of different energy carriers, or by developing control and optimization strategies for more sustainable operation of smart grids.

Methodology: The student will choose one of the following three directions to put the emphasis on: case scenarios, modeling or simulations. Development of case scenarios will require research on future grid developments including projections on renewable energy deployment, electric vehicle and storage adoption rates, heat pump and/or natural gas perspective, etc. Development of models focuses on representation of new technologies, such as electrolizers, fuel cells, new communication protocols like IEC 61850, ZigBee, and others. Finally, development of simulations, focuses on extending current simulation tools, such as PowerFactory and RTDS, with new simulation capabilities and new models.

Industry relevance: This is a great opportunity to pick your favorite technology and build contextual knowledge by developing future case scenarios, or obtain more in depth knowledge about the device by developing its model and simulations. In addition, you will have exposure to commonly used industrial tools, such as PowerFactory.

Contact details:

- Supervisor: Milos Cvetkovic (m.cvetkovic@tudelft.nl)

Calculation of R, L, and C matrices of a disk winding and verification of the analytical formula with measurement

Problem definition: From literature, it is known how to calculate self and mutual inductances between two turns or between two coils. The solution exist even for the case in which an iron core links the two coils. Hence it is possible to calculate a lossy inductance matrix from which L and R matrices can be extracted. Our previous research work shows that a proper value for the effective conductivity of the core plays an important role in the evaluation of the inductances. Some deviation has been observed between analytical and FEM simulation when frequency increases to MHz range. The task in this part is to write a MATLAB code that will be used to compute Inductance and resistance matrices L and R respectively, for a given winding geometry; as well as to pinpoint the correct way of defining the effective value of core conductivity that must be used in analytical formulas. Vector Network Analyser (VNA) will be used to perform measurement on actual winding to verify the calculated R and L matrices (figure right).

For the computation of the capacitance matrix C simple analytical formulas are available in the literature. However, to reduce the capacitance matrix to a smaller order extra work has to be done. This is for example to reduce a N*N capacitance matrix of a disk with N turns into only one equivalent capacitance seen from its terminal. The task is to write a code to calculate the capacitance matrix and propose a validated method to reduce the capacitance matrix of a coil.

Methodology: Writing a MATLAB code to extract winding parameters from a given winding geometry and performing measurement on a sample winding to verify the analytical formulas for R, L, and C matrices.

Research objectives:

- Literature review on analytical methods for winding inductance and capacitance calculation
- Learning how to work with VNA and extract parameters of a winding experimentally
- Propose a method to reduce the capacitance matrix
- Demonstrate the correct way to calculate effect value of core conductivity

Contact details:

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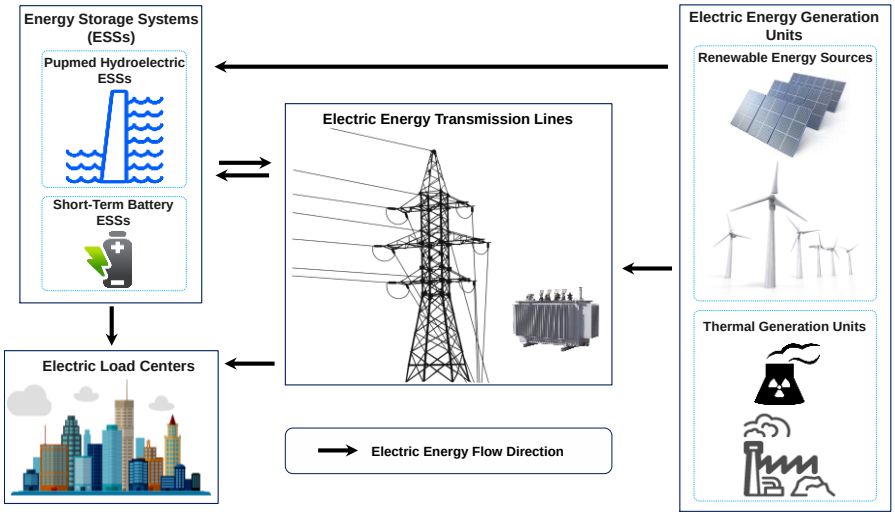
  Marjan Popov (M.Popov@tudelft.nl)

Capturing Short-Term Variability for Expansion Co-Planning of Transmission Lines and Seasonal Energy Storage Systems

Scope: This project aims to improve the computational efficiency of transmission expansion planning (TEP) using a developed algorithm to represent short-term variability of load demand and renewable energy resources, in systems with long-term seasonal energy storage systems (ESSs).



Problem definition: In a large-scale TEP model with different planning options, optimal investment decisions depend on both the investment and operation costs of the system. The operational model makes use of time-series data, but considering all time steps for each year will result in a large unsolvable model. A trade-off between accuracy and complexity is required to reach an optimal planning scheme: *a popular approach is the use of representative time periods*. Such representatives must capture ***Extreme Values*** and ***Temporal Chronology*** of data that are necessary for power system ***Adequacy*** and ***Operational Flexibility***, respectively. This project will consider the following challenges:

- Capturing the short-term variabilities in modeling ***inter-period cycles*** of long-term ESSs that can take several months, like pumped hydroelectric and power-to-gas storage technologies. This challenge is usually ignored when considering short-term battery ESS with ***intra-day cycles***.
- Preserving extreme values from ***smoothing***, a common drawback of time series aggregation methods.
- How to consider and evaluate ***decades of input data*** in the extraction of representative time periods.

Methodology: This project will deal with the mentioned challenges by implementing machine learning-based methods like clustering and importance sampling. The extracted scenarios will be examined in an expansion co-planning of transmission lines and seasonal ESSs. The optimization model of problem can be formulated and solved in the Pyomo environment (in Python), or the General Algebraic Modeling System (GAMS).

Research objectives:

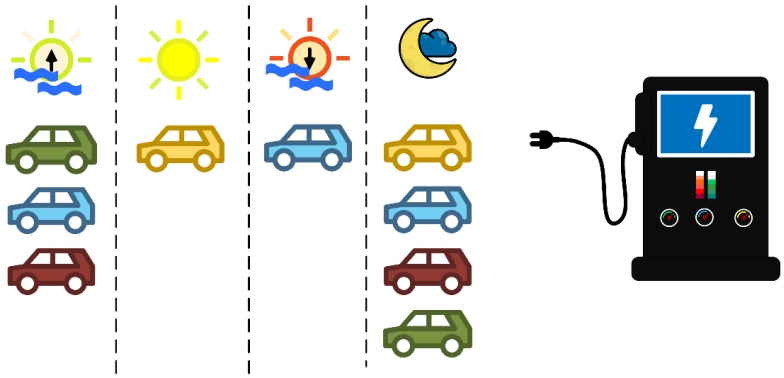
- Utilizing machine learning-based methodologies to capture the short-term variability.
- Developing methods that bias the selection of time series to focus on system-relevant properties.
- Evaluating the effectiveness of proposed method in an expansion co-planning of transmission lines and seasonal ESSs with long-term cycles, compared to methods in the literature.

Industry partner: This project is associated with the HEPPIE research project, executed by TU Delft and Réseau de Transport d'Électricité (RTE; the French TSO).

Contact details:

- ***Postdoc Researcher***: Mojtaba Moradi Sepahvand (m.moradisepahvand@tudelft.nl)
- ***Supervisor***: Simon Tindemans (s.h.tindemans@tudelft.nl)

Data-driven analysis of real EV Charging Transactions



Scope: This thesis has an open scope to analyze a large amount of electric vehicle (EV) transactions and derive meaningful conclusions regarding charging behaviour, power consumption pattern, driving pattern, etc. Depending on the student's interest, the scope can be decided later; they are encouraged to contact the project coordinator.

Problem definition: EVs, one of the most sustainable alternatives to conventional vehicles, pose serious challenges to the current electrical grid. Uncoordinated EV usage can stress the electrical network even more, which are already burdened from the changing landscape due to the influx of distributed renewable energy (DERs). On the other hand, EVs can potentially behave as valuable flexible assets deployed to decongest the networks. Knowledge about EVs' charging behavior is essential to enrich potential flexibility, which depends on numerous uncertain factors. Analyzing historical EV transactions can help solve this issue through the statistical characterization of key variables like charge time, idle time, connected time, power, and energy, which generally leads to multi-modal probability distributions.

Methodology: Numerous approaches are available to tackle the challenges mentioned above. A particular method will be decided based on the candidate's interest and skill set.

Research objectives:

- Preprocess available raw data and make an automation to update the dataset with new data over a chosen time interval.
- Identify key variables which are of statistical importance.
- Identify various uncertainties associated with EVs.

Industry relevance/partner: This project caters to the need of EV charging station owners, EV sharing platforms and DSOs. Also, the outputs of the analysis will support the quantification of flexibility for EVs.

Contact details:

PhD in-charge
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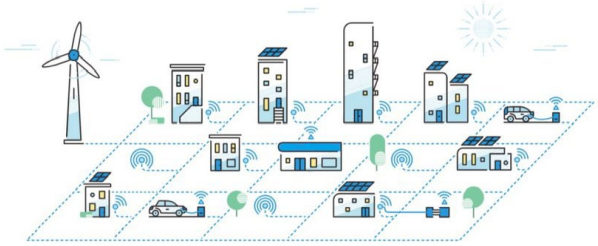
Supervisor
- Simon Tindemans (S.H.Tindemans@tudelft.nl)

Role of Flexiblity in Grid Connection Capacity Planning of Large Urban Living Spaces



Scope: This thesis aims to evaluate the impact of flexibility on determining the optimal connection capacity of large integrated urban living spaces. These spaces are characterized by a mix of residential, commercial, and public areas. The assessment will consider the technical and financial feasibility of implementing flexibility, as well as the potential for new business opportunities that may arise from its use. In this context, flexibility refers to the ability of flexible loads or generators to adjust their load demand or power output or duration of use without compromising their primary function. Examples of such flexible assets may include electric vehicles (EVs), heat pumps, and residential energy storage (RES).

Problem definition: Large residential locations typically have a high total connected load value but a low demand factor. This is because it is unlikely that all loads will be active at the same time. Furthermore, the inclusion of renewable energy sources enables self-generation, which compensates for the load and reduces overall demand. Traditionally, the connection capacity with the utility grid is determined based on the connected loads, leading to high connection costs for using the network and difficulty in allocating large connection capacities in already congested networks. However, if flexibility can be utilized to determine the most optimal connection capacity of such a location without compromising the reliability of users or the grid, it can benefit both the property owners and network operators.

Methodology: An multi-objective optimization framework could be used to model the energy system of the urban living space, which could then be solved for different competing techno-economic objectives. Some of the earlier works on flexibility and optimization frameworks can be found in here[1,2]. The student has the freedom to select other appropriate methodologies that suits his/her preferences. However, students are expected to be familiar with Python and mathematical optimization.

Highlights of this project:

- Explore the cutting-edge concept of next-generation living spaces and their integration with urban energy systems
- Discover the state-of-the-art EV infrastructure in the Netherlands and the potential opportunities of EVs in power networks
- Collaborate with industry partners and network operators, gaining valuable insights and experience
- Get first-hand experience in modelling and optimizing sustainable energy systems

Industry relevance/partner: Through this thesis, the student will have an opportunity to work closely with the stakeholders of a large residential location in the Netherlands. This project is associated with the ROBUST project (https://tki-robust.nl)

Contact details:

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Supervisor • Simon Tindemans (s.h.tindemans@tudelft.nl)

[1] N. K. Panda and N. G. Paterakis, "A Multi-objective Optimization Model for the Quantification of Flexibility in a Large Business Park," 2021 International Conference on Smart Energy Systems and Technologies (SEST), Vaasa, Finland, 2021, pp. 1-6, doi: 10.1109/SEST50973.2021.9543270.

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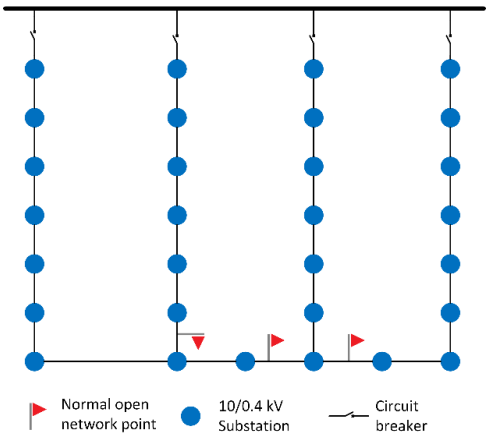
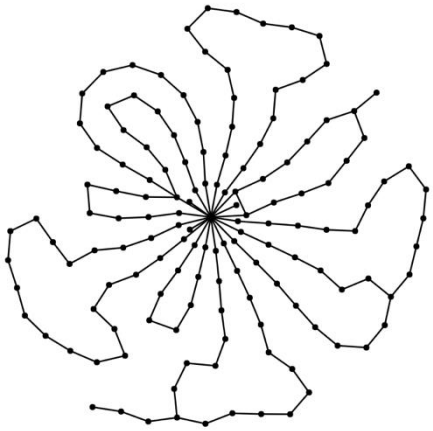
Topology Reconfiguration of MV Distribution Network with Flexible Assets





Scope: This thesis aims to assess the efficacy of topology reconfiguration in mitigating grid issues for the future considering flexible assets.

Problem definition: Network reconfiguration of distribution networks has been a well-researched area for the past decade. Most methods in the literature assume simple objectives (minimization of network losses) to find optimal topologies, which might not be the most lucrative choice operationally for the DSOs. Additionally, increasing flexible assets in the distribution networks will largely influence the optimal network topology. Hence, this thesis aims at finding the effectiveness of network reconfiguration on the grid's operational reliability considering flexible resources.

Methodology: A representative Dutch MV grid is considered as a first study case for this thesis. Efficient optimal power flow (OPF) needs to be developed to include switching models inside the power-flow formulation. Characteristics of flexible assets need to be modelled and included in the objectives of the network reconfiguration algorithm. Scenario-based analysis based on load and generation forecast for the years 2030, 2040 and 2050 will be carried out. Stochasticity can be added to the developed network reconfiguration algorithm if scope permits.

Research objectives:

- Understand topologies for MV networks in the context of the Dutch network
- Get insights into the operational challenges of network reconfiguration and normal MV network operations
- Develop MILP/ MINLP/ LP optimization models and solve them using commercially available solvers
- Develop OPF for large distribution networks

Industry relevance/partner: The student will be able to understand network topologies used in the Netherlands. After completing this thesis, the student will independently process raw network data, produce single-line diagrams from network data, simulate the network in OpenDSS/Powerfactory and interface scripting language with power flow solvers. This thesis shall provide an early insight into using network reconfiguration to solve grid congestion considering flexible assets. This project is associated with the ROBUST project (https://tki-robust.nl)

Contact details:

PhD in-charge • Nanda Kishor Panda (N.K.Panda@tudelft.nl)
Supervisor • Simon Tindemans (s.h.tindemans@tudelft.nl)

Fault Detection and Classification for Medium Voltage cables using Machine Learning Techniques.

Pic Credits: www.electricalindia.in/artificial-intelligence-an-advanced-approach-in-power-systems

Keywords: Real Time Digital Simulation (RTDS), Machine Learning (ML), Medium Voltage Distribution Grid, Online Fault Location and Classification, Phasor Measurement Units (PMU), Pattern Recognition.

Interests:

1. Are you interested in working on Real time digital simulation platform?
2. Are you willing to work on a project which involves and requires multi-domain knowledge to connect cyber world to the physical world?

Scope: This thesis project involves understanding of dynamic behavior of various faults conditions which will be later utilized to develop ML based algorithms to detect and classify the faults in the underground cables of a distribution network.

Problem definition: The disturbances in the distribution network can be recognized based on the fault signatures which can cause massive power outages over the time. However, if the disturbances are detected in time, one can plan corrective actions such that the effect of those disturbances on the grid stability is minimized.

Methodology and Research Objectives:

1. A concise literature review on available ML based networks suitable for the various types of cable faults. Additionally, getting familiar with various hardware tools and software simulation platforms
2. Preprocessing – This step reduces the size of neural networks-based classifiers improving training speed and performance. (Matlab, RSCAD)

3. Training Pattern generation and test data generation by simulating different types of faults on the MV Distribution Grid by changing fault type, fault location, fault resistance and fault inception time. (RTDS-RSCAD)
4. Planning and decisions of ML architecture for recognition of above generated training patterns (Matlab).
5. Validation through generated test data and comparison with fast acting statistical methods (available in-house).

Industry relevance: With the emergence of synchro-phasor measurement technology, there is a growing demand for fast acquisition of network variables (V, I, P & Q) to closely monitor the network and avoid major power outages. This requirement is even more serious in distribution networks due to complexity and uncertainty involved in laying underground cables (Netherlands).

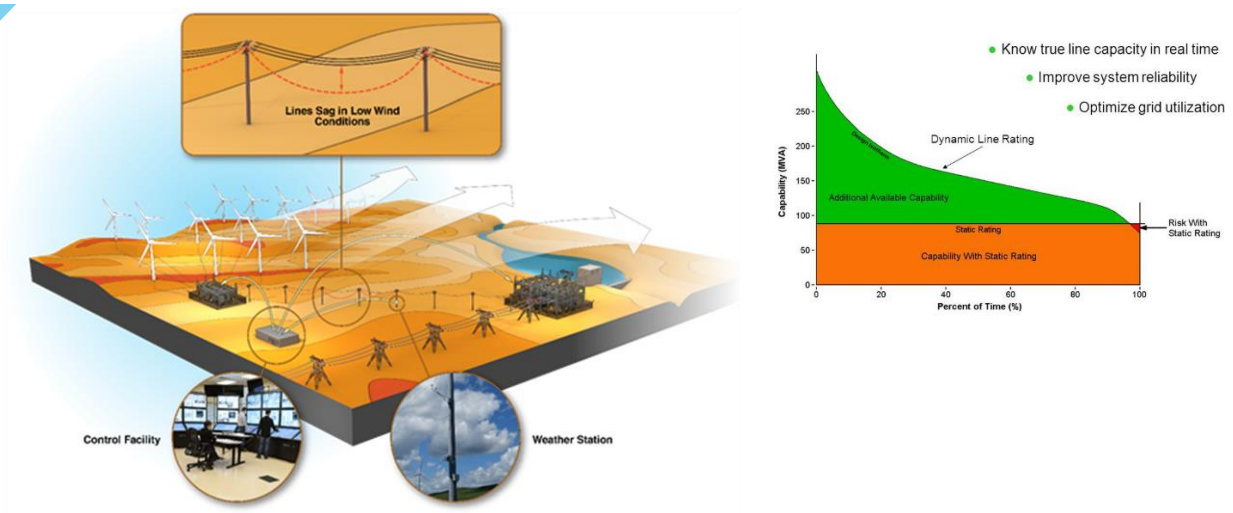
Industry Partner:

Required Background: Basics signal processing, Power Systems, Maltab/Python (your comfortability).

Contact details:

- PhD Guide: Nidarshan Kumar (N.Veerakumar@tudelft.nl)
- Supervisor 1: Marjan Popov (m.popov@tudelft.nl)
- Supervisor 2: Jose Rueda Torres (J.L.RuedaTorres@tudelft.nl)

Dynamic Thermal Rating in a Medium Voltage Distribution Network



PicCredit:Renewableenergy.inl.gov/Conventional%20Renewable%20Energy/SitePages/Dynamic%20Line%20Rating.aspx

Keywords: Real Time Digital Simulation (RTDS), Dynamic Thermal Rating (DTR), Cables and Transmission Lines, Static Thermal Rating, Thermal Current limit

Interests:

3. Are you interested in working on a project which impart knowledge to the system operators (TSO and DSO's) on optimal power capacities that their existing grids can handle based on realistic environmental conditions?
4. Are you interested in Dynamic studies and working on Real Time Digital Simulator platform?

Scope: This thesis project aims at developing algorithm for ampacity (ampere capacity) calculation to safely utilize existing transmission lines transmission capacity based on real conditions in which power lines operate. A crucial difference between static and dynamic line rating is that "static current" is calculated based on rather conventional atmospheric conditions while dynamic line rating considers actual atmospheric conditions which most of the time offer better cooling and thus allow higher "dynamic" current, contributing to improve safety.

Motivation: Infrastructure development for transmission lines (TSO's) and underground cables (DSO's) of any country is not a simple procedure due to its huge investments and critical environmental regulations. On the bright side, with growing meteorological measurements and forecasting techniques, the heating and cooling conditions of conductors based on varying power transmissions can be accurately assessed across the length of the conductors. Hence, has become a trending issue for system operators. These two factors have pushed the emergence of a trending topic "dynamic thermal rating" using which a safe and efficient exploitation of existing infrastructure is possible.

Methodology and Research Objectives:

6. A concise literature review on ampacity calculation techniques derived from CIGRE and IEEE DLR models.
7. Understanding and getting familiar with RSCAD-RTDS simulation platform with particular focus on transmission and distribution grid library.
8. 50kV ring network of Enduris (DSO) will be used as a test bench for Dynamic Line rating studies, mainly to answer the following questions and sub-objectives.

- What are the thermal current limits for a particular span operating at particular weather conditions calculated based on measurements and calculation techniques?
- What is the allowed current that would not breach the maximum allowed temperature of the conductor?
- Determination of the weakest span i.e. the span which represents a limit for the whole power line, which presumes that determination of thermal current for all spans has been performed. Furthermore, the weakest span may vary in consequence of different atmospheric conditions and span characteristics (tension, clearance margin, etc..).

9. Further behavioral analysis with special cases like great step of temperature change, old lines, stressed joints and other critical conductor components.

Industry relevance: One of the important and critical group in any TSO's or DSO's is Asset Management Group which diligently work on exploiting the established and acquired assets to its full capacity. This project targets developing such skill set.

Industry Partner:

Required Background: Power Systems, data acquisition and management, Matlab, MS Excel.

Contact details:

- PhD Guide: Nidarshan Kumar (N.Veerakumar@tudelft.nl)
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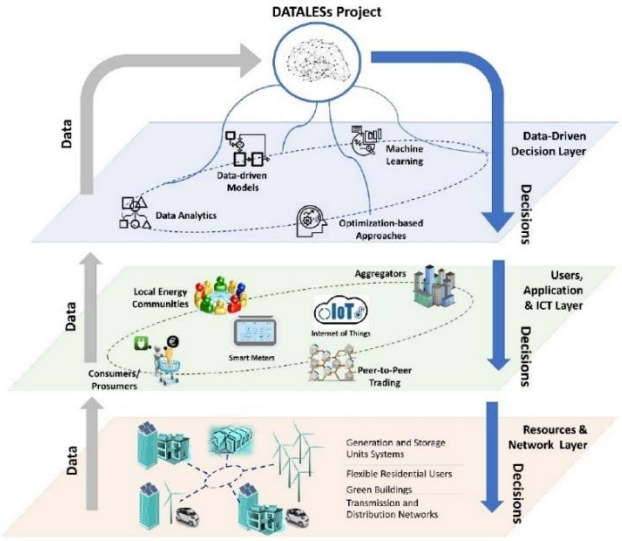
Deep Learning-based Distribution Networks Modeling: Addressing Challenges in Integrating Renewable Energy Resources



Scope: This thesis project aims to develop deep learning-based models to accurately predict power flows and improve the stability and reliability of distribution networks.

Problem definition: The integration of renewable energy resources into modern distribution networks presents several challenges, such as power fluctuations, voltage stability issues, and increased complexity. Traditional modeling and analysis techniques are not sufficient to address these challenges.

Methodology: The project will employ a combination of deep learning models and numerical methods to provide fast and accurate power flow calculations.

Research objectives:

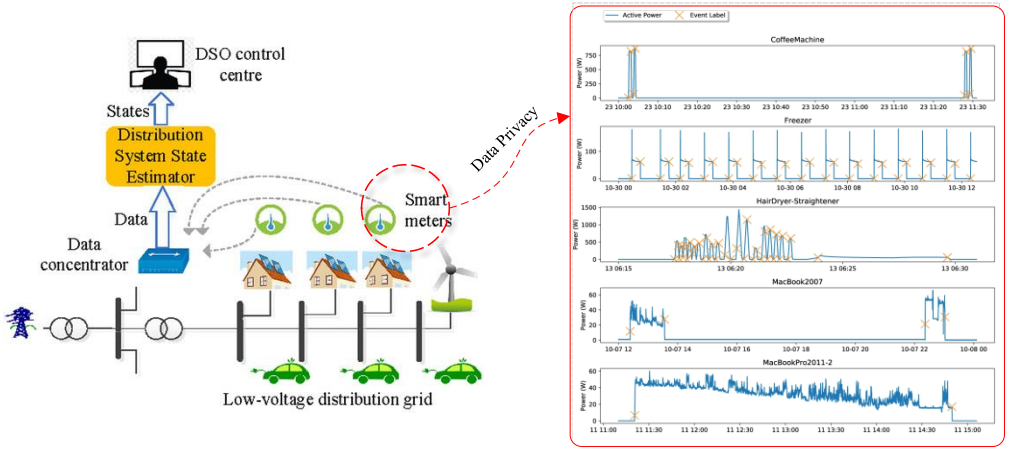
- Develop deep learning-based models to accurately predict power flows in distribution networks.
- Improve the stability and reliability of distribution networks that incorporate a large number of renewable energy resources.

Industry relevance: The project will provide students with the opportunity to work with cutting-edge technology and gain hands-on experience in deep learning-based modeling and analysis. Additionally, students will learn about the practical applications of their research in the energy industry and contribute to the development of sustainable and reliable energy systems.

Contact details:

- PhD student: Zeynab Kaseb (Z.Kaseb@tudelft.nl)
- Supervisor: Pedro Vergara Barrios (P.P.VergaraBarrios@tudelft.nl)

Measurement Data Privacy Protection in Distribution Networks



[1] Nainar, Karthikeyan, and Florin Iov. "Smart meter measurement-based state estimation for monitoring of low-voltage distribution grids." *Energies* 13.20 (2020): 5367.
[2] Pereira, Lucas, Donovan Costa, and Miguel Ribeiro. "A residential labeled dataset for smart meter data analytics." Scientific Data 9.1 (2022): 134.

Scope: This master's thesis project focuses on developing hybrid privacy protection strategies to protect measurement data privacy in distribution networks. The developed algorithms will be implemented to protect multiple kinds of smart meter (SM) data.

Problem definition: More smart meters will be deployed in distribution networks, while detailed SM data will reveal the personal information and habits of electricity users, including eating habits, studying habits, etc. If novel methods are employed to protect this SM data, users will be more willing to share their SM data with researchers to verify the novel methods. Besides, distribution system operators will obtain more real-time and detailed SM data to analyze the operation of distribution networks.

Research objectives: Our objective in this project is to develop a data privacy protection method for SM data used in various practical methods. We will enhance the security level of real-time SM data in distribution networks by analyzing the characteristics of SM data, analyzing the application of SM data, and proposing novel data privacy protection methods. Our approach will contribute to the development of smart distribution networks and alleviate concerns about the privacy of electricity consumption data. Thus, master's students who are interested in privacy protection can participate in this master's thesis project.

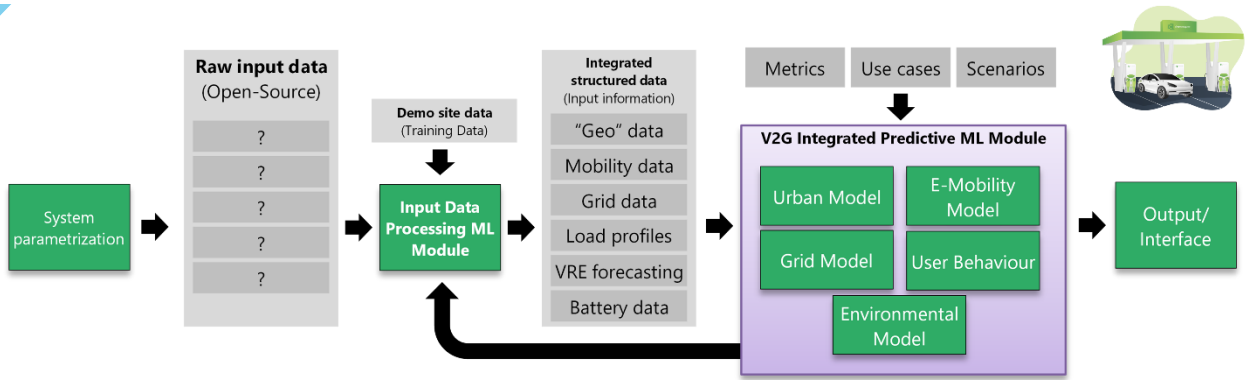
Methodology: Privacy protection technologies and machine learning methods will be explored for protecting high-dimension SM data or SM data with specific labels. There are available open libraries (e.g., scikit-learn, PyTorch, Keras, TensorFlow, etc.) to program the data privacy protection problem in Python.

Industry relevance/partner: You will obtain rich experience in the development and application of hybrid privacy protection strategies in distribution networks.

Contact details:

- PhD student: Dong Liu (D.liu-7@tudelft.nl)
- Supervisor : Dr. Pedro P. Vergara Barrios (P.P.VergaraBarrios@tudelft.nl)

DriVe2X: Optimizing Electric Vehicles through Machine Learning



Scope: The DriVe2X project aims to revolutionize the uptake of V2X by developing cutting-edge technologies suitable for mass EV deployment. Drawing on the power of data from distribution grids, driving and electric demand patterns, and mobile batteries, the project will leverage Machine Learning models to match location-specific flexibility needs and offers. By doing so, DriVe2X will pave the way for a more efficient, intelligent, and sustainable electric vehicle ecosystem, and help accelerate the transition to a zero-carbon-emission future.

Problem definition: As the world moves towards a fully sustainable, zero-carbon-emission future, electric vehicles are becoming more prevalent, and with them come exciting new challenges. One of the most fascinating of these is the ability of EVs to capture the flexible energy potential from smart charging in parking lots, homes, and charging stations, and then match it with the distribution networks' localized needs. This means that the electrical distribution grid can be actively supported while EV users are compensated for the flexibility services they provided. With the rise of EVs projected to continue in the coming years, the need for such solutions has become imminent, making this challenge more pressing and vital than ever.

Research objectives: The primary goal of this project is to develop advanced algorithms and techniques that can efficiently capture the flexible energy potential from any smart charging facility. By utilizing machine learning models, we aim to match the energy supply with the distribution networks' localized needs. This will play a crucial role in making our electric vehicle ecosystem more sustainable, efficient, and effective. The project's scope is broad; thus, providing master's students with the opportunity to define their specific research topics and contribute to the project's overall objective.

Industry relevance/partner: The DriVe2X project is a collaborative effort, with a consortium of 18 partners across Europe. These partners include research institutes, manufacturers, grid operators, municipalities, and other organizations, bringing together a diverse range of expertise and experience.

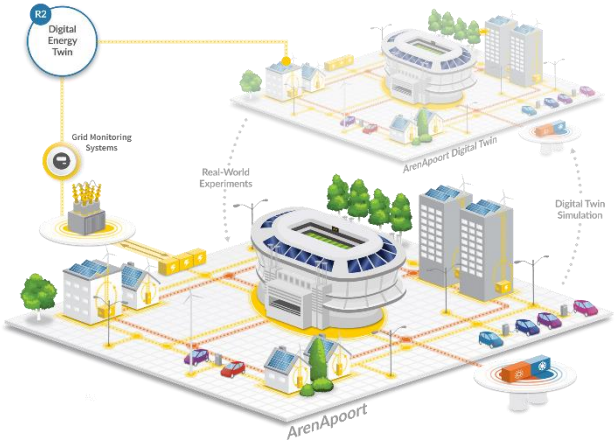
Contact details:

- PhD student: Stavros Orfanoudakis (S.Orfanoudakis@tudelft.nl)
- Supervisor: Pedro Vergara Barrios (P.P.VergaraBarrios@tudelft.nl)

DRIVE2X

European Commission | Horizon 2020 European Union funding for Research & Innovation

LIFE City Platform:
District-Scale Energy Management to Resolve Grid Problems



Scope: This MSc thesis project lies within the scope of the LIFE City Platform, a research project funded by the Ministry of Economic Affairs and Climate and by the Ministry of the Interior and Kingdom Relations of the Netherlands. The research project aims to develop a district-scale energy management platform to resolve grid problems. It will realise a replicable, innovative, integrated, and future-proof energy system for similar mixed-use districts in the Netherlands and abroad. The research will focus on the ArenApoort district in Amsterdam-Southeast.

Problem definition: DSO Alliander has forecasted that 17 out of 25 substations in Amsterdam will reach peak overloads by 2030 - hence the urgency to find alternatives to infrastructure upgrades. In other areas, limited grid capacity has halted new solar and wind projects, demanding solutions for better integration of renewables into the built environment. Therefore, smart energy solutions which unlock the full potential of flexibility from buildings and assets are essential for enabling the evolution of our sustainable energy system.

Methodology: The MSc student can define their project in line with one or more of the objectives of the LIFE City Platform project. The methodology will be discussed once the topic is chosen but may include case studies using real measurement data sets. Furthermore, it may include distribution system modelling, optimisation and machine learning methods, focusing on data generation and management strategies.

Research objectives: (examples)

- Develop a control algorithm for multiple devices and simulate the effects of control measures.
- Develop an algorithm to optimise flexibility while integrating various energy markets.
- Improve self-reliance on local clean energy.
- Create financial value for flexibility.

Industry relevance/partner: For this project, you can collaborate with one of the project partners, which includes industry partners and research institutes. The learning from this project will help you advise DSOs on potential solutions to cope with the inherent challenges of the energy transition.

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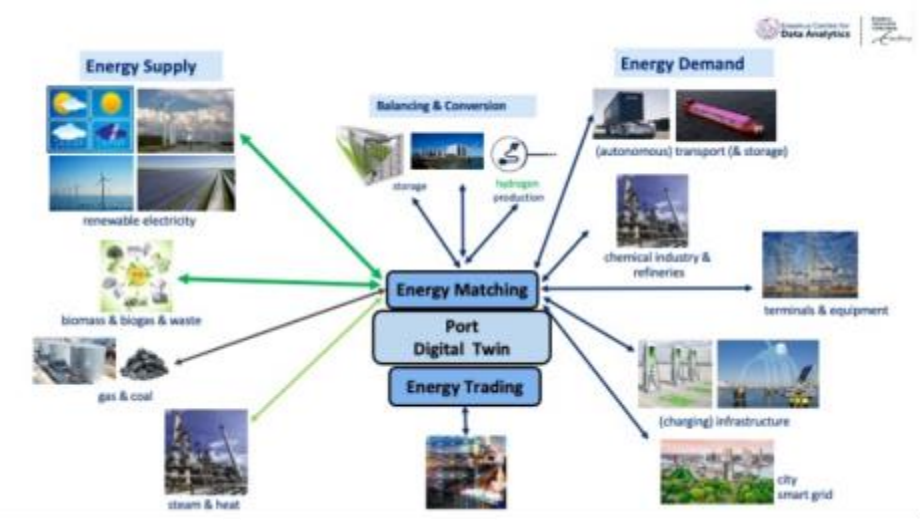
Supervisor(s): Wouter Zomerdijk (w.zomerdijk@tudelft.nl)
Supervisor(s): Pedro P. Vergara (p.p.vergarabarrios@tudelft.nl)
Website: https://www.ams-institute.org/urban-challenges/urban-energy/local-inclusive-future-energy-life-city-platform/

MAGPIE: Smart Energy Solutions to Enable Flexibility in European Green Ports



Scope: The MAGPIE project has the ambition to force a breakthrough in the supply and use of green energy carriers in transport to, from, and within ports. We will create energy-efficient solutions and support developments that make green energy carriers available to the users and contributes to the decarbonization of port-related transport.

Problem definition: The energy transition requires creative solutions for the efficient use of energy. Green ports reduce their impact on emissions by decreasing consumption and by making use of flexibility to optimally match the supply and demand of clean energy. Through this project, a unique collaboration will be formed to address the missing link between green energy supply and green energy use in port-related transport and the implementation of digitization and automation to increase transport efficiency. MAGPIE accelerates the introduction of green energy carriers) combined with the realization of optimization in ports.

Research objectives: Our main task in this project is to develop integrated smart energy solutions for green ports by providing strategic decision support on congestion points and energy system interventions through identifying synergies and barriers in flexible energy use. We also contribute to the development of an energy system simulator with embedded cross-sector flexible energy matching, which will allow assessing technical performance, identifying congestion points, quantifying flexibility needs, identifying constraints, etc. Therefore, Master's students who are interested in this project can define their master thesis project in line with one or more objectives of this huge project.

Methodology: This platform will require the application of optimization methods, energy management strategies, uncertainty modeling and development of statistical models for resource availability using bottom-up models and/or machine learning using data from different segments of a green port (maritime, in-port, hinterland).

Industry relevance/partner: The MAGPIE consortium consists of various ports, research institutes and companies.

Contact details:

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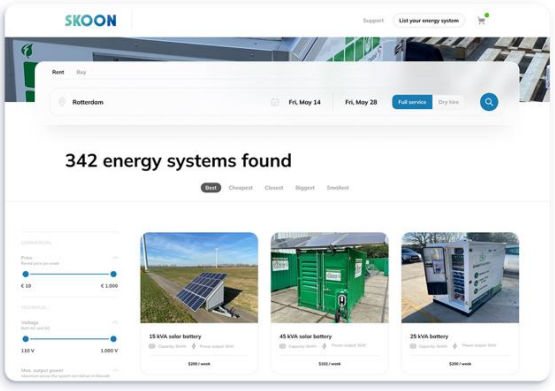
- Supervisor: Dr. Pedro P. Vergara Barrios (P.P.VergaraBarrios@tudelft.nl l)
  Website: https://www.magpie-ports.eu/magpie-project/

Solving Congestion Problems in Dutch Distribution Networks Using Mobile Energy Storage Systems



Scope: This MSc thesis project focuses on developing a framework to define the best technology fit, its location in the network and optimize its operation aiming to solve congestion problems in Dutch residential distribution networks, given its availability, technical specifications and price. A new dimension to the provision of flexibility is added by deploying mobile energy storage systems: its geographic location.

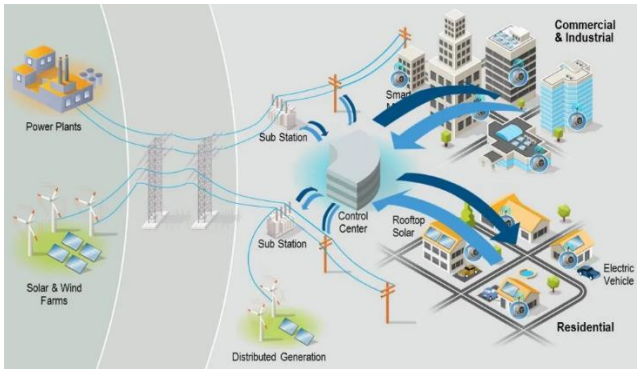
Problem definition: To mitigate the risks to the Dutch electricity system posed by the growing number of congestion events caused by the uptake of active resources like PV and EVs in distribution networks, local energy storage systems could be utilized during peak demand. Skoon Energy's platform provides scalable access to mobile batteries, which can be deployed to provide grid services at different locations, times, and types of assets. By determining the most appropriate location and type of grid service to deploy in each scenario, the optimal use of mobile batteries can be determined, reducing the need for investment in battery placement. This would allow more resources to be allocated towards optimizing the operation of these energy storage systems.

Methodology: The objective is to develop a framework that allows estimating the best energy system technology and its geographical location to solve congestion in a real case study. First, you will need to develop a power flow model in open-source software to do this. Then, develop an algorithm to optimize the operation of the defined energy storage system. Finally, provide an in-depth analysis of the suitability of different storage technology set-ups to solve congestion problems.

Industry relevance/partner: You will learn about the main operational challenges of distribution system operators and the role of flexible energy solutions, such as mobile batteries. You will also learn how to model distribution networks using open-source software. For this project, you will be working with Skoon Energy as a project partner and knowledge source. The learning from this project will help you advise Skoon Energy on potential solutions to support DSOs with the inherent challenges of the energy transition.

Contact details:
Supervisor(s): Pedro P. Vergara (p.p.vergarabarrios@tudelft.nl)
Company Supervisor(s): Peter Paul van Voorst (peterpaulvanvoorst@skoon.world)

Improving Operator Insights of Partially Observable Distribution Networks for Advanced Distribution Management Systems



Scope: This MSc thesis project focuses on improving operator insights of partially observable distribution systems. To provide insights, several models can be developed, e.g., pseudo measurement generation, observability analysis, and correlation of measurement devices, based on the student's interest. The new model will be tested and implemented as a case study.

Problem definition: To accommodate a high penetration of volatile renewable energy sources, electrical vehicle charging, and demand response, Distribution System Operators (DSOs) need to estimate the operating state of the system and achieve control under all loading and operating conditions. This estimation is performed through so-called 'state estimation' algorithms. Since the entire network may not be observable with measurement devices, pseudo measurements with large margins of error are often used. To deal with this issue, DSOs are looking for solutions to decrease the margins of error and improve the accuracy of the state estimation models.

Methodology: The objective is to develop applications for state estimation models that improve the insights of DSOs in partially observable distribution networks. First, the state-of-the-art models will be analysed, and a new method will be proposed. Then, a case study is created where the developed model will be deployed. The case study will form the basis for the impact analysis of the proposed method.

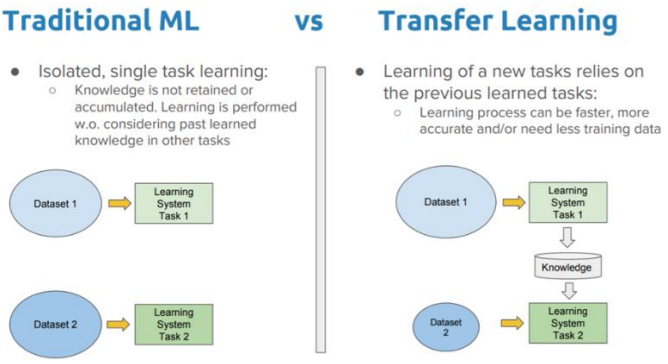
Research objectives:

- Perform an extensive literature study on the model of the student's interest.
- Develop a new approach to improve the insights for DSOs.
- Develop and study the impact of implementing the new approach in a case study.

Industry relevance/partner: You will learn about the main operational challenges of distribution system operators. You will also learn how to model distribution networks using open-source software. For this project, you will be working with one of the Dutch DSOs (Stedin) as a project partner and knowledge source. The learning from this project will help you advise DSOs on potential solutions to cope with the inherent challenges of the energy transition.

Contact details:
Supervisor(s): Wouter Zomerdijk (w.zomerdijk@tudelft.nl)
Supervisor(s): Pedro P. Vergara (p.p.vergarabarrios@tudelft.nl)
Company Supervisor(s): Nuran Cihangir Martin (Nuran.CihangirMartin@stedin.net)

Comparison of different transfer learning algorithms for electrical consumption profile generation



Scope: This research focuses on developing different transfer learning-based load profile generation algorithms to generate load profiles and compare the performances.

Problem definition: The load profile generation is an important problem in the distribution system as the generated data can be applied to train other machine learning models for system operation and planning. However, due to the privacy issue, it is usually hard to collect load profile data from the customer side directly, leading to difficulty in getting appropriate data for training purposes. Transfer learning is a potential solution to this problem. This research aims to leverage the value of different transferring learning in load profile generation.

Methodology: In this thesis, you will consider the original data as a source domain and generated data as a target domain. The research is to use transfer learning methods to transfer the data from the source domain to the target domain. Different transfer learning methods might be applied (TCA, MMD, transfer adversarial network etc.). In the end, you will also need to compare the performance of different algorithms on generation tasks.

Research objectives:

- Research different transfer learning algorithms and select suitable algorithms.
- Develop different transfer learning algorithms for load profile generation.
- Compare the performance of the generated results.

You will get: You will learn advanced generative/transfer learning algorithms and their application in energy systems. You will also get experience in Python. Besides that, you will get experience in machine learning and deep learning frameworks like Pytorch, Sk-learn, etc.

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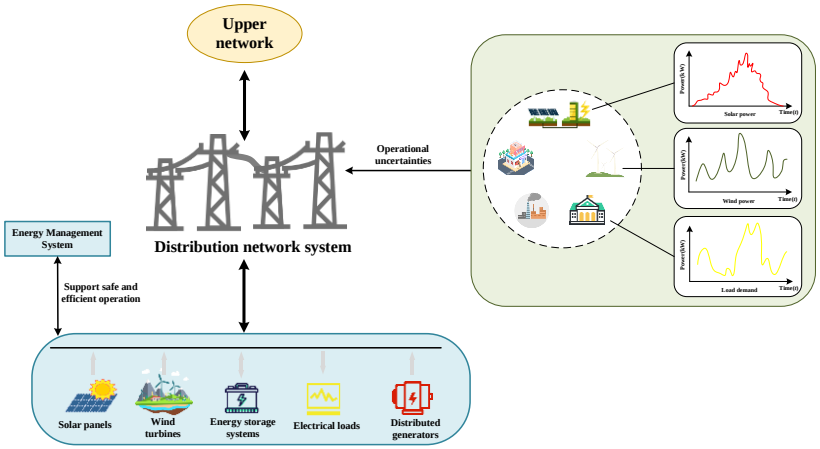
Robust Optimal Dispatching of Distribution Networks with High Penetration of Renewable Energy



Scope: This thesis will focus on developing classical optimization methods capable of providing robust decisions for dispatching resources in the distribution networks (DNs) in the presence of multiple uncertainties associated with renewable energy sources (RESs) and load consumption, to support accurate and economically-lucrative operation of DNs under uncertainty. The precise scope can be adjusted depending on the student's interest and skills.

Problem definition: The development of efficient and intelligent distribution network systems is crucial, especially with the increasing penetration of RESs and other distributed energy resources. The DNs optimal dispatching problem is mathematically formulated as an optimization problem, aiming to realize the most economically-lucrative energy scheduling while guarantee operational constraints to ensure reliable and secure operation.

Methodology: A mixed integer linear programming (MILP) / mixed integer nonlinear programming (MINLP) based optimization model will be developed to simulate the DNs dispatching process. The challenge is to determine robust decision that can guarantee the constraint enforcement in all possible scenarios. Therefore, this project will require the uncertainty handling methods (such as robust optimization, stochastic programming, etc.) to quantify the impact of uncertainties on optimal solutions and identify robust dispatching strategies under variable scenarios.

Research objectives:

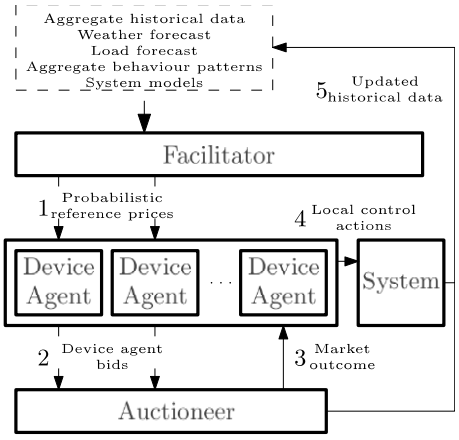
- Investigate the uncertainty handling methods commonly used in the power systems.
- Develop MILP/MINLP optimization models considering uncertainty and solve them using commercial solvers in the Python/Pyomo environment.
- Test the developed algorithm and the optimal dispatching scheme with out-of-sample test set.

Industry relevance/partner: Through this thesis, the student will be able to understand the dispatch process of DNs in the Netherlands, identify bottlenecks of the uncertainty handling methods and come up with new ideas to mitigate them. After completing this thesis, the student will independently develop more advanced optimization algorithm and provide better insight into uncertainty dispatching modelling for the distribution system operators.

Contact details:

- PhD student: Zhisheng Xiong (Z.Xiong@tudelft.nl)
- Supervisor: Dr. Pedro P. Vergara Barrios (P.P.VergaraBarrios@tudelft.nl)

Using price forecasts to coordinate large numbers of flexible devices



Scope: This project investigates the practical feasibility of a recently developed mechanism to coordinate the starting time of distributed flexible loads.

Problem definition: To keep future low-carbon grids affordable, it is essential that demand can follow supply to some extent. This requires a means for end users (and their devices) to communicate the flexibility in their electrical power demand, and a mechanism to coordinate their power consumption. This project will build upon the "F-MBC" approach that was recently developed at TU Delft. It coordinates the starting time of deferrable loads (e.g. washing machines) using a real-time market with probabilistic price forecasts. The latter are essential for the coordination of loads: with the right forecasts, they become approximately 'self-fulfilling', driving the users to optimal activation patterns. Although this has been shown to work in theory, building such a forecaster (market "facilitator") remains an open problem.

Methodology: You will implement a simple model system with a large population of deferrable loads controlled by F-MBC in Matlab or Python (preferred). Various machine learning methods can be considered to predict prices in a self-consistent manner, but reinforcement learning is a particular candidate that should be investigated. Simulation studies will be used to investigate the performance of various forecasting approaches, and their sensitivity to model parameters.

Research Objectives:

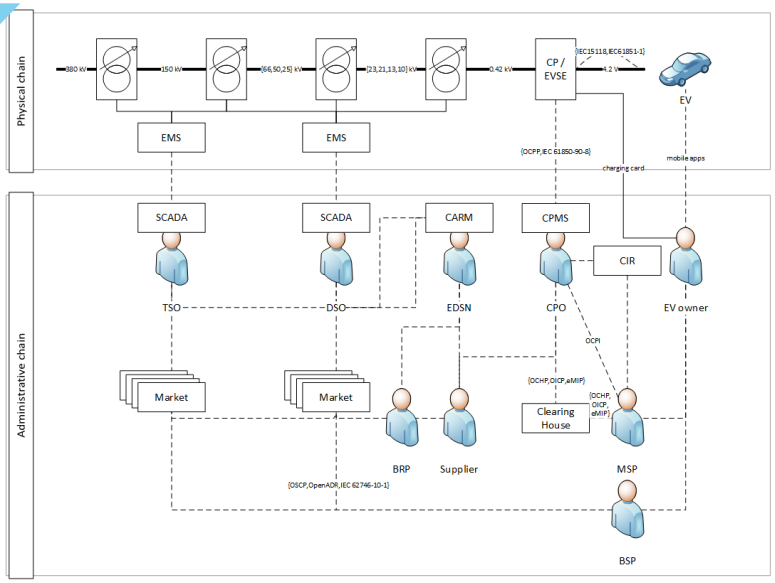
- Define a model system and implement it in Matlab/Python.
- Identify relevant machine learning approaches for the facilitator.
- Set up a learning environment and analyse the performance of the facilitator over time.

Industry relevance: Market-based control applied on coordination of flexible DERs is a recent research interest for aggregators, DSOs and energy retailers. Moreover, this research studies one of the options to open up the flexibility market to massive amount of resources, presenting business opportunities and reducing emissions.

Contact details:

- Simon Tindemans (S.H.Tindemans@tudelft.nl)

Classification of Distribution Networks and Method for Synthetic Model Generation



Scope: This thesis project will focus on analyzing the state-of-the-art of distribution network modelling and developing and training a classification model using machine learning. The objective is to develop a method for generating synthetic distribution network modelling, preferably both physical and digital, for further research.

Problem definition: Accurate data is a valuable and scarce commodity in academia. Moreover, with ever-growing collaborations with industries and governments he disturbances in the grid can be identified based on the fault signatures which can cause massive power outa, the problem of data confidentiality becomes more pressing on conducting open research

Methodology: The challenge is to determine the current state-of-the-art in terms of distribution network modelling and how machine learning can be applied to analyze large amounts of data in an efficient manner. You will apply the resulting classification to develop a method for synthetic model generation using Python and PowerFactory. Finally you will analyze the results based on the model's ability for generalization and accuracy.

Research objectives:

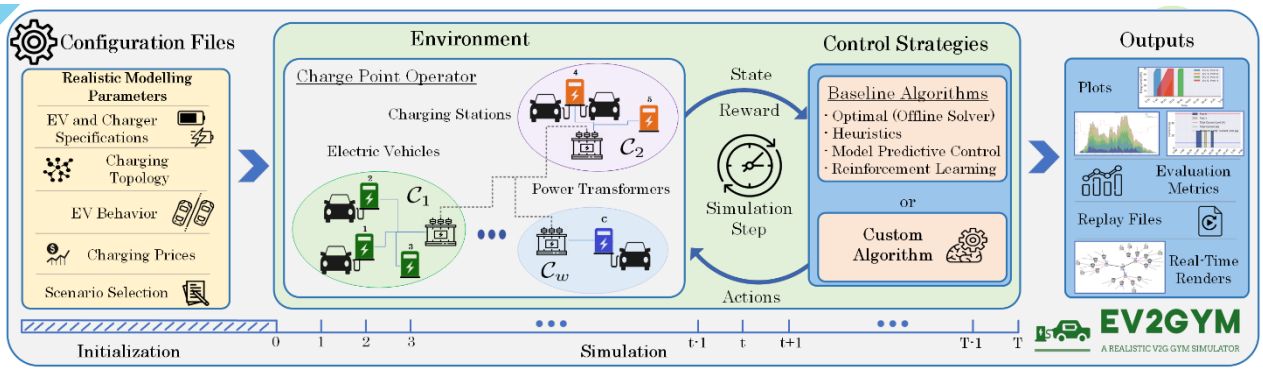
- Research distribution network modelling state-of-the-art and classification methods.
- Develop a classification model and train with data supplied by Stedin using machine learning.
- Develop a method for synthetic distribution network model generation.
- Research and apply common model performance metrics for testing validity.

Industry relevance/partner: You will work together with industry partner Stedin and improve their researching capabilities.

Contact details:

- PhD student: Sjors Hijgenaar (sjors.hijgenaar@stedin.net)
- Supervisor: Alex Stefanov (a.i.stefanov@tudelft.nl)

Efficient EV Charging Management via Reinforcement Learning



Scope: This master thesis aims to explore the application of reinforcement learning (RL) techniques in managing electric vehicle (EV) charging infrastructure. The scope encompasses the development and implementation of RL algorithms tailored for EV charging optimization, considering factors such as user preferences, grid constraints, renewable energy integration, and infrastructure scalability.

Problem definition: The exponential growth of EVs presents challenges in managing charging infrastructure efficiently. Conventional scheduling methods often struggle to adapt to dynamic conditions and user behaviors, leading to suboptimal resource utilization, increased grid stress, and elevated operational costs. Addressing these issues requires intelligent solutions capable of dynamically optimizing charging schedules while ensuring user satisfaction and grid stability.

Research objectives:

- Investigate existing challenges and limitations in current EV charging management systems.
- Review state-of-the-art RL techniques and their applicability to EV charging optimization.
- Develop a novel RL framework tailored for EV charging management, considering diverse objectives such as grid stability, user satisfaction, and cost efficiency.
- Evaluate the performance of the developed RL framework through extensive simulations, comparing it against traditional scheduling methods and benchmark algorithms.
- Analyze the scalability and sustainability aspects of the proposed RL-based EV charging management system, considering real-world deployment scenarios and future expansion possibilities.

Methodology: The master student will have the flexibility to define the scope and select specific methodologies tailored to the research objectives. Potential methodologies to consider (and not only) include:

- Model-Based RL
- Safe RL
- Hierarchical RL
- Meta-RL

Knowledge about basic ML libraries such as PyTorch and NumPy is suggested to have.

Contact details:

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- Supervisor: Pedro Vergara Barrios (P.P.VergaraBarrios@tudelft.nl)

DRIVE2X

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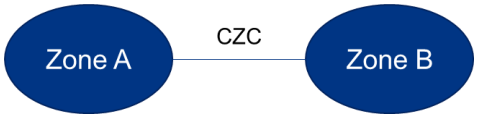
Developing a forecasting algorithm for market-based cross-zonal capacity allocation

Scope: Power systems, electricity markets, optimization and forecasting techniques

Problem definition: Cross-zonal capacity (CZC) between two bidding zones is limited. Therefore, this limitation requires the introduction of a mechanism to allocate the scarce CZC in an economically efficient manner. The CZC allocated to the day-ahead energy market (DAM) reduces the available CZC for the balancing capacity market (BCM) and vice versa, hence CZC allocation to one market increases its economic surplus but reduces the economic surplus of another market. The DAM and BCM are thus in direct competition for the available CZC of the day-ahead timeframe. Allocation of CZC to DAM results in physical flows between bidding zones not exceeding the allocated volume while allocation of CZC to BCM results in redistribution of Balancing Reserves between TSOs, that on activation may lead to physical flows not exceeding the allocated capacity. Jointly these flows should not exceed CZC limit.



The EB Regulation (a set of technical, operational and market rules for the operation of EU-wide electricity balancing markets) proposes a particular approach to allocate CZC in a market-based environment. This optimisation is called the CZC allocation optimisation function (CZCAOF), which allocates CZC between the DAM and the BCM in the most economical way, and before the gate closure time of the DAM. To use this approach, the bid curves of the DAM, which serve as inputs to the CZCAOF, need to be forecasted.

Research objective: The aim of this study is to develop a forecasting algorithm that best fits the regional specificities of each CZC allocation platform and whose output is the DAM bid curves based on the required inputs, e.g. historical DAM bid curves, weather data, integration of renewables, grid data, etc. belonging to the CZC allocation platform. This will be embedded in a simulation model to investigate the performance of the algorithm, and the effect of different design options. **This study is conducted in cooperation with the Dutch TSO, TenneT.**

Requirements: Knowledge of solving optimization problems including machine learning, data science and forecasting techniques, General knowledge of electrical engineering and/or electricity markets, Good programming skills (e.g. Python), Good communication skills.

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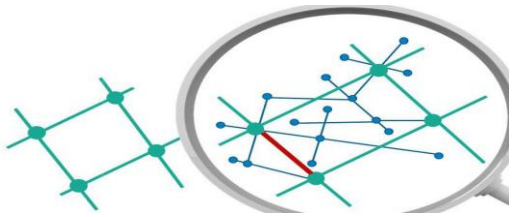
Simon Tindemans (university supervisor, s.h.tindemans@tudelft.nl)

Exploring the synergy between flood protection, sanitary infrastructure and the electricity grid



Scope: This thesis project will focus on the exploration of electric grid-congestion management strategies for local flood protection and sanitary infrastructure.

Problem definition: The electricity grid is being kept in a constant near-perfect balance between supply and demand. Nationally, this is maintained through the allocation of resources and imbalance mechanisms. However, electricity needs to be transported over long distances. Grid expansion can be slow, resulting in areas of the grid that are stretched to its limits. Grid congestion occurs when a grid overload prevents electricity to flow according to engineering design specifications (heat production, N-1 criterion), which can happen on both high-voltage transmission lines and local distribution grids. Especially in the larger metropolitan area of Amsterdam this is a challenge.

Waternet is a water utility provider also responsible for flood protection in the Amsterdam-city region. They are responsible for sewage water treatment, drinking water treatment and supply, and managing surface- and ground water levels in the region. The most energy-intensive processes are pumping and aeration of water, which possess some inherent demand-side flexibility that can be utilized.

Flexibility in energy use can be utilized for many purposes. In this thesis the potential of Waternet's flexibility will be explored for regional grid-congestion management.

Methodology:

The challenge in this thesis is to utilize the flexibility of several spatially distributed energy-consuming assets in order to prevent grid congestion in the local distribution network. An exploration needs to be done of the energy-consuming assets, identifying their location, grid-connection, capacity and available flexibility. Market-based congestion management (through GOPACS) would allow for a feasibility study by simulating participation in this market mechanisms with Model Predictive Control (MPC). Trade-offs can be investigated between frequency reserve potential and congestion management, giving Waternet an indication of the best course of action. The thesis work involves mathematical optimization of energy use, including game theoretic and ML approaches. Limited knowledge of the treatment- and pumping processes will be required. However, it will be valuable to identify the technical requirements (e.g. changing pump rate every 5 minutes, large variations in drinking water production speed) to deliver demand-side flexibility for Waternet's assets.

Research objectives:

- Topology mapping of Waternet's connections to the electricity grid
- Identification of key control decision management and dependencies in the energy use of Waternet's assets
- Quantification of the available flexibility in (yearly 5min time series) of all Waternet's assets
- Exploration of the benefits that congestion management from Waternet's assets can bring
- Investigating the trade-off between (national) imbalance regulation and (local) congestion management

Industry relevance/partner: Waternet, AMS Institute, Alliander

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- Supervisor: Arjen van der Meer (A.A.vanderMeer@tudelft.nl)
- Supervisor: Paul Voskuilen (paul.voskuilen@ams-institute.org)

Electives relevant for IEPG graduation projects

EEMCS forms https://www.tudelft.nl/en/student/faculties/eemcs-student-portal/education/forms/msc-forms/

Projects and internship		Q	ECTS	Notes
EE5010	Internship (EE)		10 -- 15	
SET3822	Internship (SET)		15	
ET4399	Extra project (EE)		15	
TUD4040	Joint Interdisciplinary Project (JIP)	1	15	
ET4300	Thesis project (EE)		45	
SET3901	Graduation project (SET)		45	

Power engineering		Q	ECTS
EE4375	Finite Element Modelling for Electrical Energy Applications	3	4
EE4655	Co-simulation of Energy Systems	3	4
EE4545	Electrical Power Systems of the Future	3	4
EE4665	Uncertainty Modelling and Risk Assessment in Electrical Power Systems	3	4
EE4C12	Machine Learning for Electrical Engineering	1	5
ET4107	Power Systems Analysis II	2	4
ET4113	Power System Dynamics	4	4
ET4114	Power System Grounding and Protection	4	3
SET3065	Intelligent Electical Power Grids	3	4
EE4536	DC and AC microgrids	4	4

Data science, signal processing, machine learning		Q	ECTS	
EE4C03	Statistical Digital Signal Processing and Modeling	1	5	
EE4540	Distributed Signal Processing	3	5	
CSE2510	Machine learning	1	5 (BSc onl	BSc course
CSE2530	Computational intelligence	3	5 (BSc onl	BSc course
CS4220	Machine learning 1	2	5	
CS4230	Machine learning 2	34	5	
EE4685	Machine learning, a Bayesian perspective	3	5	
CS4240	Deep learning	3	5	
CS4070	Multivariate data analysis	12	5	
WI4455	Statistical Inference	12	6	

Control		Q	ECTS
SC42050	Knowledge Based Control Systems	3	4
WI4221	Control of Discrete-Time Stochastic Systems	34	6
SC42125	Model Predictive Control	3	4
SC42075	Modelling and Control of Hybrid Systems	4	3
IN4150	Distributed Algorithms	2	6

Optimization		Q	ECTS	
SET3060	Energy System Optimization	1	5	
EE4530	Applied Convex Optimization	2	5	
ME46060	Engineering Optimization: Concepts and Applications	4	3	
SC42056	Optimization for Systems and Control	1	3	
SC42100	Networked and Distributed Control Systems	4	3	
WI4051TU	Introduction to operations research	12	6	
WI4207	Continuous Optimization	12	6	In Utrecht
WI4227	Discrete Optimization	12	6	

Electricity markets and regulations		Q	ECTS	
SEN1522	Electricity and Gas: Market Design and Policy Issues	2	5	
WM0637SET	Economic Policy for Sustainable Energy	3	4	
SEN1541	Sociotechnology of Future Energy Systems	4	5	
TPM001A	Sociotechnology of Future Energy Systems	1	4	
SEN1511	Engineering Optimization and Integrating Renewables in Electricity Market	1	5	similar to SET3060
SET3055	Economics and Regulation of Sustainable Energy Systems	1	4	

Agents and games		Q	ECTS	
WI4156(TU)	Game Theory	12	6	
EE3060TU	Agent-based energy markets	2	3 (BSc onl	BSc course
CS4210-A	Algorithms for Intelligent Decision Making	3	5	
SEN1211	Agent-based modelling	2	5	
SEN9120	Advanced agent-based modelling	2	5	

Cyber-security		Q	ECTS	
CS4035	Cyber Data Analytics	4	5	
ET4397IN	Network Security	3	5	
IN4253ET	"Hacking Lab" - Applied Security Analysis	3	5	
SPM5442	Cyber Risk Management	1	5	
CS4160	Blockchain Engineering	3	5	

Multi-energy systems		Q	ECTS	
SEN1531	Design of Integrated Energy Systems	3	5	
SC42075	Modelling and Control of Hybrid Systems	4	3	
SET3013	Renewable Energy	1	4	

Uncertainty, risk and stochastic simulation		Q	ECTS	
WI4052	Risk analysis	12	6	
WI4050	Uncertainty and Sensitivity Analysis	34	6	
WI4525TU	Monte Carlo simulation and stochastic processes	12	5	
WI4614	Stochastic Simulation	3	6	Every 2y; next in 21-22
SPM9446	System Reliability in Quantitative Risk Assessment	2	4	
SPM9447	Design of Safety and Security Systems	23	6	
SPM9448	Methods for Risk Analysis and Management	4	5	
WI3425TU	Monte Carlo Methods	2	3	BSc course

Programming and software engineering		Q	ECTS	
TI3115TU	Software Engineering Methods	1	5	BSc course
TI3105TU	Introduction to Python Programming	1	5	BSc course
AM1090	Introduction to Programming	2	6	BSc course
TW3710TU	Scientific Programming	1	3	BSc course
WI4260TU	Scientific Programming for Engineers	3	3	
IN4315	Software Architecture	3	5	
TW3720TU	Object Oriented Scientific Programming with C++	2	3	BSc course
WI4771TU	Object Oriented Scientific Programming with C++	2	3	
TW3740TU	Parallel Computing	1	4	BSc course
IN4049TU	Introduction to High Performance Computing	12	6	
IN4343	Real-time systems	3	5	

See also: https://software-carpentry.org

Specialist courses offered by the Delft Institute for Computer Science and Engineering

Programming on the GPU with CUDA	every quarter
http://homepage.tudelft.nl/d2b4e/gpu_flyer.pdf	
Introduction to Programmig using MPI	once a year
http://homepage.tudelft.nl/d2b4e/flyer-mpi.pdf	