Intelligent Electrical Power Grids

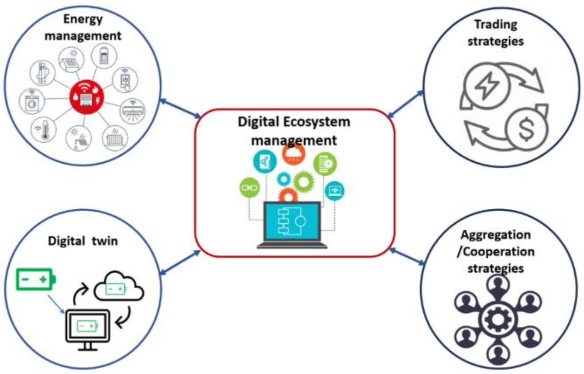
Collection of available MSc projects

November 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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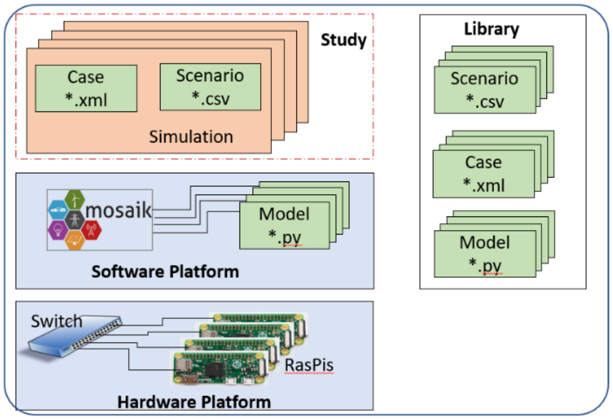
The Illuminator – energy system integration development kit

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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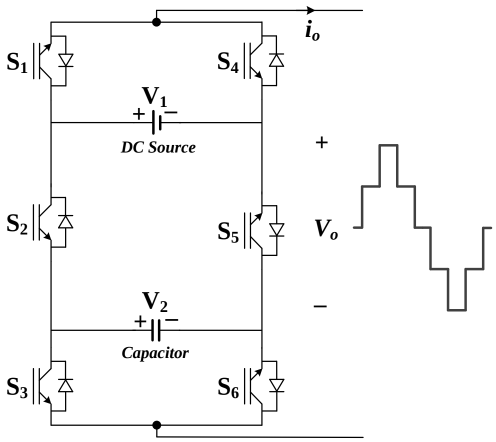
Advanced Control Design for PUC5 Converter



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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IEPG Intelligent Electrical Power Grids

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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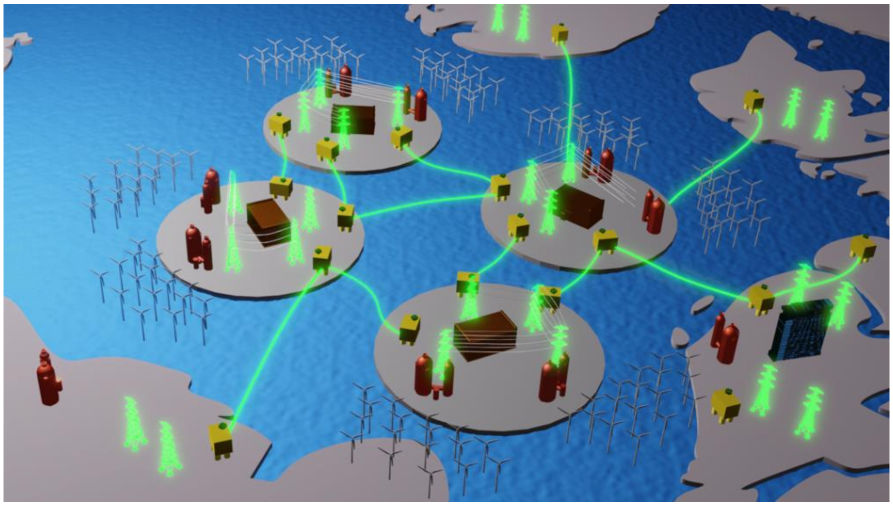
RTDS Technologies

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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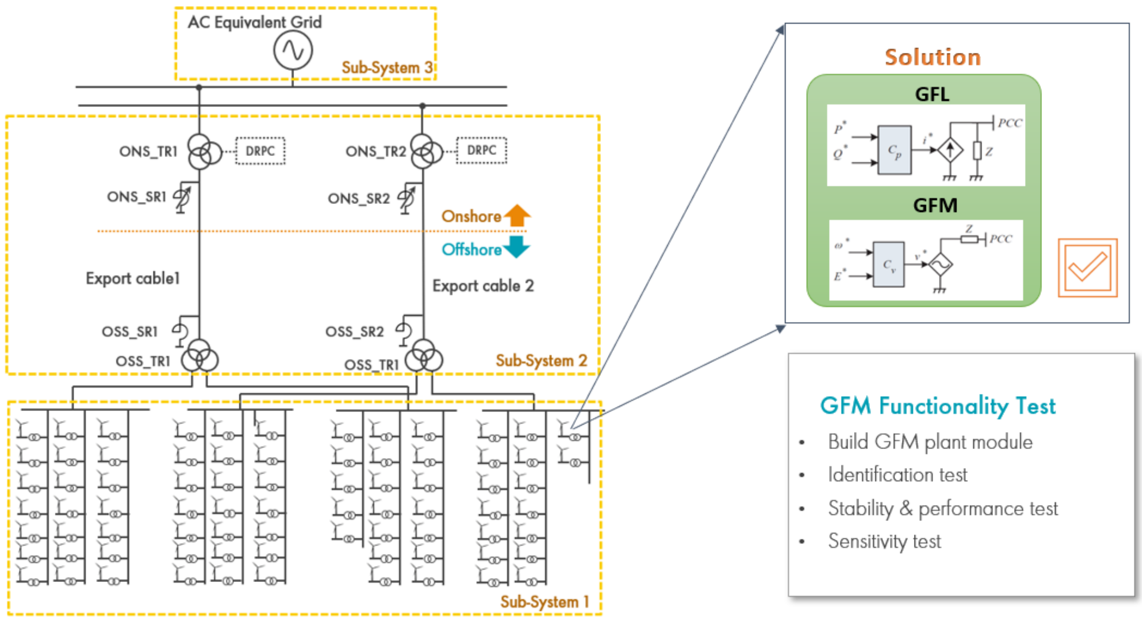
Stability analysis of offshore wind farm based on GFM technology



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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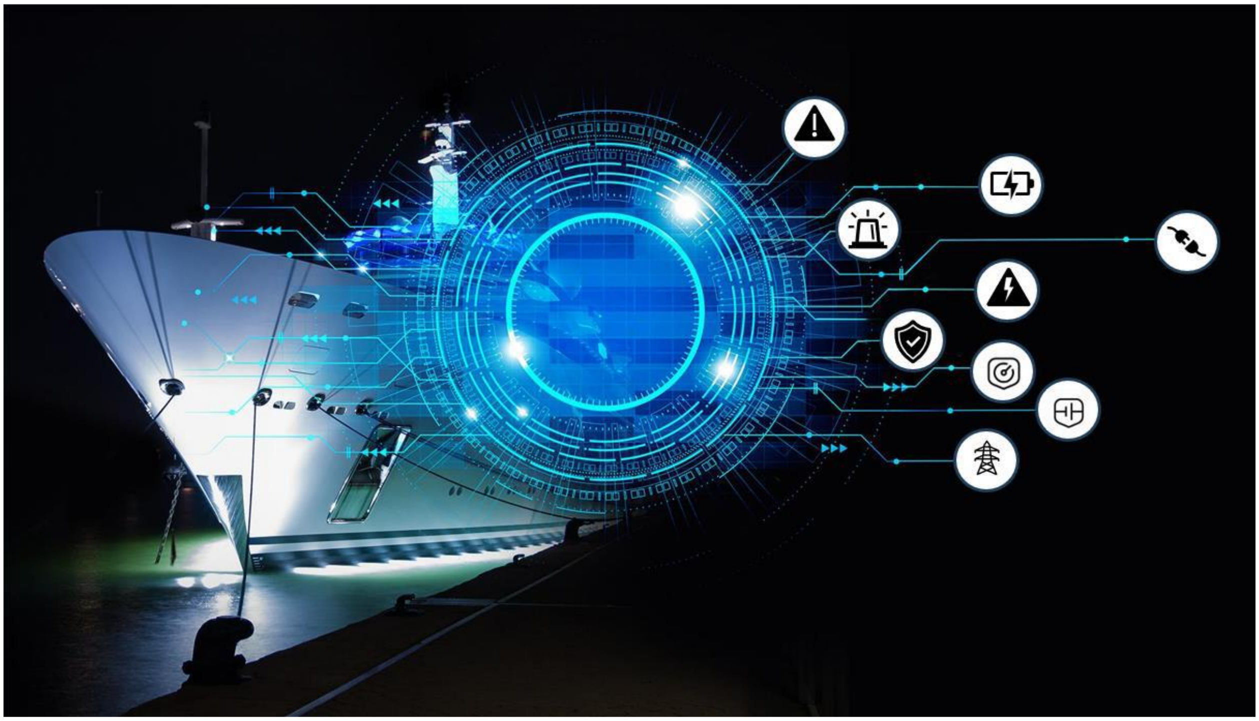
Battolyser Systems

Research and Implementation of Solid-State Circuit Breakers in DC Electrical Power Generation and Distribution Systems



Scope: This research aims to significantly advance protection technologies in maritime DC grids. The thesis will enhance maritime power systems' reliability, safety, and efficiency by focusing on SSCBs and assessing different fault identification and protection coordination approaches. This will facilitate the industry's transition to more advanced and resilient infrastructures.

Problem definition: The maritime industry is increasingly adopting DC grids for power distribution due to their enhanced efficiency and reliability compared to traditional AC systems. However, conventional mechanical protection devices such as circuit breakers and fuses have inherent limitations in response time and fault isolation capability. Solid-state circuit breakers (SSCBs) offer ultrafast switching capabilities, higher reliability, and improved protection for DC grids. This research focuses on in-depth analysis and implementation of SSCBs in DC shipboard power systems, emphasizing different fault identification and protection coordination methods.

Methodology: The methodology for this research involves a systematic approach to modeling, simulating, and validating the performance of solid-state circuit breakers (SSCBs) in DC shipboard power systems. Initially, a comprehensive literature review will be conducted to gather insights into existing SSCB technologies and fault identification methods. Advanced simulation tools such as MATLAB/Simulink will be utilized to develop detailed models of SSCBs, incorporating various fault identification techniques like overcurrent, current derivative, distance, differential, and directional protections. These SSCB models will be integrated with existing DC grid software models to ensure compatibility and seamless operation. The simulation will focus on evaluating performance metrics such as fault detection time, selectivity, reliability, and implementation complexity. Additionally, the research will include an analysis of the challenges and benefits of different protection methods in terms of speed, accuracy, and complexity. The methodology aims to provide a comprehensive understanding of SSCB integration in maritime DC grids, paving the way for more efficient and reliable power system protection.

Research objectives:

- Utilize academic journals, technical standards, and industry reports to gather information on SSCBs and protection methods.
- Identify research gaps and summarize current state-of-the-art technologies.
- Develop comprehensive models of SSCBs tailored for maritime DC grid applications.
- Integrate SSCB models with existing DC grid software models to ensure seamless operation and compatibility.
- Using different protection methods, simulate the performance of SSCBs under various fault conditions.
- Analyze these methods' speed, selectivity, reliability, and complexity in the context of SSCBs.

Industry relevance/partner: You get the opportunity to work first-hand on the new technology developments in the Maritime industry. As the software modeling of SSCBs is essential, your research substantially impacts Alewijnse Netherlands.

Contact details:

- **Supervisor:** Aleksandra Lekić (A.Lekic@tudelft.nl), Marjan Popov (M.Popov@tudelft.nl)
- **Industrial supervisor:** Zoran Malbašić (z.malbasic@alewijnse.com)

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).

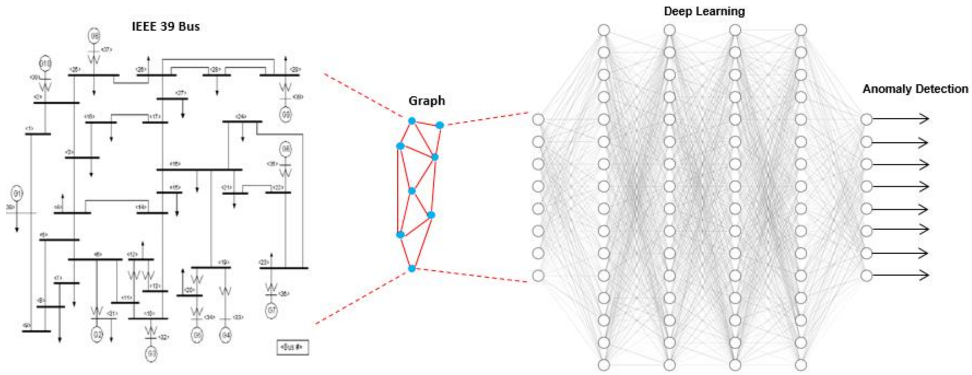
Research objectives:

- 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.

Contact details: Daily supervisor Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl), Industry Supervisor: Olaf Peters (olaf.peters@technolution.nl), Chair: Prof. Dr. Marjan Popov (M.Popov@tudelft.nl)

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:

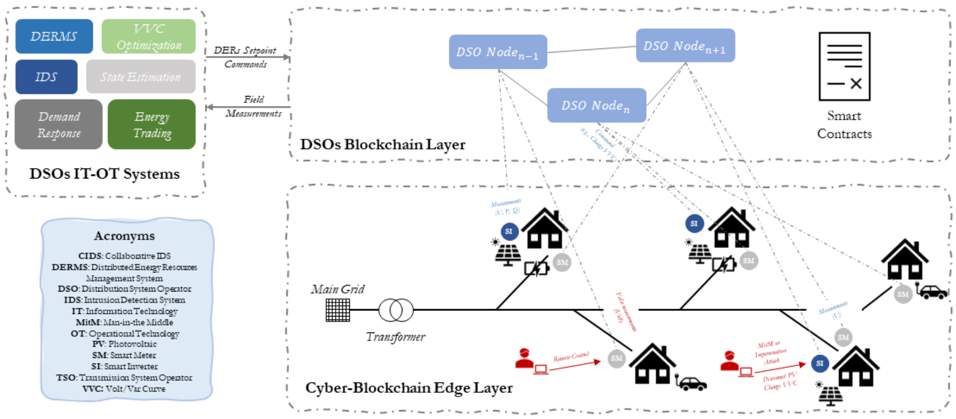
- Detect physical and cyber anomalies on the simulated power system.
- Develop a method to correlate cyber-physical anomalies.

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.

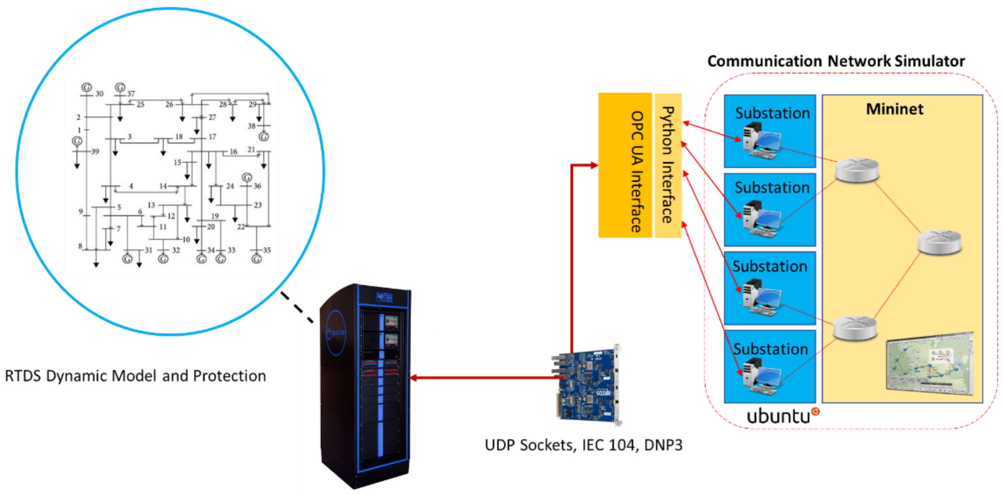
Methodology: You will contribute to prototyping a blockchain-based framework that would manage the overall workflow of DERs' control and monitoring (e.g., issued set-point commands from the DSOs). You will define the format and nature of the data to be recorded on the blockchain as well as the access 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.**

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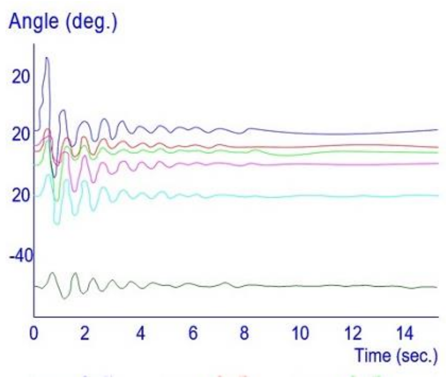
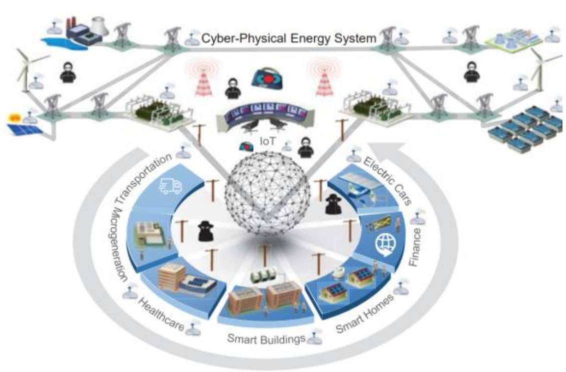
Data-Driven Cyber-Physical System Security Assessment





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.

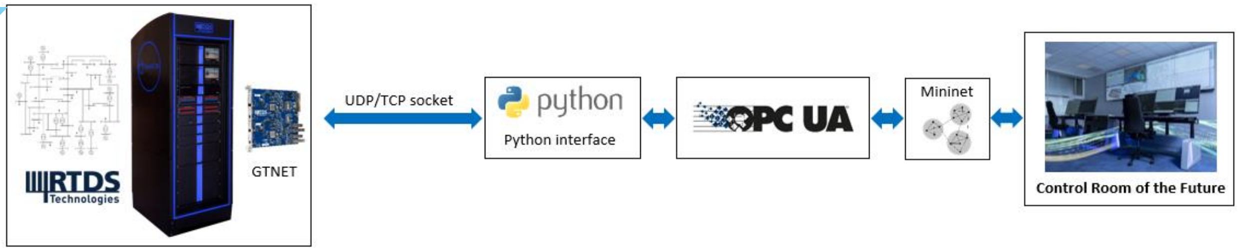
Research objectives:

- 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.

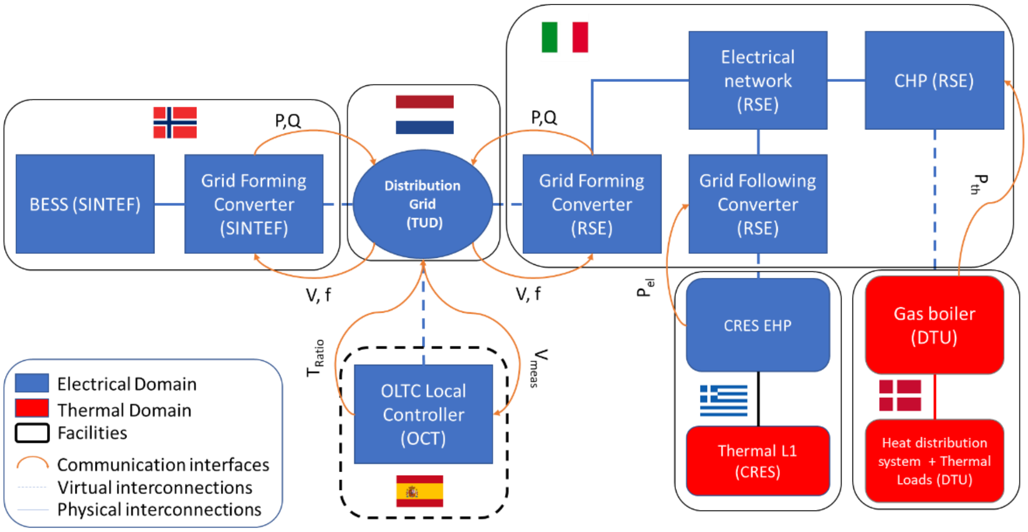
Industry relevance/partner: This MSc thesis project is part of the Control Room of the Future research programme between TU Delft and TNO. An internship with TNO on this topic is required. You will be supervised during your work placement and be given the scope to get the best out of yourself. TNO will 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)

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.

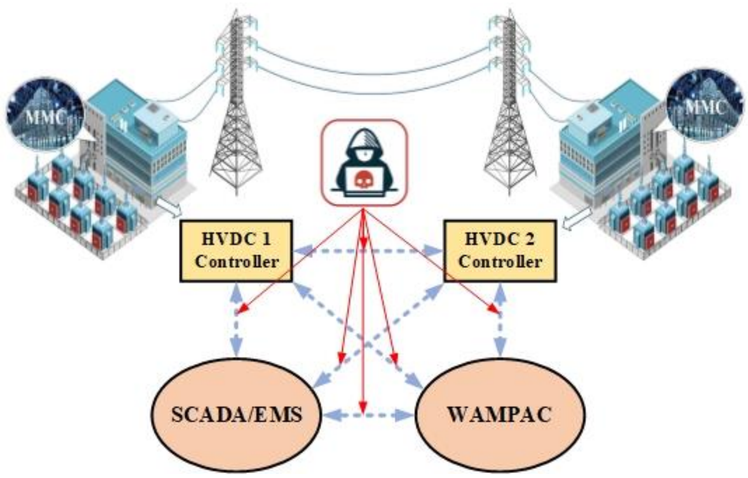
Contact details:

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.

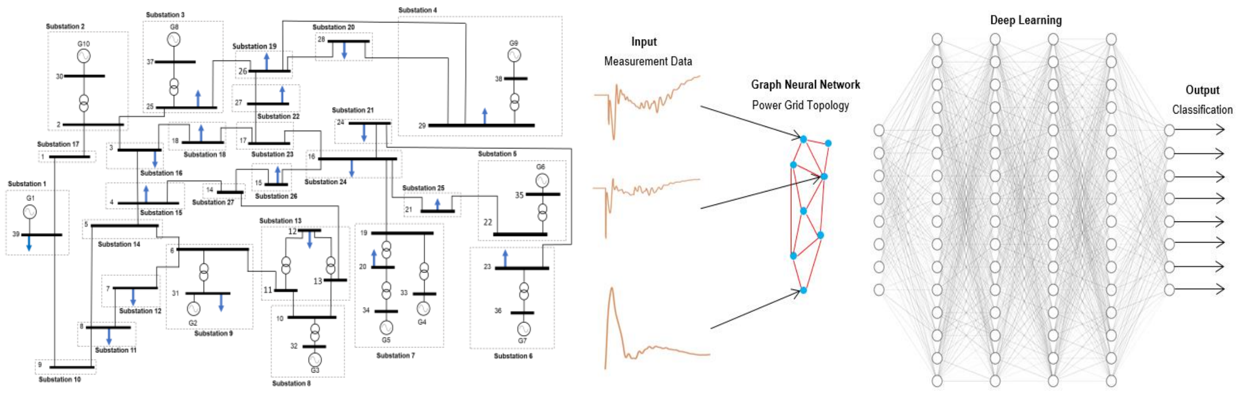
Research objectives:

- 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:

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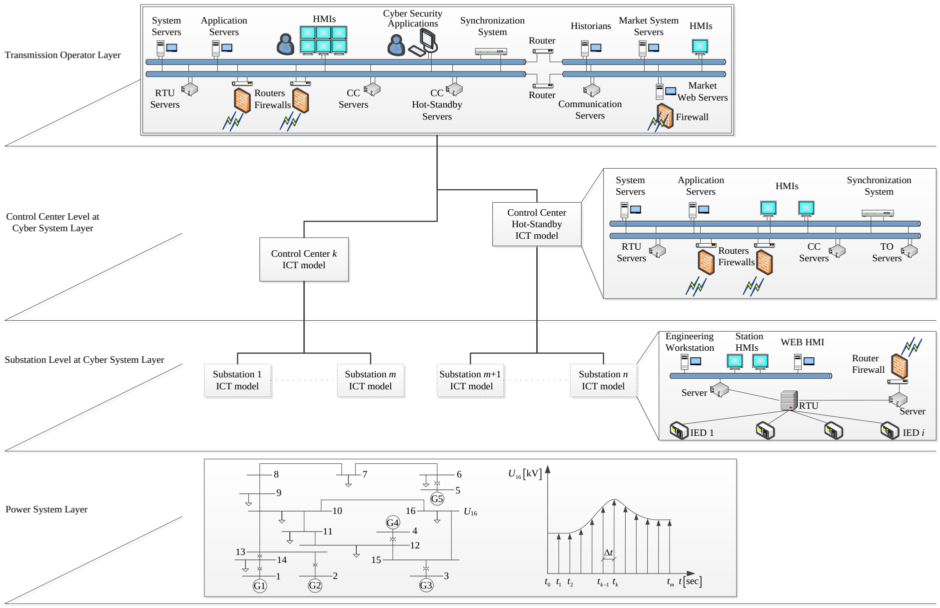
- Supervisor: Alex Stefanov (A.I.Stefanov@tudelft.nl)
- Thesis chair: Peter Palensky (P.Palensky@tudelft.nl)

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.

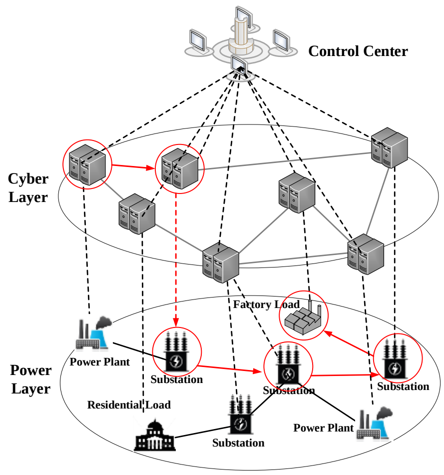
Research objectives:

- 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.

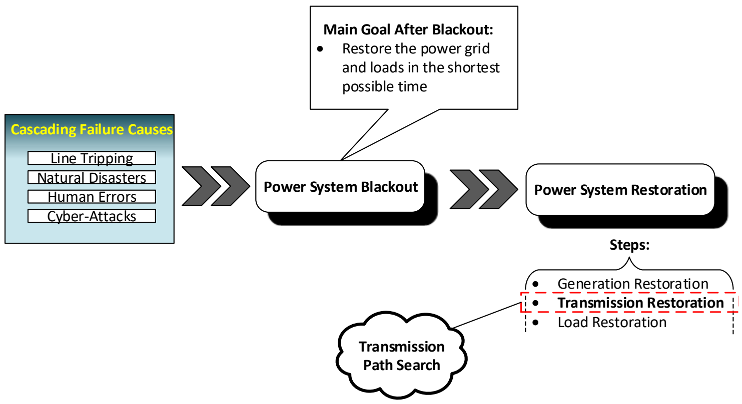
Research objectives:

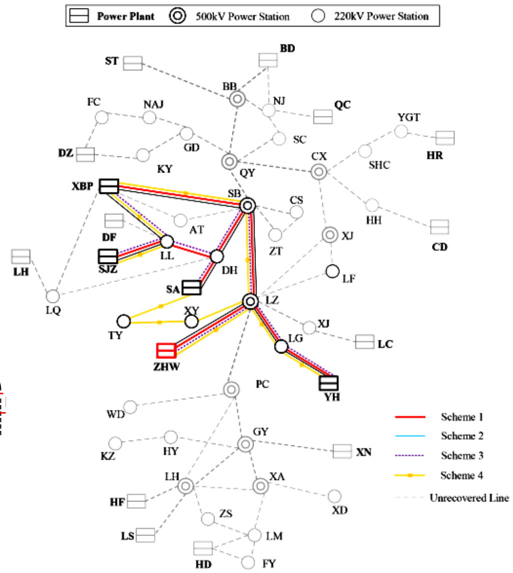
- Model CPS from both structural and operational perspectives considering the complex interdependency between cyber and physical layers.
- Develop an effective framework to analyze the impact of interdependency to modern power grids.

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.**

Contact details:

- PhD Supervisor: Mehran Hashemian Ataabadi (S.M.HashemianAtaabadi@tudelft.nl).
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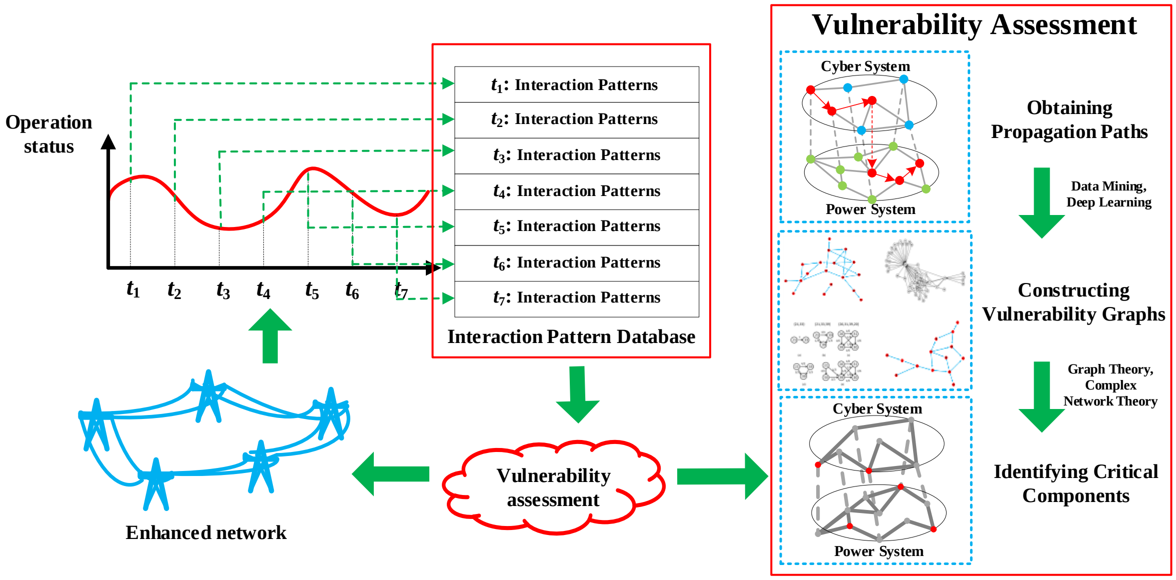
- Thesis chair: Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl).

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.

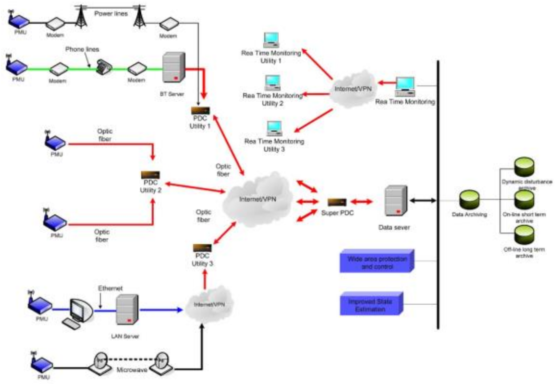
Research objectives:

- 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.**

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).

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.**

Contact details:

- PhD supervisor: Ali Abedi (a.abedi-1@tudelft.nl)
- Supervisor: Dr. Alex Stefanov (A.I.Stefanov@tudelft.nl)
- Thesis chair: Prof. Dr. Peter Palensky (P.Palensky@tudelft.nl)

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.

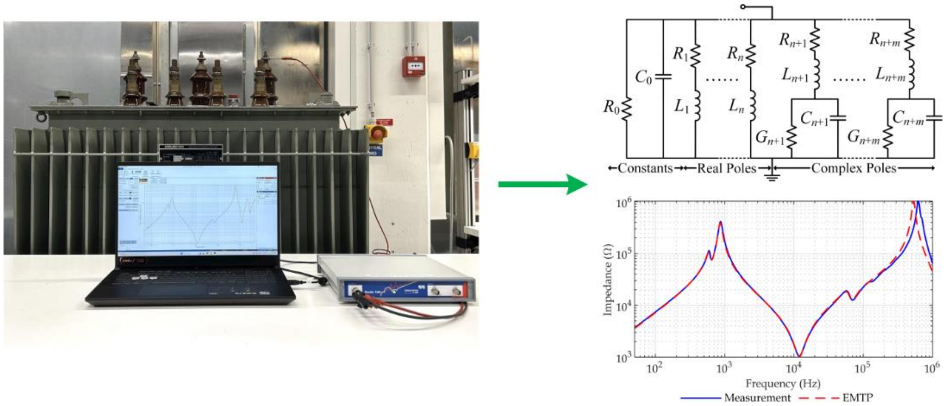
Research objectives:
- Understand the dynamics of system operations at DSO level
- Understand the role of reactive power in these dynamics
- Understand how reactive power is covered in the netcode, internal policy and customer contracts
- Understand the main sources of reactive power in distribution 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.

Contact:

Supervisor(s):
Tony Xiang: tony.xiang@alliander.com
Arjan Stam: arjan.stam@alliander.com
Pedro P. Vergara p.p.vergarabarrios@tudelft.nl

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:

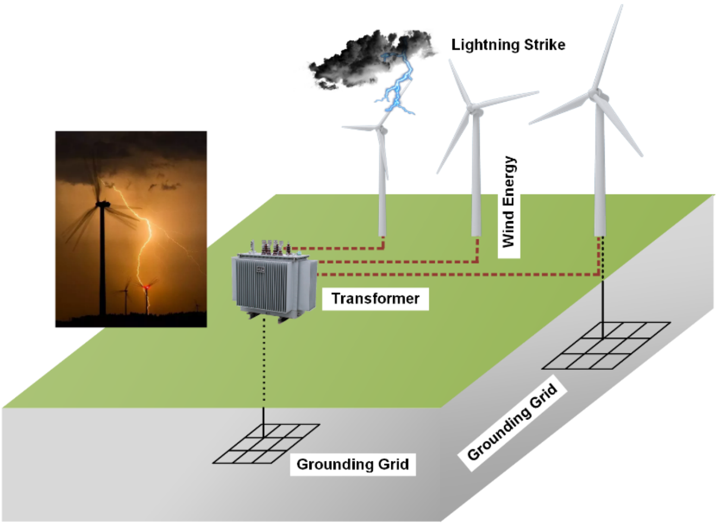
- Becoming familiar with the development of frequency-dependent models for power system equipment.
- Ensuring the physical correctness of developed models by enforcing positive element values based on the method of your choice (possibly using evolutionary algorithms or machine learning algorithms).
- 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.

Contact details:

- PhD Student: Behzad Behdani (b.behdani-1@tudelft.nl)
- Daily Supervisor: Dr. Mohamad Ghaffarian Niasar (m.ghaffarianniasar@tudelft.nl)
- Responsible Professor: Prof. Dr. Ir. Marjan Popov (m.popov@tudelft.nl)

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.

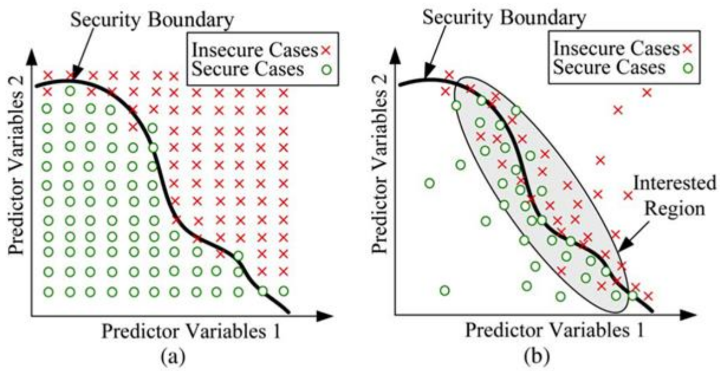
- Defining suitable protection for overvoltage protection for the system against adverse effects of lightning-induced components.

Contact details:

- PhD Supervisor: Behzad Behdani (B.Behdani-1@tudelft.nl)
- Daily Supervisor: Dr. Aleksandra Lekić (A.Lekic@tudelft.nl)
- Responsible Professor: Prof. Dr. Ir. Marjan Popov (M.Popov@tudelft.nl)



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.

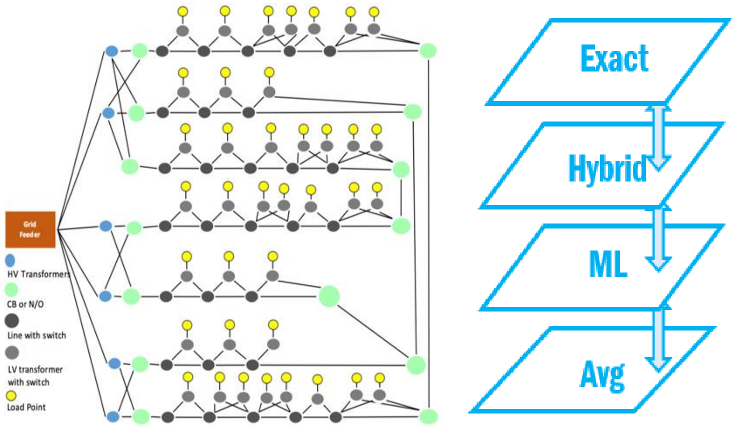
Contact detail:

- Ensieh Sharifnia (e.sharifnia@tudelft.nl)
- Dr. Jochen Cremer (j.l.cremer@tudelft.nl)
- Dr. Simon Tindemans (S.H.Tindemans@tudelft.nl)

IEPG Intelligent Electrical Power Grids

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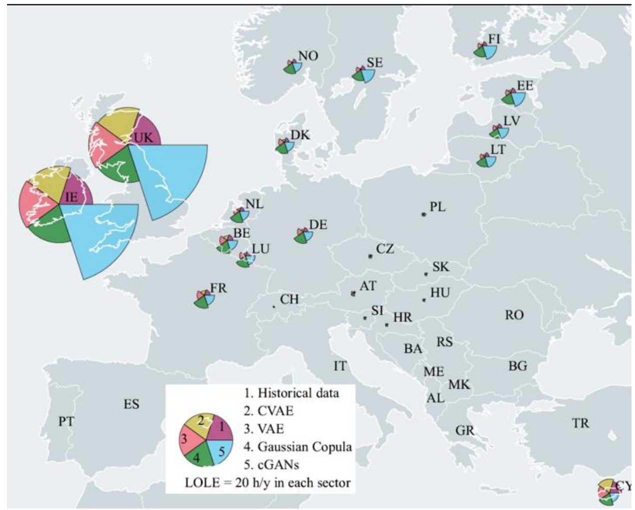
Simon Tindemans (s.h.tindemans@tudelft.nl)



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.

Contact details:
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Machine Learning-Driven Transformer Diagnosis using Sweep Frequency Response Analysis

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

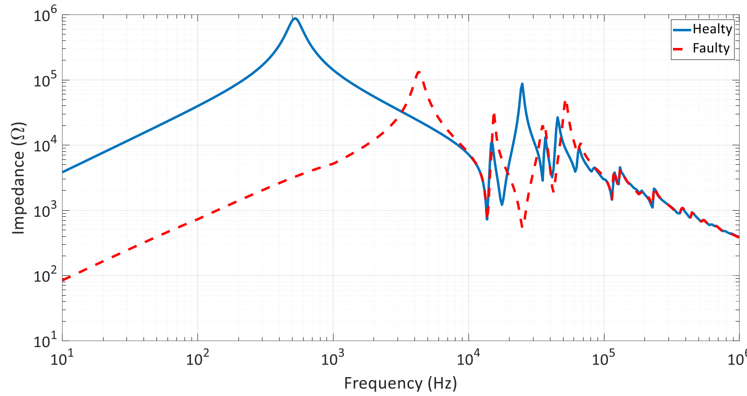


Figure 2. Transformer impedance characteristics.

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.

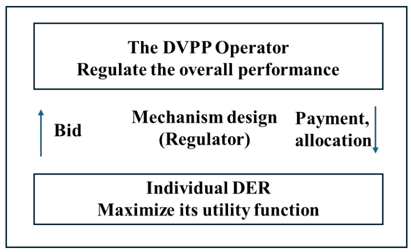
Contact details:

- PhD student: Farzad Nasirpour (f.nasirpour@tudelft.nl)
- Supervisor: Marjan Popov (m.popov@tudelft.nl)

Procurement strategies of virtual inertia and damping from DERs: From the perspective of a DVPP operator

Scope: This thesis project will focus on developing a procurement mechanism for the Dynamic Virtual Power Plant (DVPP) operator to procure virtual inertia and damping from the enclosed Distributed Energy Resources (DERs). You will combine optimization, game theory, auction theory to design the mechanism.

Problem definition: The current power systems incorporate more inverters-based generation and consequently the dynamic stability deteriorates from the loss of inertia. To mitigate this challenge, the Dynamic Virtual Power Plant (DVPP) emerges as a promising approach: it aggregates the virtual inertia/ damping of the DERs, and then provides the aggregation to the system as dynamic ancillary services. The problem is, for the DVPP operator, how to procure (i.e., what quantities and with what prices to buy) the virtual inertia/ damping from DERs, such that 1) the actual aggregation satisfies its target, 2) the economic efficiency is considered given the bid of the DERs, 3) the DERs are well incentivized to provide their services and bid truthfully their true costs.



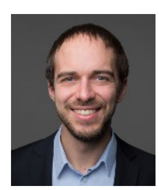
Methodology: You will first investigate the problem formulation of DVPP virtual inertia & damping procurement. Then, you will investigate different mechanisms for the formulated problem. There, you will review, compare these mechanisms, and then try to fit our problem into one suitable mechanism. You will implement your developed method in standard coding environments (MATLAB, Python, Julia) and verify the efficacy of your mechanism through case studies.

Research objectives:

- Literature review on procurement mechanisms design methods.
- Study about the DVPP virtual inertia & damping problem.
- Design and develop a mechanism for the procurement of virtual inertia and damping from DERs.
- Test and validate the properties of the developed mechanism in DVPP cases.
- Disseminate results to scientific article if results allow.

Contact details:

Daily supervisor: Haiwei Xie (H.Xie-2@tudelft.nl)
Supervisor Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)

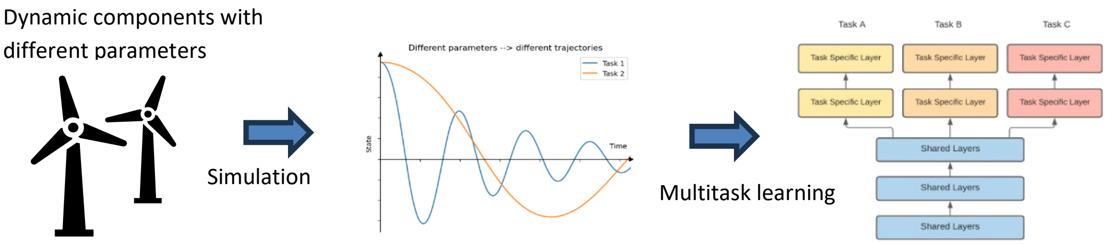


Reference:

[1] Poolla, Bala Kameshwar, et al. "A market mechanism for virtual inertia." IEEE Transactions on Smart Grid 11.4 (2020): 3570-3579.

[2] Xie, Haiwei, and Jochen L. Cremer. "Game-Theoretic Learning for Power System Dynamic Ancillary Service Provisions." *IEEE Control Systems Letters* (2024).

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:

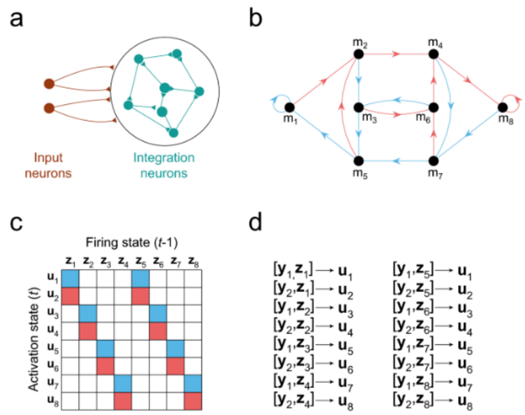
- Develop a deep understanding of PINNs and multitask learning. Formulate the learning tasks.
- Establish a credible benchmark and a standardised ML pipeline in Python or Julia.
- Score advanced methods against the benchmark.
- Analyse conceptual benefits and limitations of the different methods.
- Disseminate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

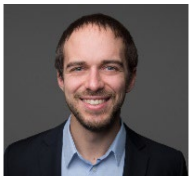
Methodology: You will develop a neural network that exploits the structure of the power system using linear algebra. There, you will investigate suitable neural networks structures, and decide for one structure based on thorough analysis. Then you will invent a tailored loss function for training your 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.

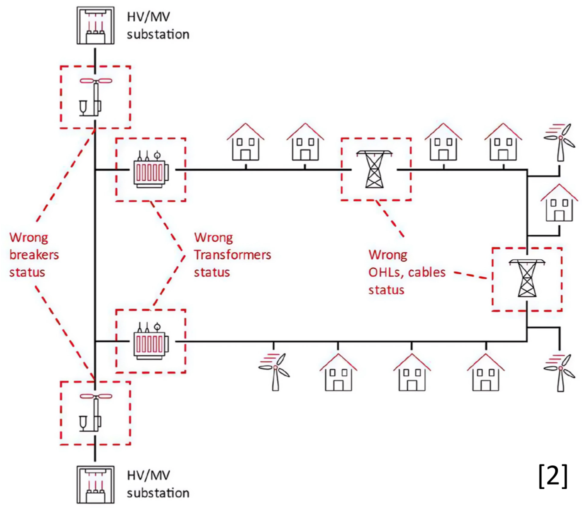
Additional note: This thesis topic is thought through, ambitious, challenging and likely leads to a scientific publication. This project is recommended if you consider to pursue a PhD afterwards. Hence, please only apply as an outstanding individual demonstrated with high-performing grades, strong scientific 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:

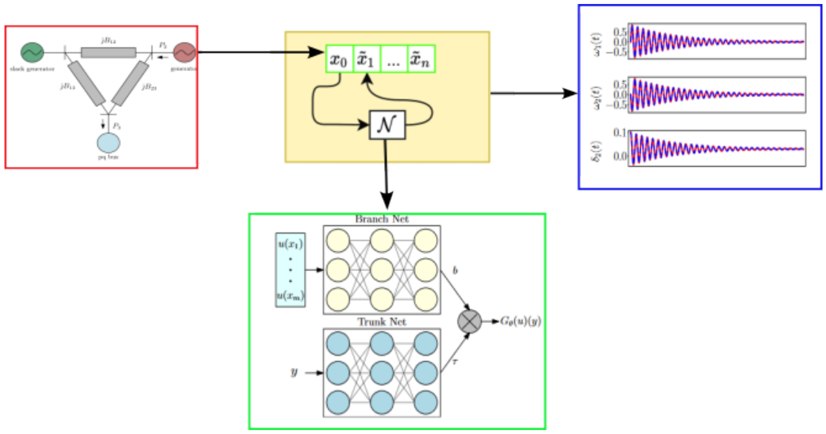
- Creating a testbed with imperfect models of tap changes within the distribution grid state estimation
- Develop an algorithm for identifying tap changer location based on measurements
- Develop an algorithm that learns state estimation with imperfect forward models of the grid topology
- Test the approach 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

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:

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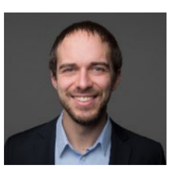
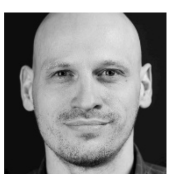
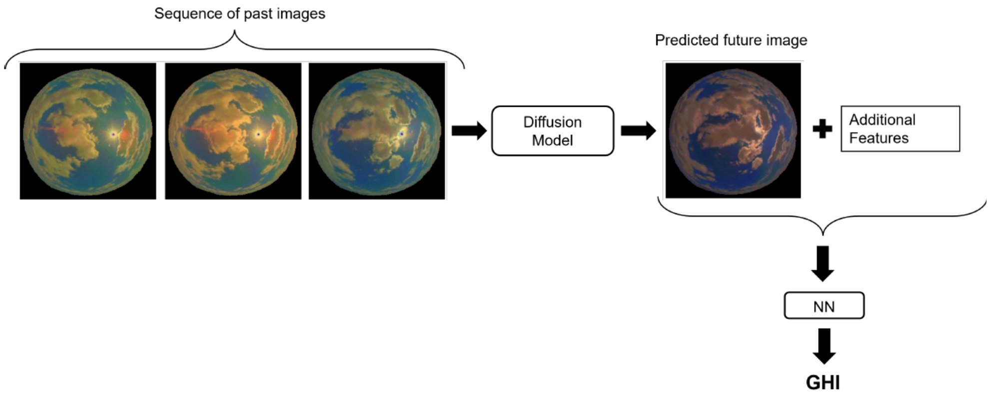
- Supervisor: Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)
- Company sup.: Dr. Jan Viebahn (jan.viebahn@tennet.eu)

Flexible Frame Forecasting Diffusion Models for PV Nowcasting

[relocation to Switzerland needed]



Scope: This thesis project will advance the state of the art of Diffusion Neural Networks to forecast cloud movements and thus predict ultra short-term trajectories of PV energy up to 15 minutes ahead.

Problem definition: High quality probabilistic ultra short-term PV forecasts are essential to safely integrate the increasing amount of PV generation into our grids. Deep Learning pipelines comprising Diffusion Models and Convolutional Neural Net-works (CNN), working on fish-eye camera images of the sky, offer a promising technical approach to this task. However, today's systems still suffer from significant issues with the forecasting quality towards the end of the prediction horizon of 15 minutes that is important to cover. This project will address these issues, by working on the next generation of Diffusion Models

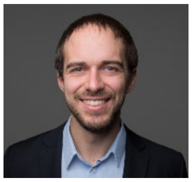
Methodology: Starting from [1] and a given large dataset of fisheye camera images from two PV installations, the project will investigate "Flexible Frame Forecasting Diffusion Models", which are trained to cover a continuous forecasting horizon which is larger than that of today's conventional Diffusion Models. Based on these new Diffusion Models, an optimized approach to achieve higher quality forecasts will be developed.

Research objectives:

- Understand the state of the art of Diffusion Models and in particular the architectures that can help to achieve the specific target
- Develop, implement and evaluate new Diffusion Model architectures
- Integrate promised Diffusion Model architectures into an optimized pipeline for probabilistic ultra short-term PV forecasting, covering the full 15 minutes ahead range

Industry relevance/partner: You will be directly sponsored by Hitachi Energy joining as intern. You will be located in Switzerland, and join Hitachi Energy as part of your MSc thesis.

Contact details:

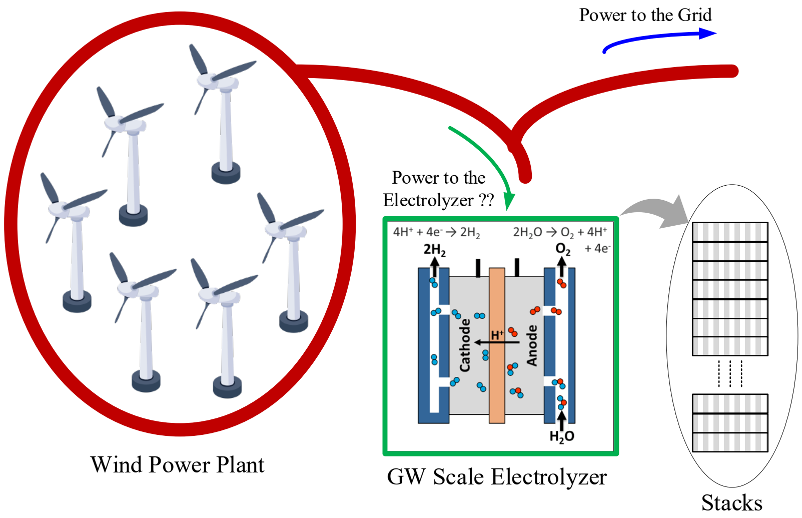


- Supervisor: Dr. Jochen Cremer (J.L.Cremer@tudelft.nl)
- Company supervisor: Dr. Jan Poland (jan.poland@hitachienergy.com)

References:

- [1] Oscar Lopez Romero, Jan Poland, and Jochen L. Cremer. "Diffusion Models for Solar PV Nowcasting". Preprint, 2024.
- [2] Rühling Cachay, S., Zhao, B., Joren, H. and Yu, R., 2024. Dyffusion: A dynamics-informed diffusion model for spatiotemporal forecasting. *Advances in Neural Information Processing Systems*, *36*.

Power Distribution System for Electrolyzer Stacks in Large-Scale Hydrogen Production Systems with Wind Power Generation



Scope: This thesis project will focus on developing the power delivery architecture and optimization for electrolyzer stacks in large-scale hydrogen production systems coupled with wind power generation systems. The aim is to enhance operational reliability, and efficiency of the system based on power electronic converters and operations.

Problem definition: In GW-scale hydrogen production systems, electrolyzer stacks must operate within specific operational envelopes to maintain system health and efficiency. However, integrating such systems with variable wind power introduces challenges, as power availability fluctuates according to wind conditions. Consequently, there is a need for a power delivery architecture that can monitor, manage, and optimize the power supplied to the stacks in real time, maximizing efficiency without exceeding operational boundaries.

Methodology: This project will design and implement a power delivery architecture using power electronics and optimization techniques to dynamically manage power distribution to the electrolyzer stacks.

Research objectives:

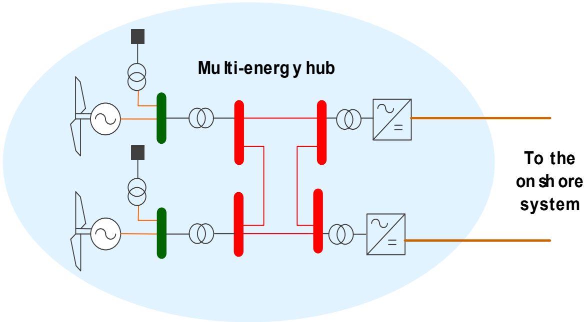
- Design a flexible and efficient power distribution system for electrolyzer stacks.
- Develop algorithms for real-time power optimization based on wind power availability.
- Enhance system reliability and efficiency by identifying methods to reduce stress on electrolyzer stacks under fluctuating wind conditions.
- Validate the architecture through simulation tests to confirm its effectiveness.

Industry relevance/partner: This project aligns with the industry's shift toward green hydrogen as a sustainable energy source. The research will provide deep familiarity with hydrogen production technologies and industrial diagnostic frameworks.

Contact details:

- PostDoc: Dwijasish Das (d.das-1@tudelft.nl)
- Supervisor: Jose Luis Rueda Torres (j.l.ruedatorres@tudelft.nl)

Optimizing Grid-Forming Converter Integration for Adaptive and Resilient Offshore Wind Energy Systems in MTDC Networks



Scope: To define, implement, and test a scalable Electromagnetic Transient (EMT) model for MTDC networks, aimed at advancing self-organizing, adaptive energy systems. This research focuses on optimizing grid-forming (GFM) converter penetration in AC-connected offshore wind farms to support a resilient, sustainable future grid.

Problem definition: The Dutch power system is poised for a transformative upgrade, with the Dutch North Sea expected to house approximately 60 GW of offshore wind infrastructure by 2050. This shift towards renewable energy necessitates advanced strategies that can facilitate the seamless integration of distributed generation, particularly offshore wind, into the power grid. To support a decarbonized energy future, this research emphasizes the optimization of GFM converter deployment, which is pivotal in managing the stability and adaptability of AC-connected offshore wind farms. As these offshore networks evolve, they require resilient configurations that can autonomously organize in response to changing operational demands, thereby supporting a self-sustaining grid. This study will be conducted through RTDS simulations to validate the effectiveness of these strategies in real-world scenarios, emphasizing optimal GFM converter placement and integration to ensure grid reliability and sustainability.

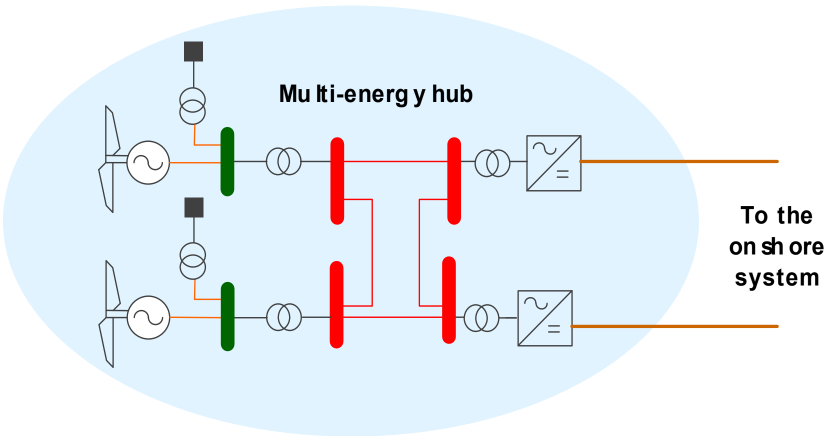
Tasks:

- Develop novel frameworks to analyse the impact of increasing GFM penetration on the emergent behaviour of large-scale clustered offshore wind farms within self-organizing power grids.
- Leverage these frameworks to determine GFM penetration limits considering system strength, stability, and network impedance.
- Utilize optimization methods to design grid integration strategies with an optimal mix of GFM and Grid Following (GFL) converters for enhanced grid security and stability.

Contact details:

- José Rueda Torres (j.l.ruedatorres@tudelft.nl) - promotor
- Monika Sharma (m.sharma-3@tudelft.nl) – daily supervisor

Investigation on Oscillation Damping in MTDC Networks



Scope: Definition, implementation, and testing of an EMT generic (e.g. white box models) and scalable (e.g.1 GW, 2 GW,….,size) model for simulation damping controllers in MTDC networks.

Problem definition: The Dutch power system is anticipated to undergo a significant technological upgrade by 2050, resulting in the operation of approximately 60 GW offshore infrastructure in the Dutch part of the North Sea. This infrastructure will undergo a modular development, i.e. a small offshore module (subsystem) with several multi-GW scale and responsive wind power plants, HVDC interconnector, including the possibility of local responsive demand like electrolysers. However, these grids are susceptible to oscillations during post-fault recovery after DC faults, which can impact the stability and performance. Therefore, it is crucial to investigate on effective damping techniques to mitigate these oscillations and ensure reliable operation. The entire study will be conducted in RTDS.

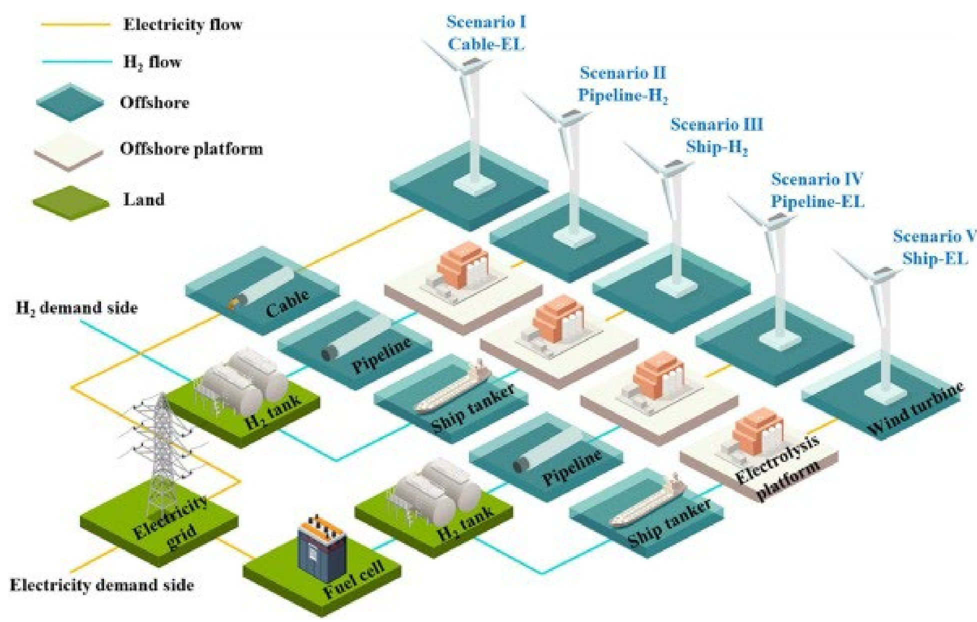
Tasks:

- Select top 2-3 best damping control methods for DC-side oscillations in MTDC systems based on a critical literature review.
- Investigate the criticality of different perturbations by using an existing EMT model of an offshore-onshore system with an embedded MTDC, aiming to ascertain the suitability of different options of modulating signal for damping of DC-side oscillations.
- Devise a method to perform adaptive control of power electronic converters for the purpose of effective oscillation damping under random operating conditions and disturbances.

Contact details:

- José Rueda Torres (j.l.ruedatorres@tudelft.nl) - promotor
- Monika Sharma (m.sharma-3@tudelft.nl) – daily supervisor

Hierarchical Modeling and Control of Large-scale Wind-Hydrogen Energy Systems



Scope: This thesis project aims to develop accurate modeling and control strategies for large-scale autonomous wind-hydrogen hybrid systems. By focusing on the synergies between large-scale (e.g., hundreds of MW) wind power plants and electrolyzer plants, the project addresses the need for stable, resilient, and efficient renewable energy integration and large-scale hydrogen production.

Problem definition: The efficient integration of large-scale wind power plants and electrolyzer plants presents a promising approach for the large-scale utilization of renewable energy resources and the production of green hydrogen. Advanced control and operation strategies are essential to enable stable operation and maximize the benefits of these hybrid systems for both electricity supply and hydrogen production. However, large-scale wind-hydrogen energy systems (WHES) are highly complex, with dynamic interactions between multiple components and challenges posed by stochastic operational conditions. These conditions contribute to stability-related issues that must be understood and managed. Therefore, there is an urgent need for accurate modeling methods that capture the dynamic coupling between components. In parallel, advanced control strategies are crucial to ensure the system's resilience and stability. A comprehensive investigation into accurate hierarchical modeling and control strategies for WHES is essential to address these stability and operational challenges.

Methodology: The challenge is to develop accurate modular and aggregated models to capture the dynamics of large-scale WHESs and design autonomous control strategies to ensure stable operation under stochastic conditions. To achieve this purpose, you will start by theoretically developing modeling and control methods for the system, and then test them by building a simulation model of the system in a simulation tool (e.g., PowerFactory, RSCAD). Finally, the methods will be evaluated for stability and effectiveness across different operational scenarios.

Research objectives:

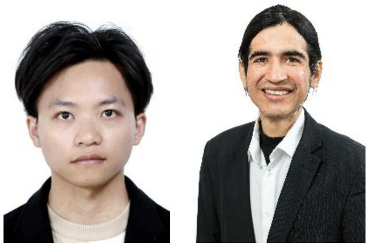
- Develop modular-based detailed and aggregated modeling techniques to capture the dynamic behavior of a WHES for various stability studies.
- Design autonomous control strategies for enhanced stability of the WHES under stochastic conditions.

- Design synergistic control methods to optimally provide grid services from the WHES.
- Propose a smooth switching strategy between autonomous and instantaneous system support modes for the WHES.
- Test the developed modeling and control methods within a common power system simulation tool.

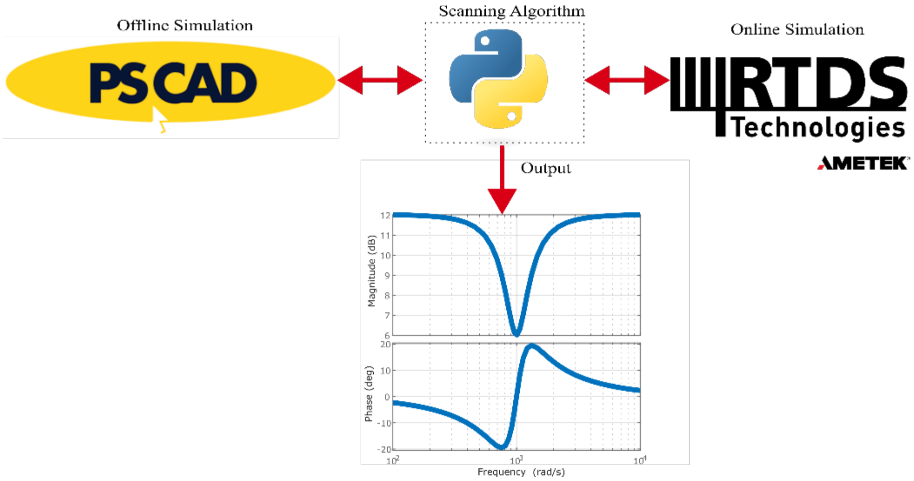
Industry relevance/partner: You will learn about advanced modeling and control methods for wind-hydrogen hybrid systems and you will get experience in one of the major industry tools in PowerFactory or RSCAD.

Contact details:

- Supervisor: Chunjun Huang (C.J.Huang@tudelft.nl)
- Co-supervisor: Jose Rueda Torres (J.L.RuedaTorres@tudelft.nl)



Open-source impedance scanning tool for online-offline simulations



Scope: This thesis project aims to develop an open-source tool designed for scanning the impedance of an electrical network, which will subsequently be used to assess the power systems stability.

Problem definition: The integration of power converter-based renewable energy sources has heightened the risk of interactions between converters and the grid. Since manufacturers typically supply black-box EMT models, purely analytical methods for stability analysis are impractical. An open-source impedance scanning tool capable of functioning with both offline and online simulation tools to extract impedance data from simulations could address this challenge effectively.

Methodology: You will develop and implement an automated impedance scanning algorithm in Python for both offline and online simulation tools (PSCAD and RSCAD). This impedance data will then be used to assess power system stability using the Bode/Nyquist stability criteria.

Research objectives:

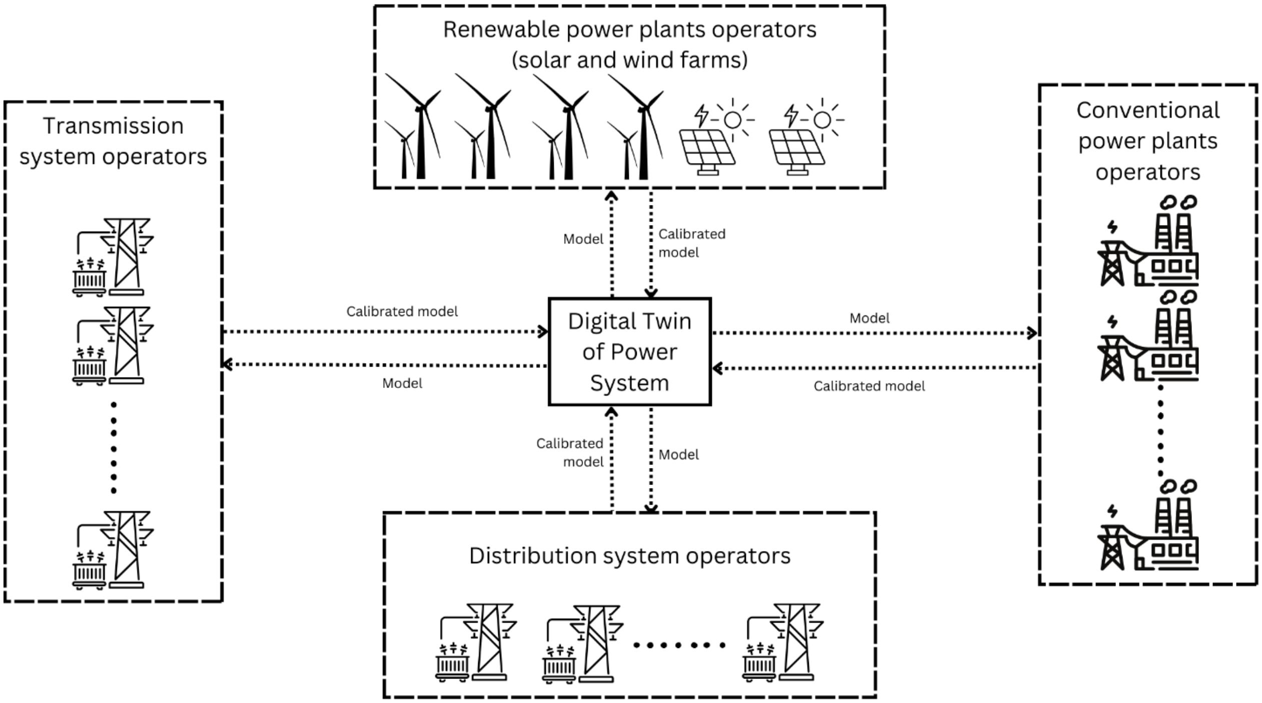
- Develop a Python-based tool for frequency scanning of the system in both online and offline simulations.
- Create an algorithm to extract system impedance through Fourier analysis.
- Apply Bode/Nyquist stability criterion to evaluate system stability.
- Explore various control strategies to improve system stability.

Industry relevance/partner: You will gain knowledge about stability issues related to the integration of power converter based renewable energy into power systems and acquire hands-on experience with major simulation tools, both offline (PowerFactory) and online (RSCAD).

Contact details:

- Supervisor: Nakul Narayanan K (K.NARAYANANKURUVEETTIL@tudelft.nl)
- Co-Supervisor: Dr. Jose Rueda Torres (J.L.RuedaTorres@tudelft.nl)

Real-Time Calibration of Power System Synthetic Models Using Federated Learning in a Digital Twin Framework



Scope: This project focuses on developing a federated learning approach to continuously adapt and improve the synthetic models in a digital twin framework for the Dutch EHV network. By receiving data from multiple operators without centralizing it, this project aims to enhance the twin's real-time predictive accuracy for grid behavior, even under varying renewable energy influx.

Problem definition: Current digital twin models for power systems rely heavily on centralized data, which often lacks the granularity and frequency needed for real-time adaptability. Due to data privacy and access restrictions, operators are often unable to share live operational data across regions, limiting the model's ability to stay accurate and responsive. Federated learning offers a solution by enabling each operator to locally train the digital twin model on their data and contribute to an aggregated, adaptive model without compromising data privacy. This project will develop and validate federated learning methods to allow synthetic models within the digital twin to update and respond in real time.

Methodology:

- **Model Initialization**: Set up a synthetic digital twin model based on publicly available data and historical records of the Dutch EHV network.
- **Federated Learning Framework**: Develop a federated learning system where local nodes (each representing an operator or region) train the digital twin model using local data and transmit only model updates.
- **Model Aggregation**: Implement and test aggregation algorithms to integrate updates from multiple nodes into the central synthetic model, maintaining stability and minimizing discrepancies.
- **Validation**: Validate the adaptability and accuracy of the model in a simulated environment, assessing performance improvements under different fault and renewable integration scenarios.

Research objectives:

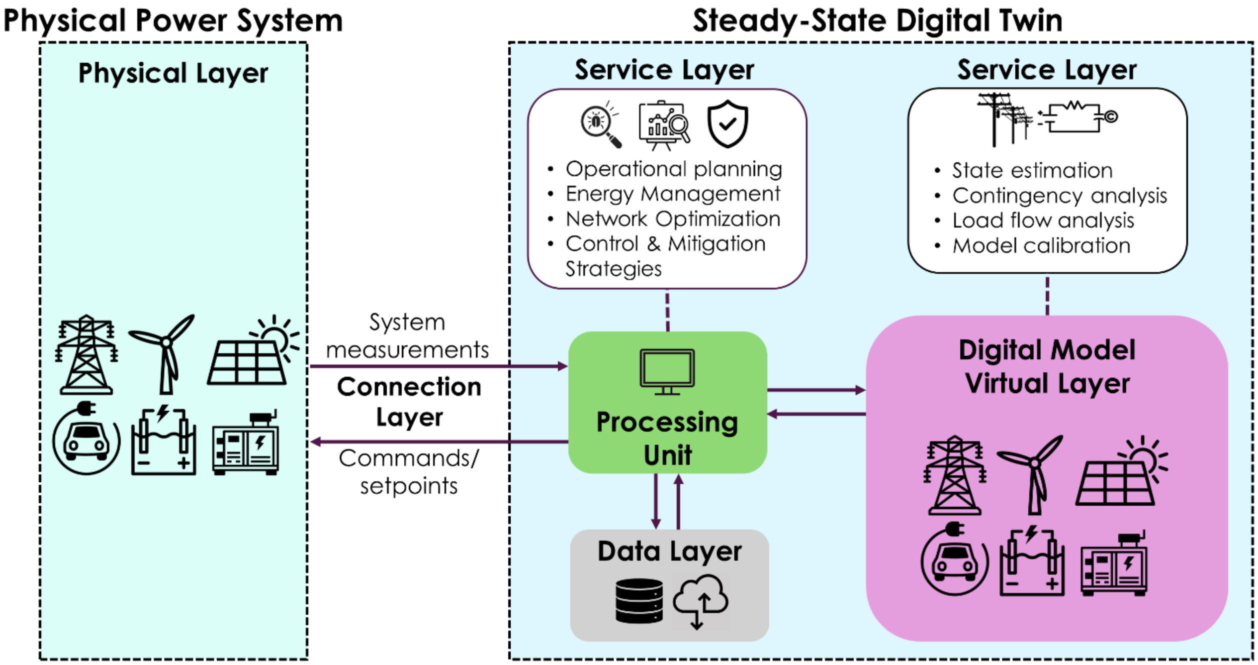
- Develop a federated learning-based method to adapt synthetic models in a digital twin framework for real-time applications.
- Design and implement an aggregation technique to seamlessly update the digital twin model from multiple local sources.
- Assess the accuracy and adaptability of the federated model in responding to real-time grid events, such as voltage fluctuations.
- Evaluate the effectiveness of federated learning in maintaining data privacy while achieving high model fidelity.

Industry relevance/partner: This project addresses key challenges in modern power systems, where data sharing is often limited due to privacy concerns. By enabling data-driven model adaptation without data centralization, this work directly benefits Transmission System Operators (TSOs) and Distribution System Operators (DSOs), allowing them to contribute to and leverage a real-time, accurate digital twin without compromising data security. The project also offers a scalable solution for future grid operations, particularly as renewable energy integration and the need for robust real-time monitoring grow.

Contact details:

- Supervisor/Promotor: José Rueda (j.l.ruedatores@tudelft.nl)
- PhD candidate (co-supervisor): Jonathan Aviles-Cedeno (j.a.avilescedeno@tudelft.nl)

State Estimator Implementation for Combined Distribution/Transmission Systems in a Digital Twin Framework



Scope: This project aims to develop a state estimator for integrated distribution and transmission networks within a digital twin framework. The initial implementation will be written in MATLAB, with potential expansion to a C-based version using PETSc (Portable, Extensible Toolkit for Scientific Computation) to enable high-performance computing, contingent on the pace of development. An existing power flow solver, available in both MATLAB and C (PETSc), will serve as the foundational starting point for this project.

Problem definition: As the power grid evolves to incorporate extensive renewable energy sources, fast and accurate state estimation becomes essential for real-time monitoring and stability control. Conventional state estimators often fail to meet the computational demands of combined transmission and distribution networks due to their complexity and lack of parallelization. This project will improve an existing solver to handle large-scale, interconnected grid models.

Methodology:

- **Enhancement of Existing Power Flow Solver:** Start by improving the existing power flow solver through the addition of new models and capabilities to better represent combined distribution and transmission network characteristics.
- **MATLAB Prototype Development:** Develop an initial state estimator prototype in MATLAB to validate the fundamental structure and functionality of the estimator.
- **Optional Transition to PETSc**: Depending on the progress and project requirements, consider transitioning the MATLAB prototype to a C-based implementation using PETSc for further development.
- **Comprehensive Testing and Validation**: Perform thorough testing in a simulated real-time environment to evaluate the estimator's speed, accuracy, and ability to handle high variability within the digital twin framework.

Research objectives:

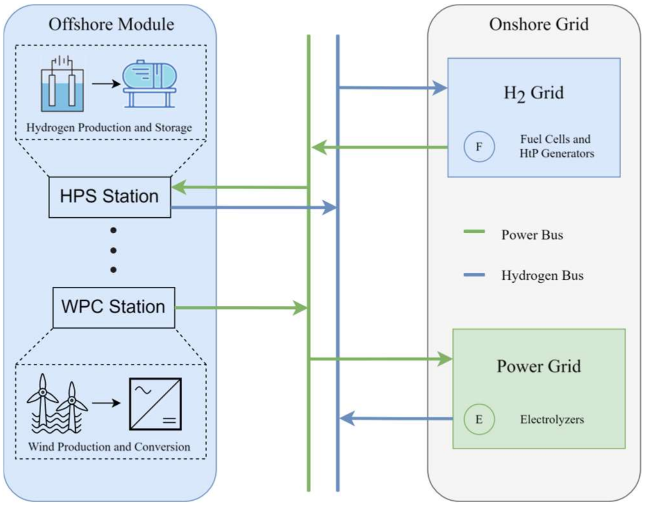
- Enhance an existing solver for efficient state estimation in combined transmission/distribution networks.
- Implement a MATLAB prototype to validate the estimator's design and functionality.
- Optional transition of the state estimator to PETSc, optimizing it for high-performance parallel computation.
- Test and validate the estimator's accuracy and computational efficiency under real-time scenarios.

Industry relevance/partner: This project responds to the increasing need for high-speed, reliable state estimation in modern grids with high renewable penetration and complex interconnected networks. This work equips TSOs and DSOs with an advanced tool for real-time grid monitoring, enhancing the effectiveness of digital twin applications in power systems.

Contact details:

- Supervisor/Promotor: José Rueda (j.l.ruedatores@tudelft.nl)
- PhD candidate (co-supervisor): Jonathan Aviles-Cedeno (j.a.avilescedeno@tudelft.nl)

Stochastic topology and power management optimization based modular design of offshore multi-energy systems



Scope: This thesis project will focus on the design of offshore multi energy systems considering the implication of optimal determination of topological arrangement and cost effective power management.

Problem definition: Hydrogen energy storage will play an important role in improving the operational efficiency and reliability of power systems with high wind energy penetration. Consequently, investigating the methodology for sizing, configurating and coupling of hybrid modules to existing power grids holds substantial significance.

Methodology: The challenge is to formulate an optimal configuration/sizing method considering the benefits of hybrid systems in improving wind energy utilization and enhancing power supply reliability while minimizing capital expenditures. After that you will have to carry out an uncertainty modelling and perform analytical or simulation based assessment of a power grid's performance where the module has been integrated.

Research objectives:

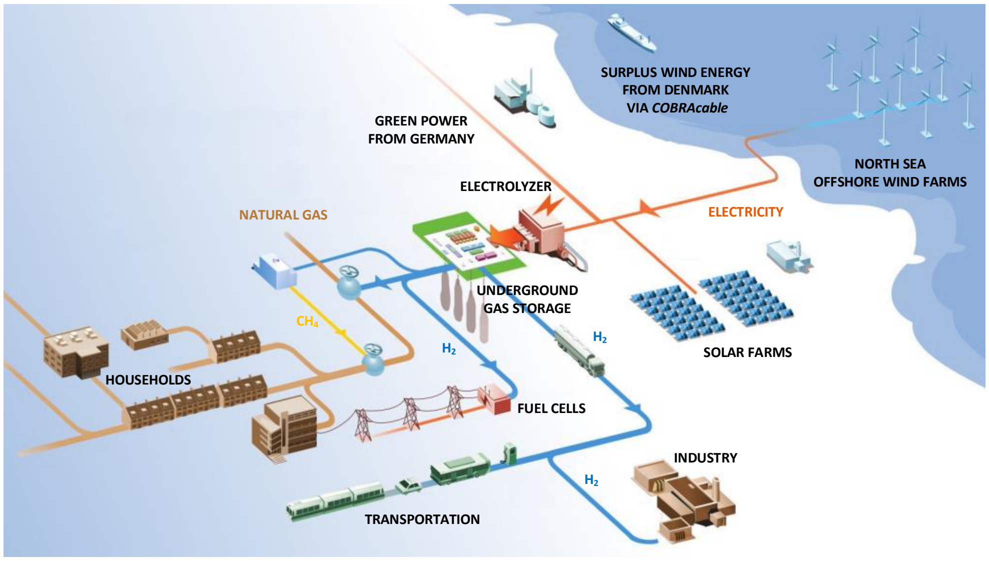
- Develop a suitable model to confidently simulate the performance given different random operating conditions of a modular multi-energy system.
- Formulate an optimization problem that confronts and effectively solves different objectives for cost effective operation subjected to different types of techno-economic constraints.
- Propose probabilistic performance metrics comparatively evaluate and rank different module configuration and operational strategies.

Industry relevance/partner: Yes, cooperation with a developer of multi-energy systems in the context of the Optimal, secure, and modular development of multi-energy networks (MADURO) project.

Contact details:

- Daily supervisor: Msc. Fernando Canales (phd student: fcanalesverdia@tudelft.nl)
- Co-supervisor: Dr. Ir. José Rueda (associate profesor: j.l.ruedatorres@tudelft.nl)
- Co-supervision of a company: TBD

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:

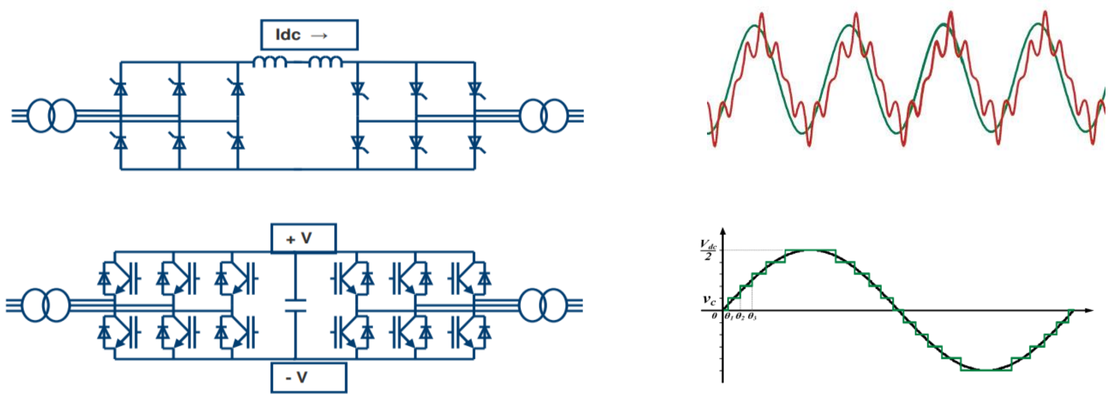
- Presenting the modular converter topology for accurate modeling of real large scale electrolyser.
- Investigating the reduction of total harmonic distortion (THD) in large scale electrolyser.
- Proposing the control scheme, required to extend the capabilities of electrolysers for ancillary service 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.

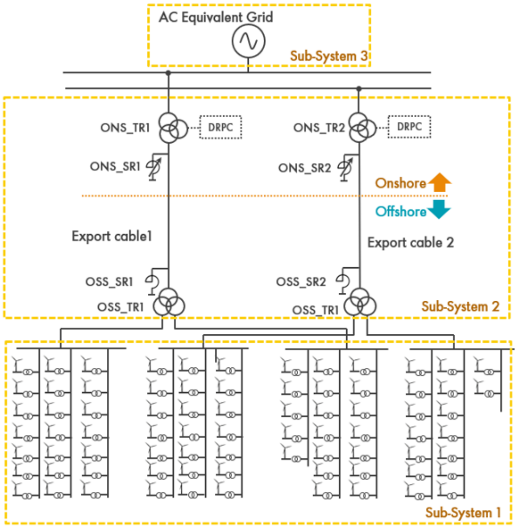
[5] Interim Report into the Low Frequency Demand Disconnection (LFDD) following Generator Trips and Frequency Excursion on 9 Aug 2019. National Grid August 2019.

Industry partner: Siemens AG, Erlangen Germany :Alvaro Hernandez

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

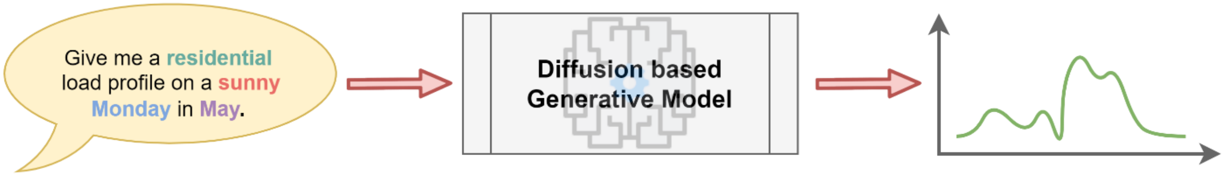
Industry partner: Company Siemens AG represented by Dr. M. Suwan, Dr. S. Al-Areqi

[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.

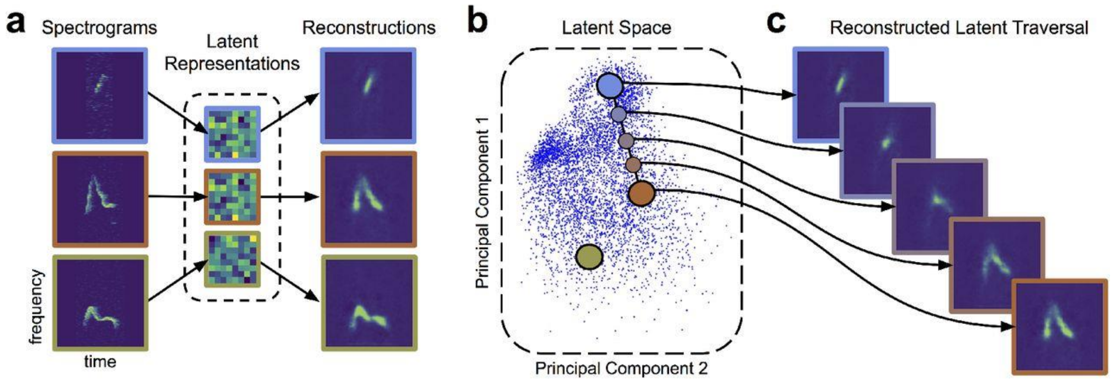
Requirements: Fluency in Python and a deep learning framework (PyTorch/Tensorflow); affinity for probability theory.

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

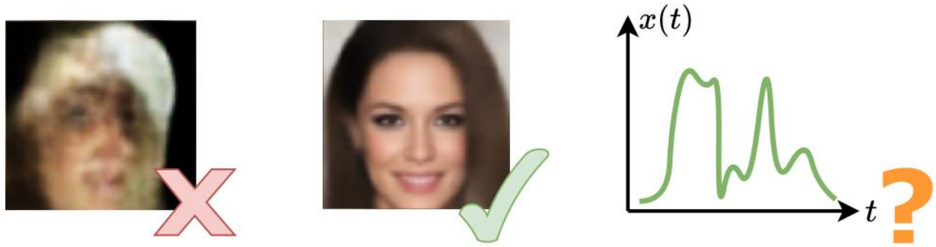
Requirements: Fluency in Python and a deep learning framework (PyTorch/Tensorflow); affinity for probability theory.

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)

Large Scale Synthetic Smart Meter Data Generation and Validation



Scope: This thesis project will focus on generating synthetic smart meter profiles and investigating meaningful validation methods to assess the generation performance.

Problem definition: Smart meter data holds great potential for future energy systems applications such as forecasting, reliability analysis, and state estimation. Unfortunately, these data is protected by GDPR and this makes it harder for DSOs to share them with third parties. Generating synthetic data using AI models is a promising approach to overcome this. However, assessing the utility of the generated data is still an open research topic.

Methodology: The recently proposed generative model GUIDE-VAE (Bölat, 2024) offers a promising way to generate user-specific data and help preserving the customer statistics. Having the topology and substation level measurements, the utility of the generated data can be assessed in aggregate level.

Research objectives:

- Literature review on data-driven smart meter applications and probabilistic modelling.
- Building a framework for training, testing, and visualizations for GUIDE-VAE trained on a large scale smart meter dataset.
- Collect possible utility assessment methods (statistical and power system application-wise) and integrate to testing in the framework.
- Propose and develop novel power system testing cases.
- Releasing the developed framework and the proposed methodology to GitHub.

Requirements: Fluency in Python and PyTorch; affinity for probability and statistics.

Industry relevance/partner: This project will be conducted in collaboration with Alliander who has a very large collection of smart meter measurements database.


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:

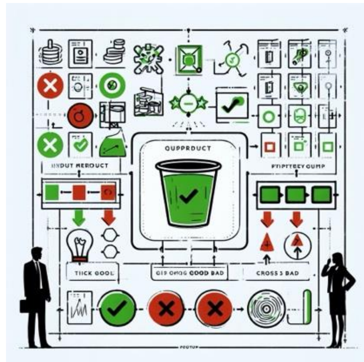
- Identify the different natures of the present and future-proof heating systems.
- Develop a machine learning algorithm to predict future heat pump or district heating load profiles based on current gas consumption data.
- Test the developed algorithm and compare it with existing methods.

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.

Contact details:

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- Supervisor: Pedro Vergara Barrios (p.p.vergarabarrios@tudelft.nl))

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)

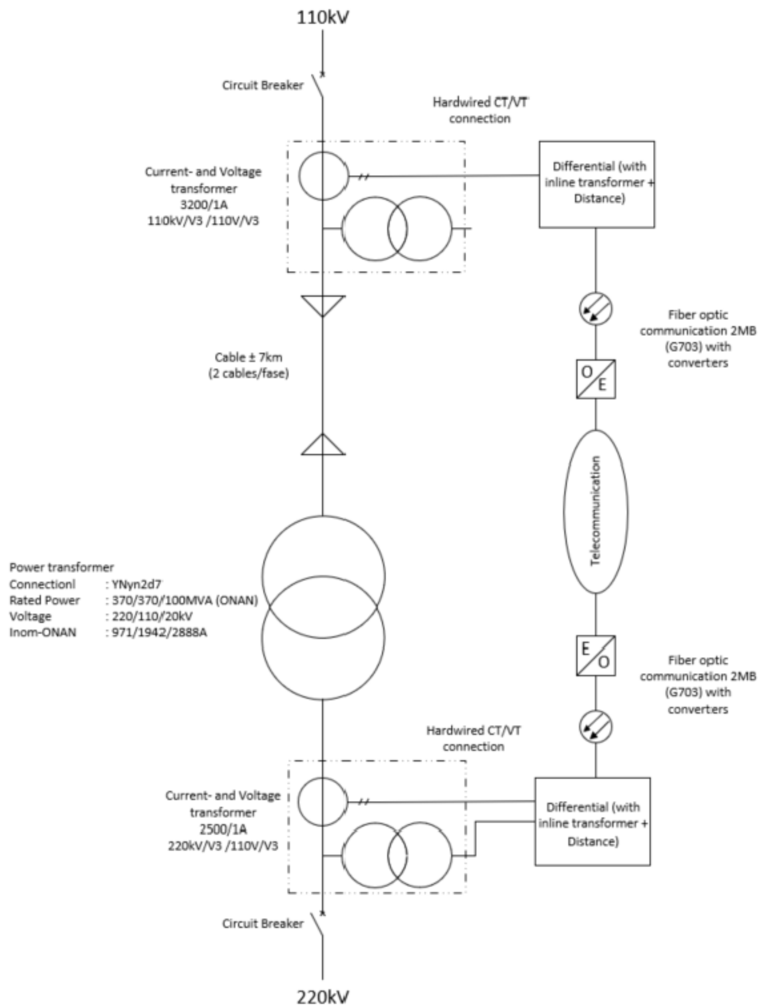

Fig. 1. Transformer differential protection

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:
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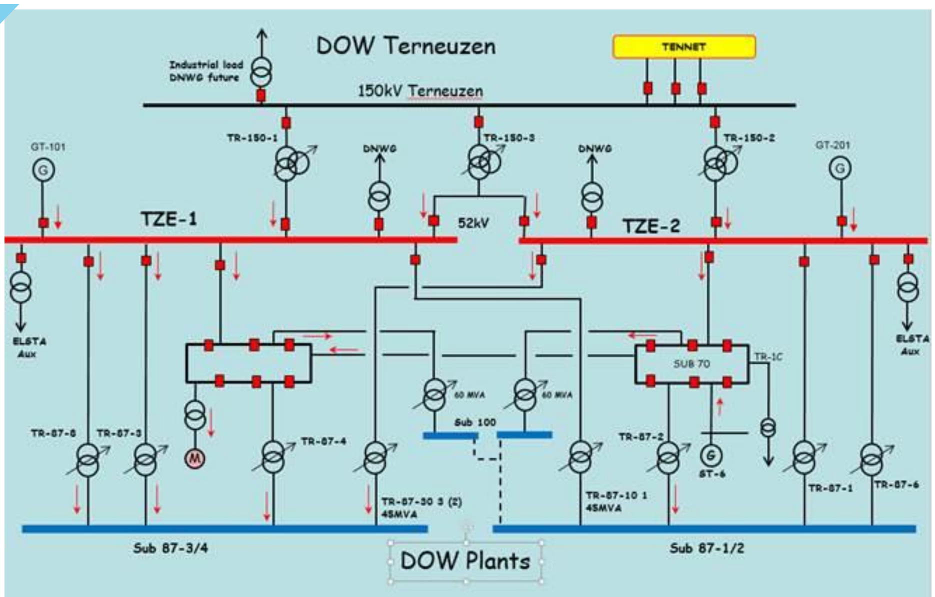
Generator protection Siemens 7UM 85 and new frequency relays



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:

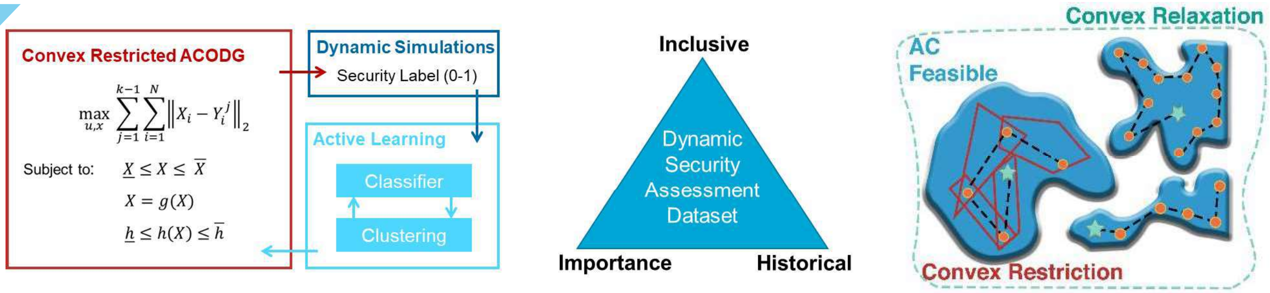
- Modeling of the generators with governors and excitation;
- Modeling the electrical load on the production site by the use of the aggregated induction motor and static models;
- Model the df/dt and voltage decay in different island scenario's, predict the network behavior;
- Do sensitivity test on 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:

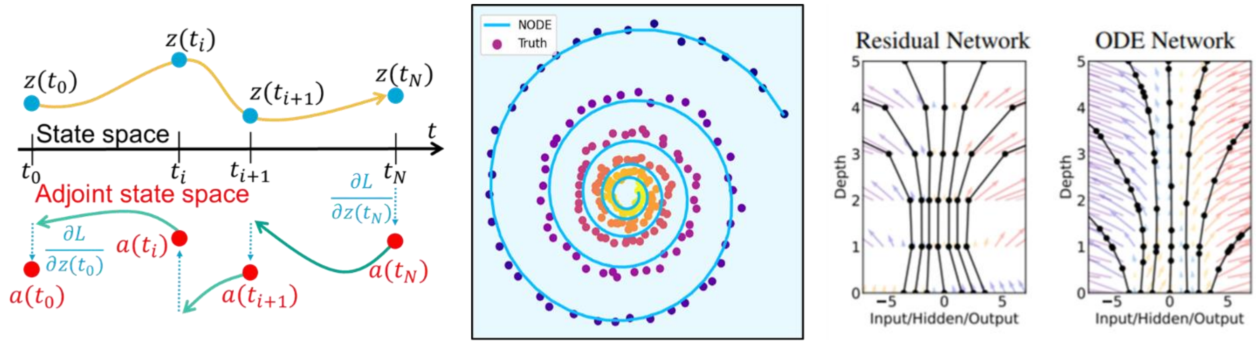
- Literature review on AC OPF, quadratic optimization, supervised learning algorithms, clustering algorithms, DSA.
- Development of the modified convex restricted AC OPF.
- Conducting dynamic root mean square (RMS) simulations on the test system.
- Development of the ML pipeline: Preprocessing, feature 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)

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.

IEPG Intelligent Electrical Power Grids

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*.

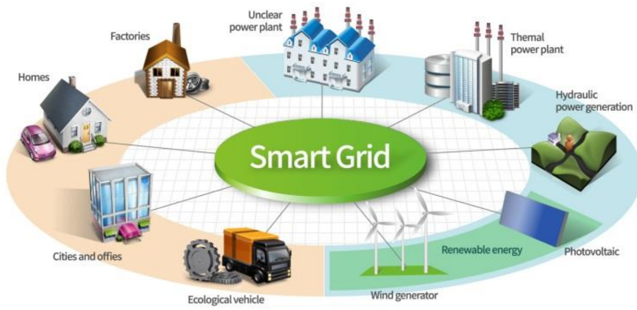
[2] Ayed, I., de Bézenac, E., Pajot, A., Brajard, J., & Gallinari, P. (2019). *Learning Dynamical Systems from Partial Observations*. http://arxiv.org/abs/1902.11136

[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:

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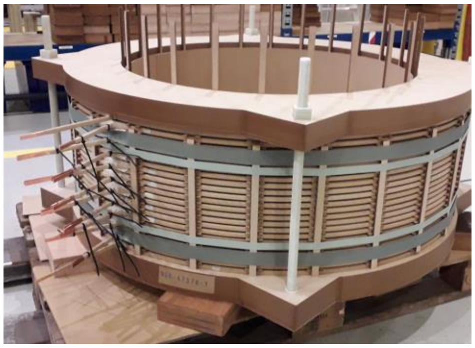
Calculation of R, L, and C matrices of a disk winding and verification of the analytical formula with measurement



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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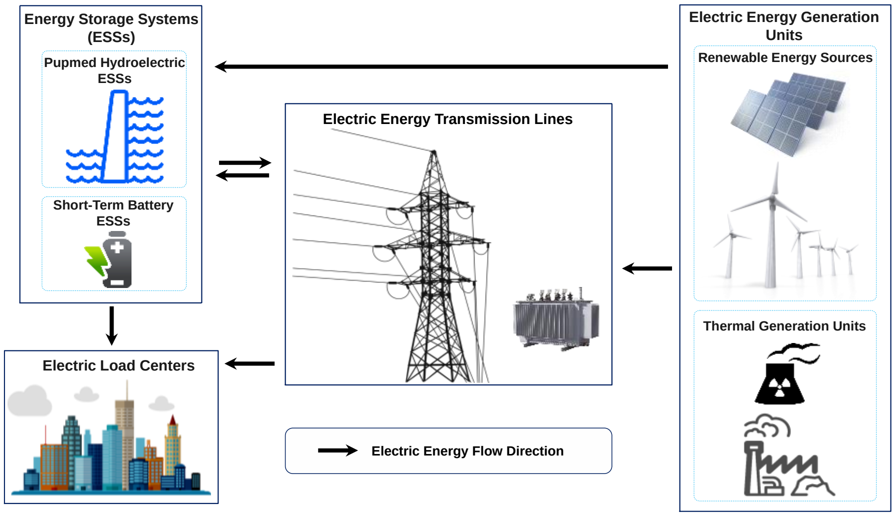
- Supervisor: Mohamad Ghaffarian Niasar (m.ghaffarianniasar@tudelft.nl)
  Marjan Popov (M.Popov@tudelft.nl)

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:

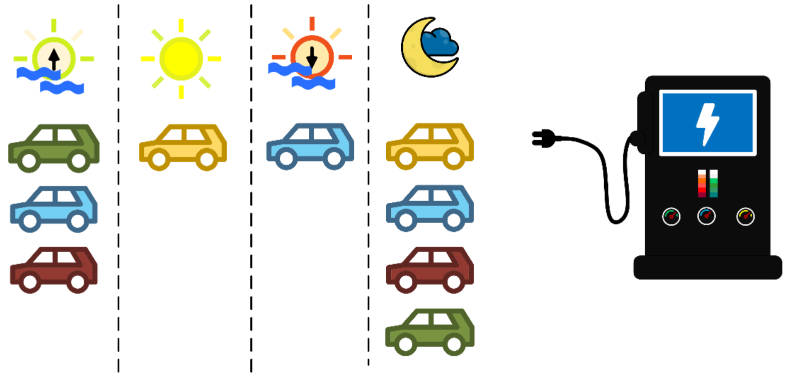
- Utilizing machine learning-based methodologies to capture the short-term variability.
- Developing methods that bias the selection of time series to focus on system-relevant properties.
- Evaluating the effectiveness of proposed method in an expansion co-planning of transmission lines and seasonal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

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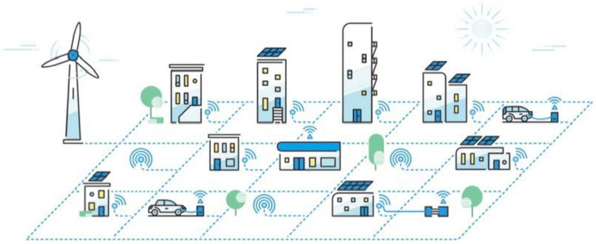
Supervisor • Simon Tindemans (S.H.Tindemans@tudelft.nl)

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)

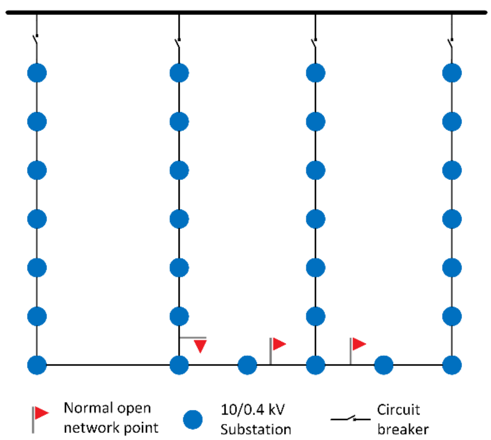
Contact details:

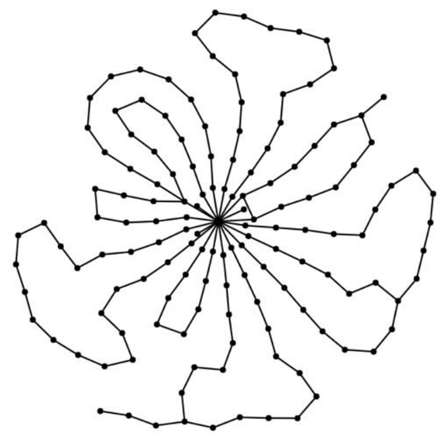
PhD in-charge • Nanda Kishor Panda (N.K.Panda@tudelft.nl)
Supervisor • Simon Tindemans (s.h.tindemans@tudelft.nl)

[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.

[2] https://repository.tudelft.nl/islandora/object/uuid%3A8c2b5e78-836a-497e-805a-932b9231e313

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.

python™ PYOMO PF

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:

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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).

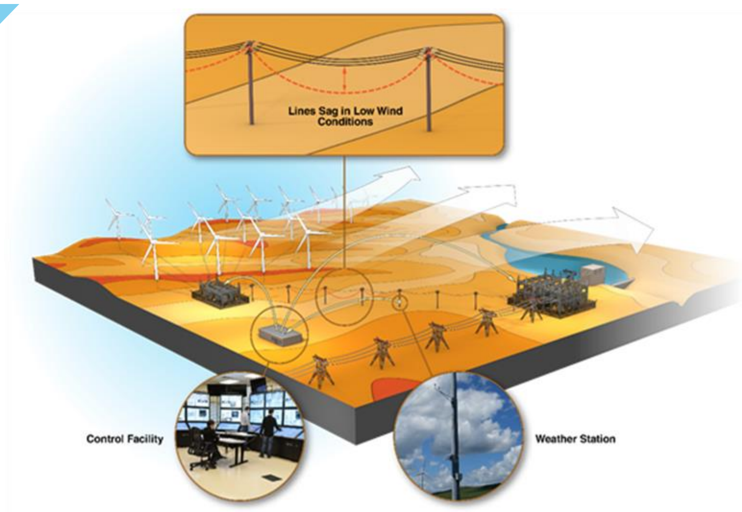
Industry Partner: enduris, STEDIN.NET, alliander

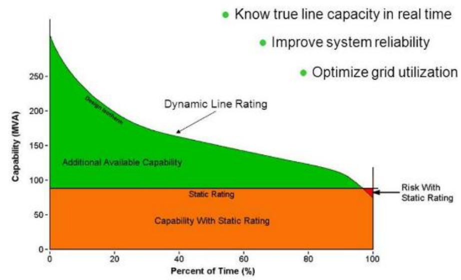
Required Background: Basics signal processing, Power Systems, Maltab/Python (your comfortability).

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.

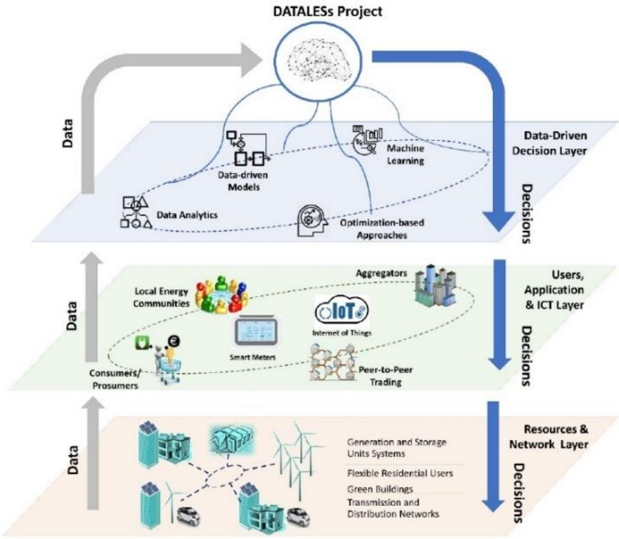
Industry Partner: VSL, enduris, STEDIN

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

Contact details:

- PhD Guide: Nidarshan Kumar (N.Veerakumar@tudelft.nl)
- Supervisor: Marjan Popov (m.popov@tudelft.nl)

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:

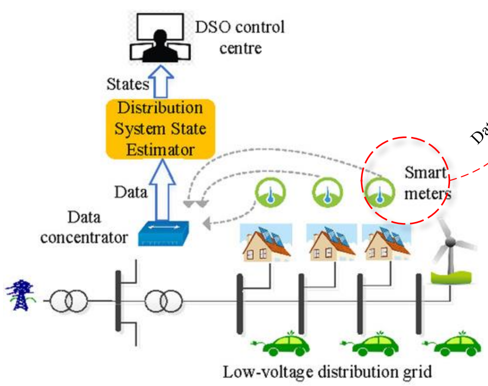
- Develop deep learning-based models to accurately predict power flows in distribution networks.
- Improve the stability and reliability of distribution networks that incorporate a large number of renewable energy resources.

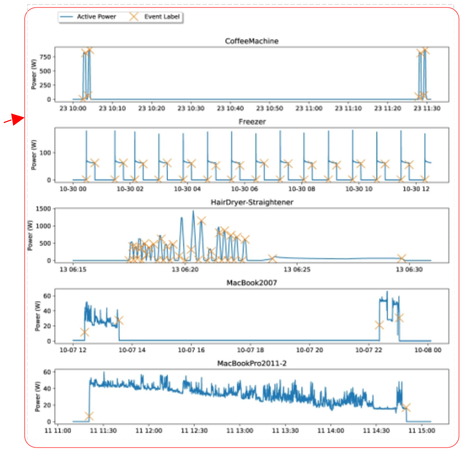
Industry relevance: The project will provide students with the opportunity to work with cutting-edge technology and gain hands-on experience in deep learning-based modeling and analysis. Additionally, students will learn about the practical applications of their research in the energy industry and contribute 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)
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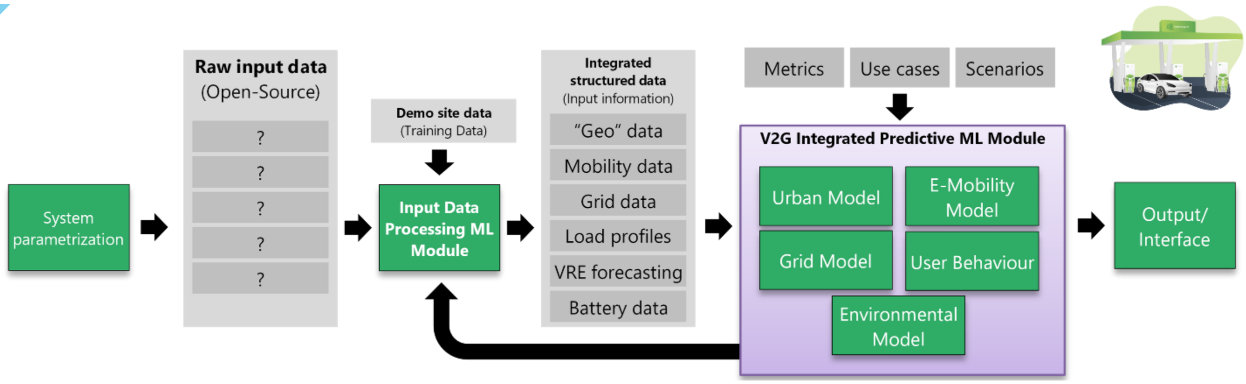
DriVe2X: Optimizing Electric Vehicles through Machine Learning



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.

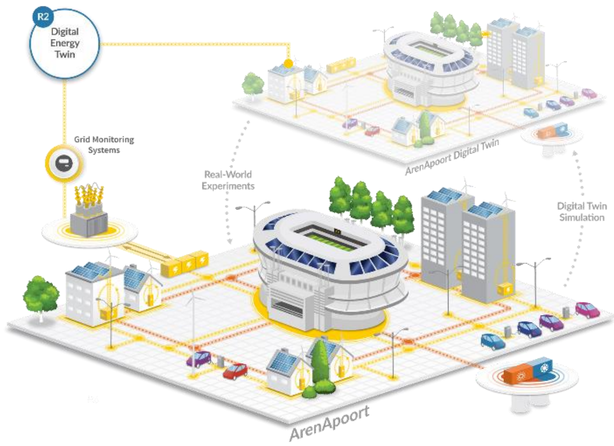
Contact details:

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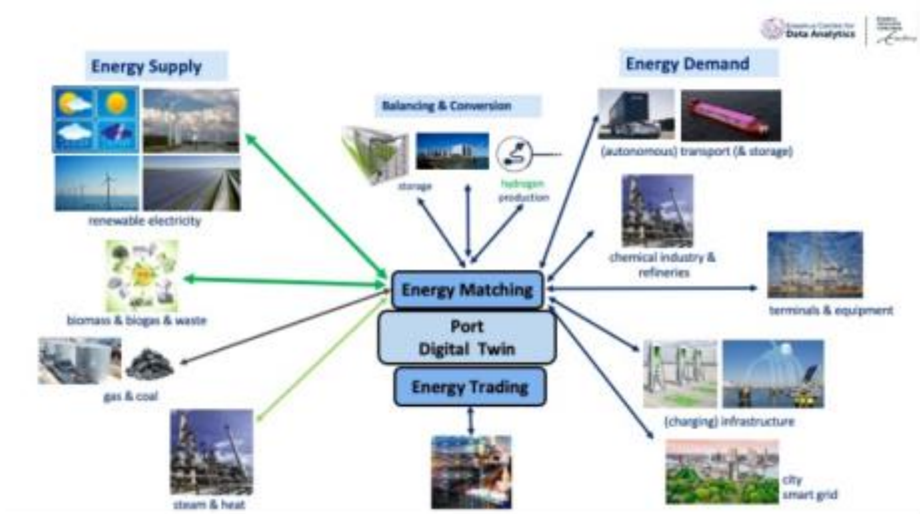
Supervisor(s): Wouter Zomerdijk (w.zomerdijk@tudelft.nl)
Supervisor(s): Pedro P. Vergara (p.p.vergarabarrios@tudelft.nl)
Website: https://www.ams-institute.org/urban-challenges/urban-energy/local-inclusive-future-energy-life-city-platform/

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.

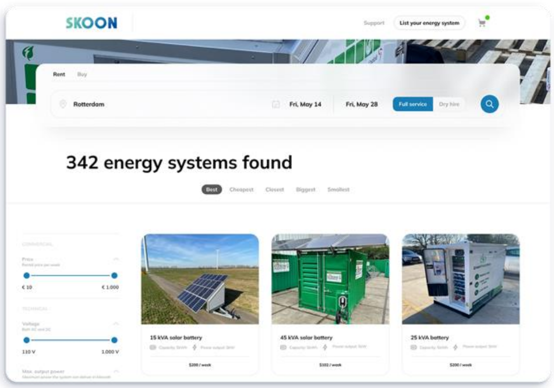
Methodology: This platform will require the application of optimization methods, energy management strategies, uncertainty modeling and development of statistical models for resource availability using bottom-up models and/or machine learning using data from different segments of a green port (maritime,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

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

Contact details:

- PhD student: Neda Vahabzad (n.vahabzad@tudelft.nl)
- 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.

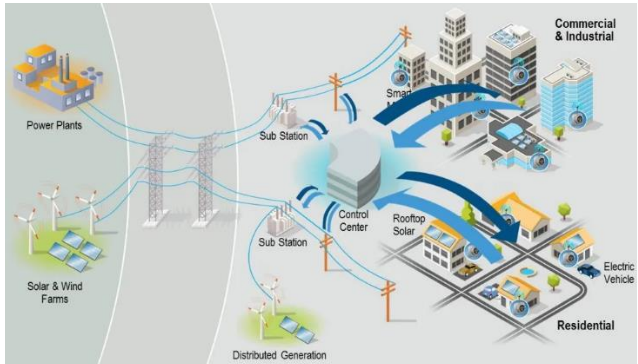
Industry relevance/partner: You will learn about the main operational challenges of distribution system operators and the role of flexible energy solutions, such as mobile batteries. You will also learn how to model distribution networks using open-source software. For this project, you will be working 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)

SKOON

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:

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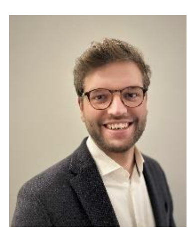
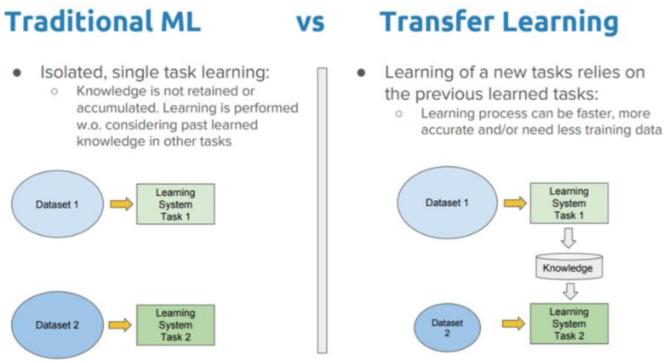
Supervisor(s): Pedro P. Vergara (p.p.vergarabarrios@tudelft.nl)
Company Supervisor(s): Nuran Cihangir Martin (Nuran.CihangirMartin@stedin.net)



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.

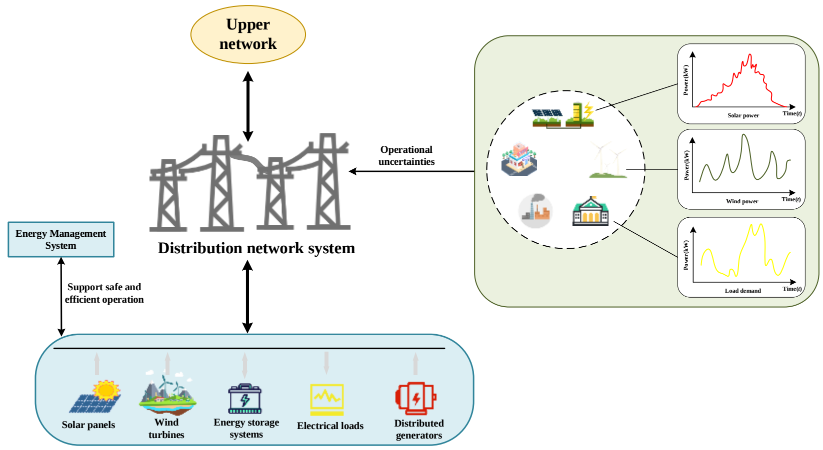
Research objectives:

- 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.

Contact details:
PhD student: Weijie Xia (w.xia@tudelft.nl)
Supervisor: Dr. PP (Pedro) Vergara Barrios (P.P.VergaraBarrios @tudelft.nl)

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:

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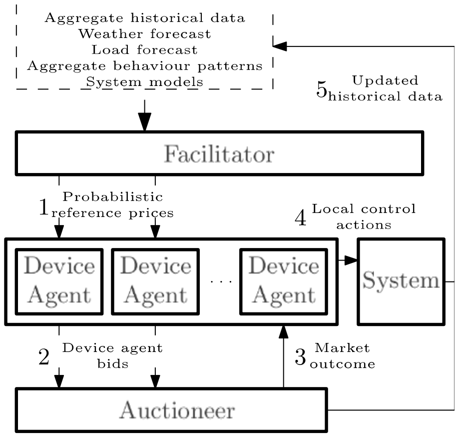
- Supervisor: Dr. Pedro P. Vergara Barrios (P.P.VergaraBarrios@tudelft.nl)

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:

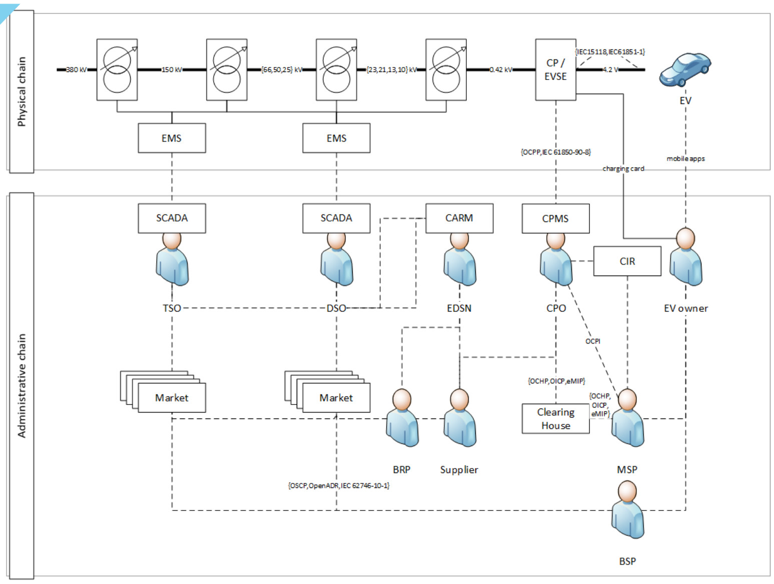
- Define a model system and implement it in Matlab/Python.
- Identify relevant machine learning approaches for the facilitator.
- Set up a learning environment and analyse the performance of the facilitator over time.

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:

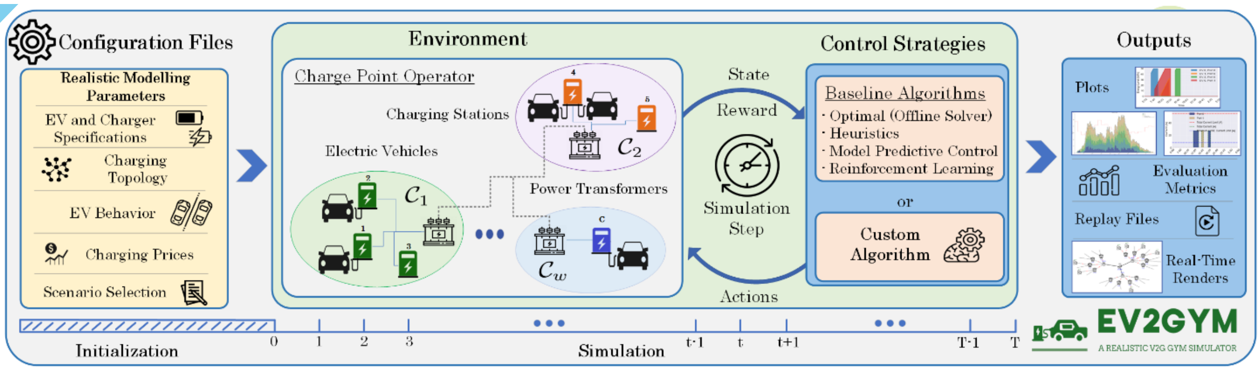
- Research distribution network modelling state-of-the-art and classification methods.
- Develop a classification model and train with data supplied by Stedin using machine learning.
- Develop a method for synthetic distribution network model generation.
- Research and apply common model performance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

- 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

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.

Contact details:
Mana Farrokhseresht, Policy advisor at TenneT TSO B.V.
(mana.farrokhseresht@tennet.eu)

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

Application of Generative AI in Offshore Wind Farm Planning

Thesis Project Scope: This thesis will focus on developing an AI algorithm for offshore wind farm planning. By applying generative AI techniques, the project aims to address critical challenges related to data scarcity and uncertainty in new wind farm locations.

Problem Definition: Wind farm planning plays a pivotal role in the effective integration of wind energy into modern power systems. However, one of the significant obstacles in wind farm planning is the lack of sufficient weather and environmental data in new, undeveloped offshore locations. This data scarcity can lead to increased uncertainty in predicting the potential energy generation of proposed wind farms, making it difficult to optimize planning and investment decisions.

Methodology: This thesis will explore the application of generative AI algorithms to enhance wind farm planning. The approach will involve developing a model that learns correlations between limited historical weather data and wind farm output, then applying the trained model to predict energy generation in new locations. The generative AI framework will simulate realistic environmental conditions, enabling more accurate planning and reducing the uncertainty inherent in data-scarce locations.

Research Objectives:

1. Develop a generative AI model to simulate offshore weather conditions, including wind speed, direction, and seasonal variations, to fill data gaps in new wind farm locations.

2. Evaluate the model's accuracy in predicting wind farm energy output by comparing generated simulations with historical data from existing offshore sites.

3. Optimize model parameters for different offshore environments, assessing how variations in location characteristics (e.g., ocean currents, topography) impact model performance.

4. Quantify the reduction in planning uncertainty achieved by using the generative AI model and determine the effects on financial and operational risk.

Contact details:

- PhD student: Weijie Xia (w.xia@tudelft.nl)
- Supervisor: Pedro Vergara Barrios(p.p.vergarabarrios@tudelft.nl)

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	