Intelligent Electrical Power Grids

Collection of available MSc projects

April 2020

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
Optimal OLTCs voltage control in future distribution networks

Scope: This thesis project will focus on building a mathematical model to regulate voltage by operating On-load Tap changers (OLTCs) in the future distribution power grid.

Problem definition: In recent years, the integration of photovoltaic generators (PVs) and plug-in EVs in distribution network has seen a rapid increase. It is easily predictable that the voltage will rise along the feeder due to the reverse power flow from PV systems during the daytime, while the voltage will drop during the night as shown in Fig.1. Moreover, the voltage will fluctuate more frequently with the changes in the sunshine. To compensate for voltage variations, now most of the distributed networks are equipped with OLTCs. These devices are an efficient way to regulate the voltage deviation and low-frequency voltage fluctuations. However, the character of OLTC is different from other voltage control techniques such as inverters. They regulate the voltage only in a discrete way and in the common range of ±5% in 2.5% steps. Other techniques such as inverters installed in PV panels can continuously change the voltage. Therefore, the challenge is to coordinate the regulation of OLTC and other devices in an optimal way.

Methodology: The challenge is to find the methodology to operate the OLTCs optimally by minimizing the maximum deviation of the voltage, power losses, switching changes, etc. Firstly, analyze the characteristics of OLTCs and other devices. Then, determine the methodology to operate the OLTCs. And finally, you also need to implement your method in one of the high PVs penetration power grid to verify its effectiveness.

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- PhD student: Aihui Fu (A.Fu@tudelft.nl)
- Supervisor: Milos Cvetkovic (m.cvetkovic@tudelft.nl)
Sliding mode control of the hybrid power systems with power electronics incorporated

Scope: This thesis project will focus on controlling method design which will enable proper operation of the multi-terminal HVDC-based (MTDC) power system when power converters are connected to both weak and hard grid, and in the case of disturbance.

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

Methodology: The challenge is to determine the best way to model Voltage Switching Converter (VSC) which will enable observation of the interaction between AC and DC power systems. Afterward, the sliding mode control for DC voltage, and AC active and reactive power should be designed to ensure the stable operation of the MTDC system. You will implement codes (MATLAB, Julia, Python, etc.) and perform simulations in the common power system tools (PowerFactory, RSCAD, etc.). One programming and simulation tool will be chosen in discussion with supervisor. Finally, the controlling algorithm will be analyzed concerning the AC power grid (weak, strong, disturbance).

Research objectives:
- Identify VSC model which will enable interaction between AC and DC power system.
- Design of nonlinear sliding mode control for hybrid power system and prove the stability using Lyapunov function approach.
- Test the developed algorithms within one of the common power system simulation tools.

Industry relevance/partner: You will get experience in one of the major industry tools in PowerFactory or RSCAD.

Contact details:
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Cyber-Physical System Modelling and Simulation for Cyber Security Investigations

Scope: This thesis project will focus on developing an integrated model of a test power system and its communication infrastructure for cyber security investigations.

Problem definition: On top of the power infrastructure reside information and communication technology (ICT) 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 system-of-system dependencies and interactions between ICT and power grids. CPS models are needed to simulate cyber attacks, analyse their impact on power system dynamics and develop mitigation techniques.

Methodology: For a standard test system, you will develop the dynamic model of the power grid using an industrial-grade power system simulation tool (DiGSIrLENT PowerFactory). The cyber system model incorporates essential ICT functionalities for real-time communication between the power grid and transmission system operator. The ICT models of power substations and control centres will be developed using communication network simulators such as OPNET, OMNet++ or NS-3. 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 and man-in-the-middle) and analyse their impact on power system dynamics at the physical system layer in an integrated environment.

Research objectives:
- Model an integrated CPS that incorporates both the power grid and its communication infrastructure.
- Simulate cyber attacks and analyse their impact on power system operation.

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

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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 (DiGSILO 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.

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NextGenGridOps Knowledge Model Supporting Massive Integration of Power Electronic Devices

**Scope:** The scope of this Master thesis project is to develop the Next Generation Grid Operations (NextGenGridOps) Knowledge Model supporting massive integration of power electronic devices into the transmission system. This is a joint MSc thesis project run by TU Delft and DNV GL.

**Problem definition:** Due to the increasing integration of renewable energy sources like wind and solar, several areas of the HVAC pan-European transmission system will in the near future be operated with extremely high penetrations of Power Electronics (PE) interfaced generators. For some periods of the day and during the year these will even become the only generating units. This will result in traditional grid operations not being able to stabilize the power grid using conventional control systems. There will be growing impact of power system stability issues associated with low inertia such as active power-frequency control. The European H2020 MIGRATE project has developed innovative solutions for managing the pan-European transmission system experiencing a proliferation of PE devices for connecting generation and consumption sites. As a next step it is important to address the valorisation of MIGRATE research results and support Transmission System Operators (TSOs) to adopt the key results and implement them into their NextGenGridOps.

**Methodology:** DNV GL is developing a NextGenGridOps Knowledge Framework in Enterprise Architect to manage the rapidly changing grid operation requirements and implementation. Enterprise Architect is an application to visualise, analyse, model, test, and maintain systems, software, processes, and architectures. DNV GL uses the Archimate 3.0 modelling language in NextGenGridOps Knowledge Framework to model market drivers, stakeholders, business processes, applications, requirements, dataflows, and hardware in a modular and layered structure. The aim is to create overview and insight in the entire grid operations domain. You will use Archimate 3.0 to further develop the Knowledge Framework with DNV GL. You will extend the experimental work in MIGRATE by analysing the efficiency of the new grid control models (grid following and grid forming control) using phasor measurement technology and Wide Area Measurement System (WAMS). You will build and model a use case for NextGenGridOps Knowledge Framework to support TSOs to analyse and implement the required changes to their existing grid operations to manage the power grid experiencing a proliferation of PE devices.

**Research objectives:**
- Develop NextGenGridOps Knowledge Model to support TSOs implement the required changes to their existing grid operations for massive integration of power electronic devices.
- Evaluate the efficiency of the new grid control models and build a use case in the Knowledge Framework.

**Industry partner:** DNV GL offers the opportunity for an internship and Master thesis project on this topic.

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NextGenGridOps Knowledge Model Supporting Deployment of Meshed HVDC Offshore Grids

Scope: The scope of this Master thesis is to develop the Next Generation Grid Operations (NextGenGridOps) Knowledge Model supporting deployment of multi-terminal High-Voltage Direct Current (HVDC) interconnections that will be established among offshore wind parks and onshore grids in different European countries. This is a joint MSc thesis project run by TU Delft and DNV GL.

Problem definition: The deployment of a common meshed offshore HVDC grid poses many technological, financial, and regulatory challenges. The European H2020 PROMOTION project has developed innovative solutions for further development and demonstration of HVDC network control systems. Complementary to this, a regulatory and financial framework has been developed for coordinated planning, construction, and operation of integrated offshore infrastructures, including an offshore grid deployment plan (roadmap) for the future offshore grid system in Europe. Next challenge to be addressed is the valorisation of the PROMOTION research results and support of Transmission System Operators (TSOs) to adopt these key results and implement them into their NextGenGridOps.

Methodology: DNV GL is developing a NextGenGridOps Knowledge Framework in Enterprise Architect to manage the rapidly changing grid operation requirements and implementation. Enterprise Architect is an application to visualise, analyse, model, test, and maintain systems, software, processes, and architectures. DNV GL uses the Archimate 3.0 modelling language in NextGenGridOps Knowledge Framework to model market drivers, stakeholders, business processes, applications, requirements, dataflows, and hardware in a modular and layered structure. The aim is to create overview and insight in the entire grid operations domain. You will use Archimate 3.0 to further develop the Knowledge Framework with DNV GL. You will extend the experimental work in PROMOTION by applying phasor measurement technology and Wide Area Measurement System (WAMS) to control the meshed HVDC network. You will build and model a use case for the NextGenGridOps Knowledge Framework to support TSOs to analyse and implement the required changes to their existing grid operations to deploy the meshed HVDC offshore grid interconnected with onshore grids in different European countries.

Research objectives:
- Develop NextGenGridOps Knowledge Model to support TSOs implement the required changes to their existing grid operations for deployment of meshed HVDC offshore grids.
- Build a use case in the Knowledge Framework to establish the reference model of the meshed HVDC offshore grid and its control requirements using WAMS.

Industry partner: DNV GL offers the opportunity for an internship and Master thesis project on this topic.

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Online State Estimation for Control Room of the Future

**Scope:** The scope of this MSc thesis project is to develop and implement an online State Estimator (SE) for control room of the future power grid. **This is a joint MSc thesis project run by TU Delft and TenneT.**

**Problem definition:** Within Energy Management Systems (EMS), state estimation is a key function for building a real-time model of the power grid. A real-time model is a quasi-static mathematical representation of the current conditions in an interconnected power system. This model is extracted at intervals from snapshots of real-time measurements and circuit breaker status. The power grid models are used in power system applications such as power flow, optimal power flow, contingency analysis, and voltage and transient stability assessment. Online state estimation algorithms estimate the power grid parameters and states when new data is available during system operation. However, various challenges are associated with online state estimation such as efficient topology processing, bad data detection, false data injection, convergence, computational performance, and update rates.

**Methodology:** In this project, the experimental setup consists of coupling a Real-Time Digital Simulator (RTDS), Wide Area Monitoring System (WAMS), communication network simulator, and DiGSIoNT PowerFactory for real-time data exchange. You will model in RTDS the IEEE 68-bus benchmark power system and simulate in real-time power system operation. WAMS provides sampled measurements and breaker status to the transmission system operator via the communication system. You will simulate communication delays that affect WAMS by using WANem or MININET. The existing WAMS infrastructure includes a basic control centre software platform, which will be extended and where all Phasor Measurement Unit (PMU) measurements are available on request. Data is communicated in real-time with DiGSIoNT PowerFactory, which implements EMS functions such as state estimation. DiGSIoNT PowerFactory uses Python for scripting and automation. You will develop the online state estimation solution in Python. This will be coupled with the real-time grid model in PowerFactory and evaluated with RTDS as a software-in-the-loop. Apart from the design and implementation of the online SE, some other topics may also be covered: operation with noisy inputs and during abnormal network conditions, effect of the loss of PMU measurements, packet delays, and presence of bad data and false data on the state estimation.

**Research objectives:**

- Couple RTDS simulated grid measurements with DiGSIoNT PowerFactory using Python.
- Implement online SE and perform sensitivity analysis of SE under different grid conditions and bad data.

**Industry partner:** This MSc thesis project is part of the Control Room of the Future research programme between TU Delft and TenneT TSO. An internship with TenneT TSO on this topic might be possible beforehand.

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Online Tuning of Power System Stabilisers for Control Room of the Future

Scope: The scope of this MSc thesis project is to develop a platform in the control room of the future power grid for measurement-based online tuning of Power System Stabilisers (PSS) of synchronous generators. This is a joint MSc thesis project run by TU Delft and TenneT.

Problem definition: Typically, in a large-scale interconnected power system, interarea oscillations may occur due to the electromechanical interactions between synchronous generators. These inherited phenomena are unique to every power system. They can cause equipment damage, financial loss, and fluctuations in system frequency, bus voltages, and tie-line power flows. The goal of this project is to design a Phasor Measurement Unit (PMU)-supported algorithm for an adaptive tuning of PSS to suppress power oscillations effectively.

Methodology: In this project, the experimental setup consists of coupling a Real-Time Digital Simulator (RTDS), Wide Area Monitoring System (WAMS), communication network simulator, open Supervisory Control and Data Acquisition (SCADA) system, and MATLAB or Python. You will model in RTDS the IEEE 68-bus benchmark power system and control systems of synchronous generators including PSS. Power oscillations are simulated in RTDS. WAMS provides sampled measurements to the transmission system operator via the communication system. You will simulate communication delays that affect WAMS by using WANem or MININET. The existing WAMS infrastructure includes a basic control centre software platform, which will be extended by using open SCADA software. At the control centre, measurements are available in real-time. You will develop an algorithm in MATLAB or Python and this will be coupled with RTDS as software-in-the-loop to tune online the parameters of PSS simulated in real-time in RTDS. To identify the generator groups that oscillate with each other an algorithm will be provided to the student. Apart from the design and implementation of the PSS tuning algorithm, some other topics may also be covered such as the impact of PMU communication delays on the control loop.

Research objectives:

- Couple RTDS simulated grid measurements with open SCADA and Python.
- Design of an adaptive measurement-based PSS tuning algorithm considering communication delays.

Industry partner: This MSc thesis project is part of the Control Room of the Future research programme between TU Delft and TenneT TSO. An internship with TenneT TSO on this topic might be possible beforehand.

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Fundamental harmonic study of systems with LCC+VSC technologies

Scope: This thesis project will be 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:

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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 will be used to educate students on energy system integration questions, to illustrate challenges of the energy transition to a broader community, and to test the acceptance and awareness of state-of-the-art energy management concepts.

**Method:** The energy system integration development kit emulates the electricity grid and the power system. It is, in essence, a set of low-power (e.g., up to 50 W) components that can be configured into a low to medium-fidelity scaled-down version of the real-world electricity grid. The hardware components and the accompanying software will be chosen and developed in such way to allow easy reconfiguration and extensive scalability of the kit.

The entire kit will be developed using open source software and off-the-shelf hardware so that it could be easily reproducible at any other place across the world. The test scenarios will be developed to illustrate the energy transition paths going forward.

Your thesis project will focus on the *design* of the hardware layer of the development kit, the *interface* to software part of the kit and the *implementation* of a simple test suite that shows the capabilities of the platform (by illustration one of the energy transition scenarios). The interface will be developed for and on Raspberry Pis; the software will be based on Python and Modelica.

This thesis is a part of broader activities led by the PowerWeb institute. You will get an opportunity to share ideas and thoughts about this concept with many researchers from academia and industry.

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prof. dr. Peter Palensky ([p.palensky@tudelft.nl](mailto:p.palensky@tudelft.nl))
Anomaly detection in complex power systems

Scope: This thesis project will focus on anomaly detection in the complex power system.

Problem definition: In data mining, anomaly detection is the identification of rare items, events or observations which raise suspicions by differing significantly from the majority of the data. It is vital in various applications of the power system, including detection of an intentional attack, technical fault, and disturbance, etc. Cyber-physical energy systems of the future are increasingly complex systems with depth integration of computation, communications, and control technology. However, the diverse nature of these components, their interlinked topology, and the sheer size of the system lead to an unprecedented level of complexity and quantity of data, which makes anomaly detection a more difficult task.

Methodology: Anomaly detection methods can be broadly categorized into statistical, proximity-based, and deviation based methods. You will implement and compare different methods, such as the mixture of Gaussians, K-nearest neighbor distances and other machine learning methods to detect anomalies.

- You will generate both normal and anomalous data for algorithm training and testing, respectively.
- Implement suitable algorithms to learn the pattern of normal data and then detect anomalies.
- Evaluate the anomaly detection performance of the algorithm by several indicators.

Research objectives:
- Specify the test system, including a model of the anomalies (type, magnitude, etc.)
- Select appropriate methods and parameters to detect anomalies in high-dimensional scenarios relevant to the power system. Universal anomaly detection methods and power system specific methods will be considered.
- Compare the performance and suitability of different anomaly detection methods.

Industry relevance/partner: You will address a problem of increasing industrial importance and learn about broadly applicable data analysis methods.

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- Supervisor: Simon Tindemans (S.H.Tindemans@tudelft.nl)
Techno-economic analysis of industrial multi-energy systems

Scope: This project will focus on the technical and the economic aspects of P2X devices in multi-energy systems.

Problem definition: Increased flexibility requirements from wind and solar, have prompted the integration of heat and gas systems into electricity through P2X devices such as boilers, electrolysers, district heating networks, etc. Not only is research needed to create smart algorithms to operate them reliably, research is also needed to assess the economics of using these systems based on the technical evaluations.

Methodology: Based on literature review, you will identify the most suitable technologies that can be used flexibly and develop different control algorithms to accommodate fluctuating renewable generation. Using these technical simulations, you will identify bottlenecks in system performance. Next, an economic evaluation will be carried out that will assess the technology from a business case perspective. The aim will be to evaluate system costs (OPEX, CAPEX, etc.) against current technologies, and in future scenarios.

Research objectives:

- Identify flexible power-to-x resources.
- Develop case study and control schemes for technical evaluation of P2X device.
- Analyse P2X device as a business case using results from technical simulations.
- Make recommendations on the feasibility of P2X devices in energy transition.

Industry relevance/partner: Smartport, Port of Rotterdam.

Contact details:

- PhD student: Digvijay Gusain (d.gusain@tudelft.nl)
- Supervisor: Milos Cvetkovic (m.cvetkovic@tudelft.nl)
Estimating Flexibility in Industrial Energy Systems using Machine Learning

Scope: This thesis project will focus on using machine learning to estimate aggregated system flexibility potential.

Problem definition: Total flexibility in energy system is not only dependent on the sum of individual component flexibilities, but also on the network conditions and operating strategy. Estimating aggregated system level flexibility is a complex operation. Analytical solutions are hard to derive, and therefore, Machine Learning methods can be used to estimate total flexibility.

Methodology: The challenge is to determine the best way to use machine learning to maximize system flexibility. System flexibility is defined as ability of the system to absorb any predictable or unpredictable changes in the system. You will be developing detailed models for testing and training of ML models.

Research objectives:

- Develop an industrial multi-energy system optimization model.
- Collect data for renewables and generate testing and training data, develop ML models.
- Analyse relationships to estimate the flexibility of the system when additional resources are added.
- Analyse possible analytical relationships for quantification of flexibility.

Industry relevance/partner: Using ML techniques in energy systems will prepare you for latest advances in energy transition, many of which focus on data driven model rather than physical models of systems.

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Modeling and optimal scheduling of energy usage for an industrial park

Scope: This thesis will focus on developing an optimal scheduling algorithm for a complex energy industrial ecosystem including a hybrid electric-gas boiler and an electric power heat pump.

Problem definition: Industrial areas are places of huge interest for analyzing the concept of energy flexibility in a complex energy ecosystem. Conversion between one energy domain to another can help increase reliability and counter uncertainty in generation and consumption. Variability in renewable generation can be utilized by converting it to, let’s say, heat, to reduce our dependence on other expensive fuel sources (like gas). Low quality heat can also be upgraded using electricity via heat pumps.

Uncertainty in renewable generation will be handled by optimally rationing the usage of energy to charge EV fleets or heat water in the hybrid boiler for chemical processes in industrial area, or upgrading waste heat using heat pumps. By using an optimal scheduling algorithm, the costs of energy can be reduced and the dependence on natural gas can be reduced. The system will be modelled in OpenModelica and scheduling algorithm will be developed in Python.

Research objectives:

- Develop relatively simple models for hybrid boilers and heat pumps in OpenModelica
- Develop an optimal scheduling algorithm
- Create a simulation case study to show the performance of the optimal scheduling algorithm

Industry partner: No

Contact details:

- PhD student: Digvijay Gusain (d.gusain@tudelft.nl)
- Supervisor: Milos Cvetkovic (m.cvetkovic@tudelft.nl)
Modular converter topology for accurate modeling of large scale electrolyser

**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 electrolyser 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.

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Modeling Optimization-based Controlled Islanding

Scope: The goal of the project is to propose and implement some improvements for optimization-based controlled network separation (also known as controlled islanding). The approach is planned to be based on mixed integer linear programming (MILP).

Problem definition: Controlled islanding is a novel approach for wide-area system protection. It is used as the last resort measure to save the network from a dangerous instability that could otherwise lead to a blackout. Controlled islanding aims to isolate the dangerous disturbance in an island to prevent it from spreading to the healthy parts of the network.

Methodology: Controlled islanding shall be modelled as a discrete optimization problem. This will involve working with MATLAB and some state-of-the-art optimization modelling tools (e.g., Gurobi). The student will be provided with some starting models, codes and literature. The main goal of the project is to increase the computational efficiency and/or the modeling accuracy of the optimization-based controlled network separation based on the ideas from literature and own creativity.

Project objectives:

- Study of the existing MILP-based formulations of controlled islanding.
- Study of optimization modeling with Gurobi (a state-of-the-art optimization solver). This requires the basic knowledge of the Python programming language (or C/C++, or Java).
- Implementation of the basic controlled islanding model as MILP using Gurobi and Matlab.
- Improvement of the basic model in terms of computational efficiency and/or accuracy.

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- Supervisor: Dr. Marjan Popov (m.popov@tudelft.nl)
Optimization-based controlled islanding

Scope: The goal of the thesis is the design of an optimization algorithm for controlled network separation (also known as controlled islanding). The solution is planned to be mainly based on mixed integer linear programming (MILP).

Problem definition: Controlled islanding is a novel approach for wide-area system protection. It is used as the last resort measure to save the network from a dangerous instability that could otherwise lead to a blackout. Controlled islanding aims to isolate the dangerous disturbance in an island to prevent it from spreading to the healthy parts of the network.

Methodology: Controlled islanding shall be modelled a discrete optimization problem. This will involve working with MATLAB and some state-of-the art optimization modelling tools (e.g., GAMS or Gurobi). The outcomes of controlled network separation shall be simulated in DlgSILENT Powerfactory (an interface between PowerFactory and other tools will be provided). In addition, the student will be provided with some starting models, codes and literature to develop an improved algorithm according to the objectives below. The last thesis objective is deemed as the most important one.

Thesis objectives:

- Study of the existing MILP-based formulations of controlled islanding
- Iteratively improve the basic MILP formulation to decrease the computational time
- Extend the model by incorporating additional constraints related to power system stability
- Devise efficient approaches to incorporate the reactive power into the algorithm

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- Supervisor: Dr. Marjan Popov (m.popov@tudelft.nl)
Background: Out-of-step protection (OOS protection) can be classified as a system integrity protection scheme (SIPS), whose goal is to save an interconnected power system when two or more of its parts lose synchronism. The loss of synchronism is a very dangerous “in extremis” condition characterized by abnormal currents, voltages, and frequencies over a large power network area. If not mitigated quickly, it leads to a physical destruction of equipment and costly wide-area power system failures.

Problem definition: Out-of-step protection should differentiate between stable and unstable power swings in a real-time fashion and to separate the accelerating parts of the power system as soon as their instability becomes irreversible. The protection reaction speed is very crucial, as even small delays in separating the system can lead to unnecessary stresses on the equipment. Therefore, implementing OOS protection on RTDS (Real-Time Digital Simulator) with all practical time delays is an important task.

Methodology: The student will be given access to the existing RTDS infrastructure and software tools (see the image on the top). The student will also receive some wide-area OOS protection prototypes. The main goal is to adapt these initial blocks and to develop the new ones to obtain a feasible real-time OOS protection environment based on PMUs (Phasor Measurement Units). A secondary goal is to study the out-of-step conditions and factors that have an influence on them.

Thesis objectives: Conceptual design of the real-time OOS protection framework; incorporation of existing online algorithms (generator coherency, disturbance detection etc.); implementation of OOS protection in RTDS as SiL (Software-in-the-Loop); design and simulation of multiple blackout scenarios to test your real-time OOS protection implementation.

Contact details:
- PostDoc: Dr. Ilya Tyuryukanov (i.tyuryukanov@tudelft.nl)
- Supervisor: Dr. Marjan Popov (m.popov@tudelft.nl)
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


**Contact details:**

- Supervisor: José Rueda Torres (j.l.ruedatorres@tudelft.nl)
- Co-supervisor: Dr …. (....@....)
EMT Digital Twin of the 380 kV Dutch Transmission System

Scope: Definition, implementation, and testing of an EMT model of the Dutch high voltage transmission system in order to study its dynamic behavior in future operational scenarios and topologies.

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

Tasks:

- Literature review of the different techniques used for EMT modelling and simulation.
- Develop a Digital Twin by using generic models and parameters defined in IEEE and CIGRE standards. The Digital Twin shall have different operating points, topologies, and dispatch conditions including:
  - Different amount of conventional and renewable generators with their control systems
  - Different models of transmission lines (HVAC and HVDC) and controllable loads (e.g. electrolyzers).
  - Dynamic equivalents of neighboring countries and subsystems in lower voltage levels (e.g. 200 kV, 150 kV, 110 kV).
- Identify and test different perturbations in the system with the goal of using different signal records for the study of the oscillatory phenomena based on signal processing techniques.
- Development of a method to ensure optimal initialization in each simulated condition.
- Development of a method to tune the models of components and their control systems in an automated manner.

Contact details:
- Supervisor: José Rueda Torres (j.l.ruedatorres@tudelft.nl)
- Co-supervisors: Prof. Peter Palensky, Dr. Aleksandra Lekic-Vervoort
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:


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)
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)
Fast transfer relay testing on RDTS system in combination with a 7UT transformer relay.

Scope: The project is focused on testing on Siemens 7UT relay by making use of RTDS.

Problem definition: DOW installations are equipped with 6 kV motors that are supposed to be kept in operation. There has been work done on this by using EMTP. In order to observe the performance of the motors, real time simulations will be needed. In this project, refined models should be built in RTDS environment and the testing of the relay will be performed in real time. The advantage is to see the performance of the motors during fault and after the fault is removed.

Methodology: RTDS modeling and real time testing

Research objectives:
- Building an RTDS model for DOW site Tarragona North 15 kV/6 kV systems
- Modeling induction motor
- Modeling a 15 kV generator
- Modeling the transient torques on the motors
- Test relay on different scenario’s with RTDS
- Define best settings and run sensitivities

Industry relevance/partner: DOW Terneuzen

Contact details:
- Supervisor: M. Popov (m.popov@tudelft.nl)
Application of 61850 for testing protection functions in RTDS

**Scope:** This project deals with the evaluation of distance and directional overcurrent protection in RTDS environment by utilizing 61850 communication protocol.

**Problem definition:** Fault currents resulting from distribution generation utilizing power electronics are different in amplitude, form and duration. In this context, under specific circumstances, protection may not operate or faces delayed operation. Therefore, it is important to perform numerous tests in order to observe the protection performance.

**Methodology:** The work will be developed in two parts; in the first part the protection will be tested by using IEC 60255-121 on particular distance protection functions only, the effect of harmonics, and the saturation should be examined. In the second part, a test network in RTDS environment will be built and the protection will be tested for different operation conditions (strong and weak network) as well as different faults. The network will also be modified (synchronous generation and wind power infeed) in order to find the limits of the protection performance.

**Project objectives:**

- Protection performance against different fault currents (1-f, 2-f, 3-f, 2f-g) allocated on different distance from the busbar, different relay characteristics and settings
- Investigation of the the effect of the CT saturation will be investigated
- A comparison of the performance of the distance relay with the overcurrent relay will be also performed.

**Contact details:**

- Supervisors: Dr. Marjan Popov (m.popov@tudelft.nl), and Marko Tealane M.Tealane@tudelft.nl
Future smart grid scenarios: Modeling and simulation

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

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

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

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

Contact details:
- Supervisor: Milos Cvetkovic (m.cvetkovic@tudelft.nl)
Modeling a 100% renewable power system

**Scope:** The Paris agreement anticipates eventual transition to a 100% renewable power system. To achieve this transition, governments and grid operators use energy transition models to decide on the share of different technologies in the power system, investments into grid reinforcements, levels of subsidies and taxes to incentivize the right behavior of energy companies, etc.

**Problem definition:** Energy transition models have to make many simplifications in order to represent highly complex future power systems. These simplifications range from technology simplifications to the adjustments in time and spatial resolution of the power system. For example, energy transition models use very crude assumptions regarding the amount of storage or demand response in the power system. In this thesis, we look at different methods to improve the accuracy of energy transition models. By doing this, we are helping the governments, grid operators and energy companies to transition quicker to the sustainable future.

**Methodology:** The student can 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 overcoming simplifications of the energy transition models. Finally, development of simulations, focuses on extending current simulation tools with the new models and case scenarios.

**Industry relevance:** While working on this thesis topic, you will get the knowledge that you could use in any company that is interested in case scenario studies and modeling of energy transition, such as consulting companies, grid operators, institutes, large energy companies, startups providing advice on energy transition, etc.

This research is related to the EU H2020 project TradeRES and comes with an opportunity to work in close collaboration with industrial partners.

**Contact details:**
- Supervisor: Milos Cvetkovic (m.cvetkovic@tudelft.nl)
Modeling local energy communities

Scope: Local energy communities are increasingly becoming an important factor in the energy transition. While the new technologies (such as EVs, IoT, blockchain, etc.) are becoming more affordable, various neighborhoods and communities are seeking to reduce their carbon footprint by self-sufficient operation and governance. Such self-sufficient (decentralized) approach to locally managing energy is in contrast with our current operation paradigms which rely heavily on the grid operator.

Problem definition: This thesis explores the design and operation concepts for local energy communities of the future. Local energy communities have to be designed and operated in a fair, affordable, sustainable and reliable way. This includes the operation and maintenance of the underlying infrastructure, mechanisms for cost-effective and transparent trading of energy, the approaches for investment into collective assets, overall reliability of the energy community and business models to support design choices in each of these aspects.

Methodology: The student can choose one of the following three directions to put the emphasis on: case scenarios, energy markets and behavioral aspects. 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 energy markets focuses on alternative market models for running local energy communities. Finally, exploration of behavioral aspects looks at the role of the prosumer in the local energy community.

Industry relevance: While working on this thesis topic, you will get the knowledge that you could use in any company that is dealing with energy transition in urban environments.

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

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:**

![Industry Partner Logos]

**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

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

Interests:

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

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

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

Methodology and Research Objectives:

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

What is the allowed current that would not breach the maximum allowed temperature of the conductor?

Determination of the weakest span i.e. the span which represents a limit for the whole power line, which presumes that determination of thermal current for all spans has been performed. Furthermore, the weakest span may vary in consequence of different atmospheric conditions and span characteristics (tension, clearance margin, etc.).

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

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

**Industry Partner:**

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

**Contact details:**

- PhD Guide: Nidarshan Kumar ([N.Veerakumar@tudelft.nl](mailto:N.Veerakumar@tudelft.nl))
- Supervisor: Marjan Popov ([m.popov@tudelft.nl](mailto:m.popov@tudelft.nl))
Developing a Digital Sibling for the Dutch National Grid

Scope: This project will develop a steady state model of the Dutch National HV Electricity Grid.

Problem definition. A key challenge in integrating RES into the grid arises from the variability and uncertainty in its power production, affecting the grid stability, reliability, and economics. To counter these challenges, ideas such as energy sector integration, large scale battery integration, demand response, network expansion planning, have been proposed. An indispensable component in validation of all the proposed strategies is a numerical model of the power grid.

Methodology: The student will conduct an extensive data analysis of the available data from various network operators and literature. Once the model is developed, the student will create scenarios pertaining to wind penetrations, perform locational analysis, identify energy system integration challenges for electricity, heat and gas network coupling.

Research objectives:
- Develop a digital sibling for Dutch national HV grid in Python/Julia.
- Perform extensive data and literature survey.
- Create future scenarios for the Dutch electricity grid based on national outlooks.
- Identify challenges in integration of electricity grid with gas/heat network at HV/LV level.

Contact details:
- PhD student: Digvijay Gusain (d.gusain@tudelft.nl)
- Supervisors: Milos Cvetkovic (m.cvetkovic@tudelft.nl)  
  Peter Palensky (p.palensky@tudelft.nl)
State Estimation in Medium Voltage Distribution Networks

**Scope:** This project will focus on the development of algorithms for estimation of voltages, currents and powers at all points of meshed medium voltage networks based on a limited set of measurements.

**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 start to form a significant problem. New algorithms have to be developed in order to resolve this problem.

**Research objectives:**

- Identify the best suitable method for state estimation in medium voltage networks with large penetration of renewable energy sources.
- Develop algorithms for reliable estimation of network state with a minimum number of available measurements.
- Implement, test and validate the developed algorithms using Vision Network Analysis software and measurements available from distribution network operators.

**Industry relevance/partner:** The project will be performed in close cooperation with Phase to Phase company. Phase to Phase develops Vision Network Analysis software, which is widely used by network operators and industry. The results of this research will be applied in practice by Dutch distribution network operators.

**Contact details:**

- Supervisor from TU Delft: Simon Tindemans (S.H.Tindemans@tudelft.nl)
- Supervisor from the company: Anton Ishchenko (anton.ishchenko@phasetophase.nl)
Data-based forecasting of future electricity spotmarket price-series

Scope: This thesis project will focus on developing methods of estimating the effect of energy-scenarios on future time-series of electricity spotmarket prices.

Problem definition: Demand management of electricity is necessary to keep the future electricity grid as reliable as it is now. One method of demand management is through flexible pricing of electricity, where the availability of electricity is reflected in the price through scarcity of a product. This gives an economic incentive to shift electricity use is time, which is called demand-side management, demand-side control or demand response.

The future status of the energy system is divided into scenarios, like in the Dutch “Net van de Toekomst”. The energy system is changing fast and can still go in many directions. Will there be a fleet of driving batteries stabilizing the grid? Is hydrogen becoming an economically feasible solution for storage of excess wind energy? Is nuclear energy making its return? Will Norway become Europe’s battery-pack? These generating and storage techniques influence electricity market prices, possibly making or braking the business case for large-scale demand response.

Estimating the effect of energy scenarios on future electricity market prices can aid decision makers in picking a future-proof DR strategy which will result in a win-win for the grid and the user, enabling the energy transition.

Methodology: The challenge in this thesis is to determine the effects of uncertain measures in uncertain circumstances. Using energy-market models like the Energy Transition Model (ETM) allow us to estimate the influence of energy scenarios on Day Ahead Market prices. However, this is a deterministic model only taking a single year of weather into account. By using concepts like Artificial Intelligence a robust estimate can be made by taking several uncertainties into account. Which is key in risk-management and decision making. Bayesian Inference could be used to estimate changes in different electricity markets compared to another one. Models could be coupled to estimate the effects of (combinations of) European energy scenarios.

Research objectives:
- Gather relevant future energy scenarios (NL or EU-wide)
- Identify models that can estimate their effects on electricity prices – and apply them
- Include several uncertainties in the estimation (e.g. installed capacity, available storage, weather conditions)
- Estimate effects on multiple market-mechanisms (e.g. Day Ahead Market, Intraday Market, Imbalance Market)

Industry relevance/partner: No.

Contact details:
- PhD student: Ties van der Heijden (T.J.T.Heijden@tudelft.nl)
- Supervisor: Edo Abraham (E.Abraham@tudelft.nl)
- Supervisor: Peter Palensky (P.Palensky@tudelft.nl)
Generative Adversarial Networks for Load Profile Generation

Scope: This project investigates whether Generative Adversarial Networks (GANs) can be used to generate new realistic load profiles on the basis of a database of existing load profiles.

Problem definition: Network planning studies and simulation-based testing of operational tools often require customer load profiles, either individually or in aggregation. Two common limitations are often encountered: (1) the amount of available data may not be sufficient for the use of data-intensive algorithms; (2) load profiles of individual users cannot be shared due to privacy concerns. Synthetic load profile generators have been developed to address these concerns. Recently, GANs have been recognized as powerful tools to generate synthetic datasets with properties that closely resemble those of a source dataset.

Methodology: You will develop a GAN training and testing codebase in Python. Existing load profile datasets will be used for training/validation/testing.

Objectives:
- Perform a statistical analysis of existing load profile dataset.
- In-depth literature search of applications of GANs to time series generation.
- Training and evaluation of GAN for relevant use cases (data ‘enrichment’, privacy preservation).
- Evaluate performance at different aggregation levels.
- Produce code that can be re-used by other students and researchers.

Industry relevance/partner: This work is relevant for distribution system operators, both for their own use, and to enable them to synthesize depersonalized load profiles for external use. There may be opportunities to work with DSOs on this project.

Contact details:
Simon Tindemans (s.h.tindemans@tudelft.nl)
Daily supervision: Chenguang Wang (c.wang-8@tudelft.nl)
Cross-border participation in capacity mechanisms

Scope: This project investigates the security of supply benefits that result from the interconnection of neighboring electrical systems – and whether current policy proposals accurately value these benefits.

Problem definition: In order to avoid supply shortages during low-wind peak load hours, a number of European countries are deploying capacity mechanisms that incentivize construction of new generating resources. The European Commission is adamant that such schemes should not discriminate against foreign providers: for example, Dutch generators should be able to sell ‘capacity’ in the GB capacity auction, by way of the BritNed interconnector between the two countries. Current proposals to manage cross-border trading on capacity markets are based on a simple representation of a ‘capacity product’ (MW) analogous to energy (MWh). However, this may not do justice to its underlying complexity.

Methodology and objectives: The project scope and objectives will differ substantially based on your interest. Attending EE4665 Uncertainty Modelling and Risk Assessment is essential for all options. Some projects may involve co-supervision by Laurens de Vries at TPM. Options include:

- Quantifying cross-border contributions to capacity markets using computational studies. You will design a simple multi-area test system (e.g. a region with 3 or more countries) and quantify capacity contributions using Monte Carlo simulations. This approach will require basic knowledge of optimisation, programming skills (Python preferred). Useful electives include Monte Carlo Simulation of Stochastic Processes, Scientific Programming for Engineers.
- A detailed study of the techno-economic case for cross-border capacity trading. You will create a simple two-area model with probabilistic models of generation and load. You will formulate various methods for cross-border capacity investments, and assess whether they facilitate or interfere with a fair allocation of capacity payments. This will require knowledge of economics and the use of basic probability theory.

Contact details:
Simon Tindemans (s.h.tindemans@tudelft.nl)
Distributed control of refrigeration loads and air conditioners

Scope: This simulation-based project investigates the behavior of large numbers of thermostatically controlled loads equipped with a decentralized stochastic power tracking controller.

Problem definition: Thermostatically controlled loads (TCLs) such as refrigerators are exceptionally suitable as a low-cost provider of flexibility to the grid: their power consumption can be shifted by 10s of minutes without noticeable effects on cooling performance. This project investigates the ‘real world’ robustness of a robust decentralised control scheme for heterogeneous TCLs, by considering sensitivities to model misspecification, changes in ambient temperature, door openings, etc.

Methodology: This project consists of two main elements. First, the definition of relevant physical models for refrigerators, and various power system use cases (e.g. frequency support, alleviating ramping constraints or congestion). Second, implementing simulations in Python (control algorithm is provided) to test use cases at scale and across many random realisations. You should be skilled in the use of Python and familiar with elementary probability theory. A useful elective is Monte Carlo Simulation of Stochastic Processes.

Research objectives:
- Define an appropriate study model (e.g. refrigerators, air conditioners) and research available literature for mathematical models and their associated physical/practical constraints
- Define power system use cases
- Implement simulation tool
- Quantify the performance of aggregate TCLs as flexible resource, and identify factors that influence it.

Industry relevance: This project addresses an important industrial challenge. How can stochastic appliances in a largely uncontrolled environment be relied upon to provide critical grid services?

Contact:
Simon Tindemans (s.h.tindemans@tudelft.nl)
**EASY-RES** Enable Ancillary Services by Renewable Energy Sources

**Scope:**
This thesis project will focus on developing techniques and methodologies to test the ancillary services for power grid stability and security in power hardware in loop with RTDS.

**Problem definition:** The stability and security of the traditional electrical power systems is largely based on the operation of central power plants with synchronous generators (SG). Today, the SGs provide the following ancillary services to grid: (i) Reactive power, (ii) Inertial response, (iii) High-frequency power smoothing, and (iv) Fault ride through.

In the future energy system, the growing penetration of converter-interfaced (thus inertia-less) solar panels and wind turbines will eventually replace dispatchable SGs. Therefore, the future DRES inverters should also take over the role of SGs in providing required ancillary services to the power grid.

**Methodology/Research objective:**
Simulation test models of DRES will be developed including converters controllers with ancillary services capability. DRES of interest are wind turbines, solar panels, and energy storage systems. Students can choose which DRES and ancillary services they want to focus on. The models will be simulated in Real-Time Digital Simulator (RTDS) and tested with power hardware in loop. The converter controllers should be developed to provide services such as adjustable virtual inertia and adjustable power-frequency droop curve.

**Industry relevance/partner:** Transmission and distribution system operators are partners of this project and are highly interested in future capabilities of DRES to provide ancillary services. Experience with RTDS is highly valued by the industry.

**Contact details:**
- PhD: Umer Mushtaq ([U.Mushtaq@tudelft.nl](mailto:U.Mushtaq@tudelft.nl))
- Supervisor: Milos Cvetkovic ([m.cvetkovic@tudelft.nl](mailto:m.cvetkovic@tudelft.nl))

This project has received funding from the European Union’s Horizon 2020 Programme for research and innovation under Grant Agreement no 764090.
### Electives relevant for IEPG graduation projects

#### EEMCS forms

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### Programming and software engineering

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

- Programming on the GPU with CUDA
  - http://homepage.tudelft.nl/d2b4e/gpu_flyer.pdf
  - every quarter

- Introduction to Programming using MPI
  - http://homepage.tudelft.nl/d2b4e/mpi.pdf
  - once a year