Intelligent Electrical Power Grids

Collection of available MSc projects

February 2018

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
Master's Thesis Proposal

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

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- Supervisor: José Rueda Torres (j.l.ruedatorres@tudelft.nl)
Implementation of Synthetic Inertia control for offshore wind power plants in PowerFactory

Scope: This thesis project will be focused on the implementation of Synthetic Inertia control for offshore wind power plants in PowerFactory.

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. Recently these devices are able to contribute to the frequency regulation of the grid by introducing special control techniques for these purposes.

Methodology: You will ascertain and compare the state of the art research in synthetic inertia in order to implement these controls schemes in a quasi-stationary (RMS) model representation in PowerFactory. The control approaches implemented will then analyzed in order to determine the influence of these scheme in the frequency regulation of a three area power system.

Research objectives:

- Literature review in wind turbine modelling and synthetic inertia.
- Implementation of several synthetic inertia controls approaches in PowerFactory.
- Perform sensitivity analysis of the control parameters in terms of the frequency regulation for the power systems to be considered.

Industry partner: No

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Work towards advanced metropolitan solutions: Urban Energy flexibility sharing

Scope: Ready to work on the energy Uber? You will assess the challenges and solutions for sharing energy and its flexibility and develop a demonstration platform taking into account various physical boundary conditions.

Problem definition: Wouldn't it be terrific to buy your electricity from one of your neighbours instead of one of the big, polluting electricity suppliers? Large metropolitan areas tend to urbanise even further: higher population density, more wealth, more energy consumption, mainly electricity. At the same time we need to prepare ourselves for the generations ahead of us. Utilising sustainable energy, cross-domain synergies, and technological improvements aids us in working on a so-called circular economy that handles the changing urban environment.

The emergence of Cyber-Physical Energy systems opens up a wide variety of possibilities to utilise the power system. It allows us to leave the centralised top down (generation-transmission-distribution) paradigm behind us and it enables we are heading towards a decentralised bottom up approach in which local electricity trading initiatives thrive. The Internet of Things tools are there: smart meters, smart domestic devices, etc. It is hence time to utilise these and build an experimental platform in which forecasted consumption, prosumption, and eventually flexibility can be traded and tuned.

Method: You will devise, specify, and develop a demonstrator of the web-based front-end as well as the computational back-end of such a sharing platform. The project consists of a state-of-the-art assessment of flexibilty sharing platforms, market modelling, privacy management solutions, and applicability of existing (simulation) tools, among others. Subsequently, you will select the core tools and devise a demonstration use case that mimics a typical urban environment. The development of the front-end and back-end will go hand in hand. Together with your supervisors you will continually check the applicability of the specified features and conceivable amendments.

Python, blockchain, game theory, power flow, teamplayer. Do these keywords ring a bell for you? Are you interested? Do you think such a platform is feasible or do we need to take a different approach? It would be great having a chat with YOU!

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dr M. Cvetkovic, M.Sc.
prof. dr. Peter Palensky
Model-based predictive control schemes for future smart grids

Scope: This thesis project will focus on developing a model based predictive control algorithms for direct deployment in the control rooms of future smart grids.

Problem definition: Modern control rooms equipped with wide area protection and control (WAMPAC) systems are able to monitor the faults happening in a power system but they fail to automatically detect the catastrophic cascading effects associated with some faults, which may even lead to a system blackout. The thesis addresses this problem in a smart grid paradigm, where we expect the electricity grid to develop more towards a self-healing grid. Thus aims at developing model-based predictive control algorithms with a focus on specific applications such as under voltage load shedding (UVLS) schemes for short-term voltage instabilities.

Methodology: The project starts by defining the test systems and scale of work with an aim to determine the best model based predictive control schemes for under voltage load shedding using PMU measurements from the system. Software such as RSCAD/RTDS, PowerFactory can be used for this purpose. At a later stage the work can be extended to using high-performance computing facility of the group for performance improvement of developed algorithms.

Research objectives:

1. Literature review on Under-Voltage Load Shedding schemes.
2. Explore algorithms for model-based predictive control.
3. Implement the most suitable algorithm and analyze the performance.

Industry Relevance: RTDS/Power Factory are the states of the art power system simulation softwares used by electric utilities throughout the world and the project helps you to gain greater insights into using them.

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Probabilistic Reliability Assessment of 10-Year System Development in the Netherlands

**Scope:** To implement the probabilistic assessment methodology developed in GARPUR project (Generally Accepted Reliability Principle with Uncertainty modelling and through probabilistic Risk assessment) for assessing the reliability level of different expansion options within a 10 year time horizon in Netherlands.

**Problem definition:** Current practice for reliability analysis in the context of transmission expansion planning is mostly based on multi-scenario deterministic power flow analysis combined with matrix-based risk appraisal. The GARPUR project has shown the consideration of probabilistic models of input variables (e.g. variability of renewable energy generation, weather dependent failure rates) has implications in the level of risk associated to a given candidate option for system development. GARPUR also proposed a generalized probabilistic methodology to assess the expected value of investment and operational cost in long-term transmission planning. This methodology considers, besides the probabilistic nature of input variables, also issues relevant for the shorter time frame (e.g. maintenance planning, re-dispatch, market behavior, failure of corrective control actions) that until now are generally ignored in long-term planning. Therefore, the application of the GARPUR methodology constitutes a valuable opportunity to develop existing (mostly deterministic) methodologies to account for the more variable system conditions of the future, while generating risk indicators of better quality.

**Methodology:** In this MSc research, the starting point concerns with the study of GARPUR probabilistic methodology for long-term transmission planning (its mathematical formulation) and the recommended improved probabilistic models for reliability analysis. Next, the GARPUR probabilistic methodology for long-term transmission planning shall be implemented by using the probabilistic models and tools available in TenneT TSO BV. Improvements of the models currently used by TenneT TSO BV, based on the recommendations issue by GARPUR shall be proposed and tested. The outcomes of this study shall be
compared with the outcomes of TenneT’s approach for definition of its bi-annual 10-year capacity statement - i.e. the so-called 2018-2028 Quality and Capacity Plan (2018 QCP).

Research objectives:

- Determination of the feasibility and approximations needed to apply GARPUR probabilistic methodology for long-term transmission planning on a real-case study (Dutch transmission system).
- Development of a computationally efficient GARPUR methodology for long-term transmission planning based on available probabilistic models and software packages in TenneT TSO BV.
- Performing sensitivity analysis of the main parameters behind GARPUR methodology, which have a strong influence on the resulting level of reliability risk, to determine the bounds of acceptable risk level.
- Assessment of extensions, based on recommendations issued by GARPUR, of the existing probabilistic models used in TenneT TSO BV.

Industry partner: TenneT TSO BV

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Visualization of Indicators for Power System Stability

Scope: To investigate the possibilities of visualization of indicators for power system stability. The main objective is to develop a way to visualize stability indicators for clear interpretation in a control room.

Problem definition: In the future, power electronics (PE) will be applied more often in the power system. Possible applications of PE are: solar PV, wind turbines, HVDC connections and PE-connected load. The increased level of PE will have an impact on the stability behavior of the power system. Therefore, this impact and the development of new Key Performance Indicators (KPIs) for stability are currently being considered in the MIGRATE project. To be useful in system operation, a good visualization of the stability indicators is needed.

Methodology: In this MSc research, various possibilities of visualization of stability indicators will be studied. Possible solutions might be: fuzzy inference system, risk matrix/diagrams, visualization in a console. Various options will be studied and compared to answer the question: how can the information best be presented, in a consistent way and without losing valuable information?

Research objectives:
- To investigate the challenges and possibilities of the visualization of stability indicators
- To study and compare various possibilities of stability indicator visualization
- To develop and propose a method of visualization that could be used in the control room

Industry partner: No

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Fault-based Reliability Analysis of an MMC-HVDC Link by considering its Control Structure Performance

Scope: To develop a reliability model for MMC-HVDC connections, based on possible faults and the fault behavior of the connection.

Problem definition: HVDC connections will be implemented more often in the future in (international) offshore grids. As these offshore grids transport large amounts of electrical energy, it is important that HVDC connections are as reliable as possible. Generally in reliability analysis, assumptions are made about possible component failures and their consequence for the connection availability. To make the reliability analysis more realistic, it is important to consider that the control structures within the converter stations have an unneglectable role. Developing a reliability model, based on the more probable AC faults (that can occur around the HVDC converter stations) and considering the influence of the internal regulators (control blocks), is becoming a very interesting topic for the industry and scientific community nowadays.

Methodology: The research starts with the development and analysis of a VSC-HVDC model of a two-terminal MMC-HVDC link. Various possible faults in the connection are then studied, taking the probability of these faults into account. Based on the fault behavior and the fault probabilities, a reliability model of the HVDC connection will be developed then.

Research objectives:

- To create a VSC-HVDC model and to study various possible faults.
- To create a reliability model of the HVDC connection based on the fault characteristics
- To give recommendations about how the reliability of the HVDC connection can be improved.

Industry partner: No

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Reliability Assessment of offshore HVDC Grids

Scope: To develop a reliability model of (international) offshore HVDC grids. The reliability of offshore grid will be assessed, while taking the behavior of the national power systems into account as well.

Problem definition: In the future, an offshore HVDC grid will be implemented in the North Sea to collect the wind energy from large-scale offshore wind farms and to enable the international exchange of electrical energy. As this offshore grid carries substantial amounts of electrical power, it is important that this grid is highly reliable. Previous studies have shown that offshore components are less reliable than onshore components, mainly because of the much longer repair time. Other studies showed that implementing redundancy in offshore networks to increase the reliability often is not economical, but this has to be verified for large-scale, international offshore grids. The inclusion of the (market) behavior of national power systems is essential for studying the reliability of international offshore networks.

Methodology: In this MSc research, an approach to analyze the reliability of offshore HVDC grids will be developed. The reliability of the offshore grid is assessed and the most optimal level of redundancy will be determined. Describing the international load flow scenario is an essential part of this research.

Research objectives:

- Collection of the input information (like component parameters and load flow scenarios)
- To develop a reliability model for offshore HVDC grids
- To assess the reliability and give recommendations about the optimal level of redundancy

Industry partner: No

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Collaborative approach to holistic smart grid simulation

Scope: This project aims at developing a method that allows multiple TSOs and/or DSOs to interconnect the dynamic simulations of their smart grids and analyze grid interactions in unprecedented detail.

Problem definition: The grid of each TSO or DSO interacts with neighboring grids, but these interactions have not been considered in detail in the past. The complexity of modern smart grids calls for these interactions to be better analyzed. TSOs and DSOs can collaborate by remotely interconnecting their already existing simulations, just as their real grids are interconnected. There are two types of problems that need to be solved to make collaborative simulation possible and you can choose which to focus on.

1. Models: Models of different subsystems need to be developed or adjusted to make the interconnection possible and the simulation results accurate.
2. Infrastructure: Servers running different simulation packages need to be interconnected and efficiently orchestrated so that the simulations can collaborate while they run.

Methodology: You will determine the best way to couple simulators from a power system modelling point of view. You will then model a scenario to test the co-simulation. Finally, you will determine the capabilities and limitations of your co-simulation solution.

Research objectives:

- Explore the available methods for coupling system dynamics.
- Determine the best method for the specific case of TSO/DSO model interconnections.
- Evaluate the method and its limitations from the accuracy and performance viewpoints.

Industry relevance: You will become an advanced user of at least one industry-standard software package and programming language.

Contact details:

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Exploring the scalability of coupled transmission/distribution dynamic simulation

Scope: This project aims at exploring the scalability challenges and limits of coupled simulations that analyze dynamic transmission/distribution grid interactions.

Problem definition: One way to analyze dynamic interactions between transmission and distribution grids is by coupling several simulators, each simulating either a transmission or distribution grid. To effectively analyze these interactions, a large number of distribution grids need to be connected to the transmission grid. As the number of grids increases, the coupled simulation can lose accuracy or become too slow. Your task is to explore the challenges that come with simulating a large and realistic grid (big transmission grid, several distribution grids), and propose methods for overcoming the challenges you identify.

Methodology: You will develop representative grid models and couple them using our co-simulation platform based on PowerFactory+Windows Server 2012+Python 3.4. You will then examine the behavior of the simulation as the number of coupled grids increases (is the physical phenomena accurately represented? Is the simulation slow?). You will then identify the challenges that arise and propose solutions.

Research objectives:

- Determine the characteristics of the required grid models.
- Determine the best method for the specific case of TSO/DSO model interconnections.
- Evaluate the performance of the simulation methods.

Industry relevance: You will become an advanced user of at least one industry-standard software package and programming language.

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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

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Modeling a waste steam based electrical generator

Scope: This thesis will focus on developing a waste steam based electric generator in OpenModelica. The generator is conceptualized by Synext (http://synext-energy.com/). After modeling, the contribution of generator to improve energy efficiency in an industrial setup will be analyzed.

Problem definition: One of the key areas of focus today among industries is to increase their energy usage efficiency. Currently, lots of energy in industry goes to waste in form of heat and steam. Utilizing this waste product to convert into useful form of energy (like electricity) increases efficiency while also reducing the cost of production in the long term for the industry.

A key contribution of this work will be to integrate this developed model with an electrical circuit test case consisting of other sources of electricity (like solar and wind) and loads that would represent an industrial distribution network. Various use cases will be constructed to prove the increased energy efficiency using this generator model.

Research objectives:

- Develop a unique linear generator system in OpenModelica and contribute to its library.
- Develop an electrical test case network representative of an industrial distribution network.
- Analyse the developed generator in various use cases and scenarios to affirm increased energy efficiency and cost savings as a result.

Industry partner: Synext

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Modelling and simulation of ESS in PowerFactory for frequency stability studies

Scope: This thesis will focus on developing a simulation model in PowerFactory for control and integration of ESS (Energy Storage System) at the system level of multi area power systems.

Problem definition: Reduced inertia as a consequent of global Integration of power electronic based components, is known as one of the main important challenges of future power grids. ESS at the large scale for the grid application has a great potential to play a key role in the future, especially for providing flexibility to the system and participating in frequency response ancillary services. Incorporating a proper ESS model and control to improve dynamic response of the system is the main focus of this study.

Methodology: You will perform a proper ESS model (super capacitors or batteries) for transmission level in PowerFactory. Performing control and analysis of the ESS for improving the frequency response after a contingency on one test system (like the Great Britain, GB, test model) is the main task of this project. Good knowledge in PowerFactory modeling and programming for control will be essential for this project.

Research objectives:
- Literature review and State of the Art (SOA) on the subject.
- Modelling of ESS in PowerFactory for frequency control scheme and of one multi area test power system.
- Proposing a control methodology for ESS and dynamic improvement of the system frequency response.

Industry partner: No

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High level coordination of HVDC links in multi-area interconnected systems

**Scope:** This thesis will focus on developing a simulation model in DIgSILENT Powerfactory for control and coordination HVDC (High Voltage Direct Current) links at the system level of multi area interconnected systems.

**Problem definition:** Considering the current trends of research for massive integration power electronic based component into the grid, like European supergrid, several HVDC links will appear between the areas for interconnecting different regions or for transferring the power over a very long distance. This issue will bring different challenges especially in terms of coordination and proper control of HVDC links at the system level. The main focus in this proposal will be given to high-level control and coordination of HVDC links, mainly in the scheme of AGC (Automatic Generation Control) operation, to deal with proper damping of oscillations and frequency response improvement.

**Methodology:** You will perform a proper supervisory control system for coordination of VSC stations of HVDC links with all different synchronous generators (the ones participating on secondary frequency response) in one interconnected test systems. The used platform for this task will be DIgSILENT Powerfactory software. Small signal analysis with eigenvalues, (to show the damping effects of DC link) mainly in the scheme of AGC interconnected system with HVDC will be part of your task as well.

**Research objectives:**
- Literature review and State of the Art (SOA) on the subject.
- Modelling of a supervisory controller for frequency control scheme and HVDC coordination in PowerFactory.
- Developing a tuning procedure for the gains of the controller using Python scripts.

**Industry partner:** No

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A MATLAB toolbox for area identification in power systems

Scope: This thesis project is about the development of a power system area identification toolbox for the use in the industry (by TSOs). Area identification in power systems is a relevant topic, as well defined control areas enhance the performance of many existing and prospective area-based control schemes (e.g., load frequency control or secondary voltage control).

Problem definition: The toolbox should include several area identification algorithms implemented in MATLAB and an interface between these functions and PSS/E, the leading power system simulation software which is widely used in industry. After completing the toolbox and the interface, various case studies on relevant network models in PSS/E should be designed and conducted to verify the developed functionalities and their impact on power system.

Methodology: You will start with some existing code to couple MATLAB and PSS/E, as well with several implemented area identification algorithms in MATLAB. At first, the toolbox structure should be defined. Next, the MATLAB to PSS/E interface and the area identification algorithms should be adjusted and augmented in accordance with the specified toolbox structure. Finally, the case studies should be performed on several test networks to validate the toolbox and the algorithms.

Thesis objectives:

- Study area identification and area-based control of power systems.
- Create a MATLAB-PSS/E toolbox that makes several area identification algorithms better usable by professionals from industry (this requires coding in MATLAB and Python).
- Evaluate the toolbox by performing case studies on several power system models.

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Analysis and Design of a Dynamic Crowbar Protection to Enhance the Fault Ride through Capability in Wind Turbines Type 3

Scope: This thesis project will focus on test the actual crowbar protection in a real time simulator and develop crowbar scheme in order to effectively connect and reconnect the Double Feed Induction Generator to the grid.

Problem definition: Currently, the ability of low-voltage ride-through (LVRT) is one of the requirements established in grid codes in order to connect wind farms to power grids. In wind turbines with DFIG is difficult to achieve LVRT for its weak ability to withstand grid voltage disturbances. In order to keep DFIG connecting to power grid during faults, is commonly used, a rotor side crowbar protection. This is a simple but effective method against surge current caused by sudden dip of grid voltage during LVRT periods. Several strategies have been implemented for the use and design of crowbar protections. Most of them are based on specific types of faults and sceneries of the grid. In this sense an active control crowbar strategy is necessary to overcome most of the grid sceneries.

Methodology: You will thoroughly understand the behavior of the DFIG wind turbine and will implement a model in RSCAD. The model must include grid code specification as well positive and negative sequences control. Classical crowbar strategies will be implemented to understand the influence of the different strategies in the DFIG LVRT. A dynamic crowbar strategy will be develop to enhance the fault ride through capability and increase the power quality of the DFIG.

Research objectives:

- Develop the DFIG wind turbine model in RSCAD including grid code different
- Test the actual crowbar schemes trough different sceneries
- Propose a new scheme for a smooched crowbar disconnection/reconnection.

Industry partner: No

Contact details:

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Harmonic Analysis of Ferro Resonance Phenomenon by the Modified Dynamic Harmonic Domain

Scope: This thesis project will focus on the ferroresonance phenomenon analysis by the Modified Dynamic Harmonic Domain. The phenomenon will be studied in detail in power transformers and a system to reduce the phenomena will be developed.

Problem definition: Ferroresonance usually results in overvoltages and/or high current spikes that may subject system devices to dielectric and thermal stresses resulting in failure or inaccuracy behaviors. Also, protective relays that measure these quantities are subject to incorrect operations causing unwanted outages. Ferroresonance is a widely studied phenomenon in the power system, but due to its complexity it is not well understood.

Given the right conditions it can be cataloged in: Fundamental Mode, Sub-harmonic Mode, Quasi-periodic Mode, and Chaotic Mode.

Methodology: The Modified Dynamic Harmonic Domain (MDHD) is a powerful methodology that consists on representing a time-varying quantity by the discrete Fourier transform (DFT) whose coefficients are allowed to vary slowly within a time span. The DFT permits to sampling a frequency domain signal with arbitrary frequency rate, thus allowing interharmonics, subharmonics and harmonics to be handled within the transient analysis. Doing a correct use of the MDHD technique is expected to have a clear understanding of the phenomenon given the opportunity to analyze, prevent and suppress effectively the phenomenon of Ferroresonance.

As a plus the technique is potentially used in real-time simulation and hardware in the loop analysis.

Research objectives:
- Full understanding and application of the Modified Dynamic Harmonic Domain.
- Ferroresonance evaluation and characterization in Transformers.
- Dynamic control to reduce the Ferroresonance phenomenon based on frequency and damping impedance with a harmonic and/or interharmonic selection.

Industry partner: No

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High Impedance Fault Detection and Identification in Distribution Systems

**Scope:** This thesis project will focus on developing a new detection method for high impedance faults in distributed systems. Hardware in the loop (HiL) with relays from different vendors will be tested in a system with different scenarios including capacitor switching, synchronous generator switching, unbalanced load condition, DG switching as well as faults with and without DG will the performance of the relays will be compared against the proposed detection method.

**Problem definition:** High impedance fault (HIF) is hard to detect owing to their relatively small magnitude compared to normal currents. When an overhead power line loses its support, fall on a poor conductive surface or substance, a high Impedance Fault results. As the fault current is very small during it becomes very difficult to be sensed by over current relay.

**Methodology:** You will fully understand the fault detection methods for high impedance faults. Then a proposed identification method will be simulate in real time. The method will be tested in a system in different scenarios including distributed generators. The behavior of the proposed method will be tested against real relays in a HiL tests.

**Research objectives:**

- Develop a distributed system in real time
- Develop and implement in real time a new detection method for high impedance faults
- Compare the results with relays different vendors in a HiL test

**Industry partner:** No

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Probabilistic assessment of damping control methods in power systems dominated by power electronic interfaced renewable generation


Problem definition: The progressive phase out of conventional power plants with synchronous generators entails the loss of big sources of damping for low frequency electromechanical oscillations. In addition, the variability of the operating conditions introduced by the stochastic behavior of the non-synchronous and power electronic interfaced renewable energy based power plants affects the effectiveness of damping controllers.

Methodology: You will perform a probabilistic assessment of the oscillatory stability of the Great Britain System in a configuration corresponding to the year 2035 (70% power share from RES). Observability and controllability indicators will be defined for PMU signals and their variability will be studied to elucidate the most attractive loops for supplementary damping control at wind power plants. Finally, you’ll compare two state-of-the-art structures for damping control.

Research objectives:

- Literature review on probabilistic stability assessment, observability and controllability indicators, and damping controllers.
- Modelling of the damping controllers for wind power plant in PowerFactory for RMS simulations.
- Develop of scripts in Python for probabilistic stability assessment and automatic calculation of observability and controllability indices.
- Application of the mean-variance mapping optimization for tuning of the damping controllers.

Industry partner: No

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Placement of power system damping controllers based on normal form analysis

**Scope:** Study and development of scripts in Matlab/Python to apply the principles of normal form analysis to tackle the selection of the location of damping controllers, which shall be superimposed on conventional and power electronic interfaced generation to mitigate poorly damped low frequency oscillations.

**Problem definition:** The progressive phase out of conventional power plants with synchronous generators entails the loss of big sources inertia. Additionally, the loss of phase out of synchronous generators entails the loss if the main and major sources for damping control. In view of this, the likelihood of having poorly damped low frequency (e.g. < 1 Hz) electromechanical oscillations is expected to increase in systems with high penetration levels of power electronic interfaced generation (e.g. wind, solar).

Furthermore, the variability of the operating conditions introduced by the stochastic behavior of the non-synchronous and power electronic interfaced renewable energy based power plants affects the effectiveness of the few remaining damping controllers. This situation can cause the system to have more than one low frequency oscillatory mode.

**Methodology:** You conduct a comprehensive study on the theory behind normal form analysis, as well as the physical nature of low frequency electromechanical oscillations. Next, scripts in Matlab/Python shall be developed to perform the calculations needed from point of view of normal forms analysis. A case study, based on one of the existing IEEE benchmark systems for stability analysis, shall be built by using an open source tool, or alternatively, a commercial tool like DlgSILENT PowerFactory. The case study shall have both, conventional and power electronic interfaced generation. Your scrips shall allow to estimate oscillatory stability degree of the system as well as to quantify the interdependencies of different oscillatory modes w.r.t. different locations and design parameters of damping controllers. The approach based on normal form analysis will be validates based on comparisons with RMS simulations. Finally, you’ll contrast the information obtained based on normal form analysis against the information obtained by using the traditional approach based on (linear) state space model.

**Research objectives:**

- What are the limitations of current practice? Task: Literature review on oscillatory stability assessment, design of damping controllers, and normal form analysis.
• What are the characteristics of oscillatory modes in systems dominated by power electronic interfaced generation? Task: Modelling of the benchmark system for application of normal form analysis and RMS simulations.

• What are the main limitations/simplifications needed to implement with Matlab/Python? Task: Develop of scripts in Matlab/Python for application of normal form analysis for assessment oscillatory stability and prospective design of damping controllers.

• What are the limitations of normal form analysis based approach? Task: Sensitivity analysis for comparison with RMS simulations and classical approach based on linear state-space model.

Industry partner: No

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**Attack Library For Simulating Cyber Attacks in Network Simulator**

**Scope:** This thesis project will focus on developing a framework/library for the simulation of communication network attacks in the network simulator (e.g., OMNeT++).

**Problem definition:** A general and extensible attack library is needed to simulate various and heterogeneous attacks when conducting the research of cyber security in cyber-physical systems. This library aims to be a base reference framework to unify the simulation of attacks in network simulator. The library offers the rules that the community can follow in the attack development process.

**Methodology:** You will review the network simulators, attacks characteristics and related work in the development of attack library/framework. You will determine the architecture to build the attack library in the network simulator (OMNeT++ preferred). Then you will implement different types of attacks, i.e., confidentiality attacks (e.g., eavesdropping attacks), integrity attacks (e.g., false data injection), availability attacks (e.g., DoS attacks), or even a combination of them. Finally, you will show illustrative cases in simulating attacks using the developed library.

**Research objectives:**

- Explore the attack simulation methods in the network simulator;
- Build the attack library by providing the tools and rules to simulate various attacks;
- Implement different types of attacks using the developed attack library in the network simulator to show the generality and extensibility of the library.

**Industry partner:** No

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Real-time simulator for cyber-security of power systems

**Scope:** This thesis project focuses on developing a simulator for investigating cyber-security of smart grids. Such simulator will give an indication if a smart grid is secure under various cyber-attacks.

**Problem definition:** The simulator should model a power system in sufficient level of details to represent the impact on the grid (for example, opening and closing of circuit breakers in response to attack). Real-Time Digital Simulator (RTDS) can be used for this purpose. In addition to the power system model, the simulator should include a model of the communication system. The communication system should allow for attackers to perform attacks and for the system operators to defend the system.

**Methodology:** You will determine the best communication model and architecture that should be used together with the grid model. You will then proceed to couple simulators. You will create simple examples of attacks in order to show the capabilities of the built environment (for example, denial of service attack). Finally, you will determine the capabilities and limitations of your simulator.

**Research objectives:**

- Explore the available methods for coupling of simulation tools
- Create the co-simulation master code that synchronizes the exchange of messages between RTDS and the network simulator
- Evaluate the code on the attack case scenarios

**Cyber-security partner:** ENCS (European Network for Cyber Security)

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  Peter Palensky (p.palensky@tudelft.nl)
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Offshore wind plants with diode-rectifier offshore and VSC-HVDC onshore station

Scope: Investigation of the capability, possible limitations, and solutions to ensure robust steady state and dynamic performance of a far offshore wind power plant with a MMC-HVDC onshore station and diode rectifier based offshore station

Problem definition: The diode rectifier HVDC scheme has been recently proposed by a major HVDC vendor as a cost effective option (with even a 30% cost reduction) for the grid connection of the offshore wind plants. This scheme, uses an MMC-HVDC onshore station and diode rectifier based offshore station. Since, the diode rectifier is a passive component, a different approach is needed for the offshore wind turbines (grid forming capability).

Methodology: You will determine the best way to couple simulators from a power system modelling point of view. You will then research the characteristics of future power systems (e.g., low inertia, high penetration of renewable generation, etc.) and model a scenario to test the co-simulation. Finally, you will determine the capabilities and limitations of your co-simulation solution.

Research objectives:

- Review and definition of technical specifications for grid forming the wind turbines and the offshore wind power plant.
- Modelling of the wind power plant in PowerFactory for EMT simulations.
- Develop a hierarchical control scheme based on optimal load flow to enable online optimal reactive power management.
- Perform sensitivity analysis for the system dynamic performance under different disturbances

Industry partner: No

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- External supervisor: Mario Ndreko (mario.ndreko@tennet.eu)
A tool for testing grid code compliance of DFIG wind turbines

**Scope:** This thesis project develops a tool for automated testing of grid code compliance of DFIG turbines. A particular attention is given to the fault-ride-through requirement.

**Problem definition:** More and more wind energy is being added to the grid. Each new wind power plant must satisfy the grid code requirements which primarily guarantee that it will operate safely without endangering the rest of the system. The process of complying with grid codes could be aided by creating an automated tool to support the engineers in their studies. A candidate tool is already available at IEPG.

**Methodology:** You will analyze different grid code requirements and based on those develop the requirements for the tool. You will then research different possibilities to develop the candidate tool into a fully functional tool for grid code compliance studies. Finally, you will evaluate the tool for a case scenario of your own choice.

**Research objectives:**

- Analyze different grid code requirements
- Create a tool that can be used by engineers to test DFIG turbines for grid code compliance
- Test the tool on a case scenario

**Industry partner:** No

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Advanced communication networks for automatic generation control

**Scope:** This thesis project evaluates prototypes of different communication network configurations for automatic generation control (AGC) and analyses the impact of latencies on the performance of AGC.

**Problem definition:** The demand for electricity in power systems is constantly changing. AGC ensures that power balance is kept at all times. This control method requires frequent communication between generator units and the control center. In this project, the impact of latency and packet loss on AGC in case of different communication topologies will be evaluated.

**Methodology:** You will research different possibilities for network configuration topologies and protocols including more unconventional options (such as zigbee, etc.). Then, you will create a simulation environment which can be easily reconfigured to support variations in communication network topologies. You will then implement the AGC control algorithm and analyze the impact of latencies, packet loss, communication jams, etc.

**Research objectives:**
- Explore different communication network topologies
- Create the simulation environment that combines power system simulation and network simulation and implement AGC
- Evaluate the impact of latencies, packet loss, communication jams.

**Industry partner:** No

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Automated Distance Relay Settings Adequacy After the Network Topology Changes

Description: The focus of this study is to investigate the adequacy of the network relay settings for a new (evolving) network topology and identify the consequent vulnerable relays at selected locations in the transmission system. The proposed automated approach for adequacy checking of distance relay settings is able to improve the transmission system operators actions by providing them with a decision making tool to assess the adequacy of distance settings for an evolving network topology, especially the long-term ones, so that a proper action can be taken either before or after the topology change as needed. For example, in the scenario that the operator is provided with a list of switching actions for corrective purposes, e.g. load shedding or cost reduction, he/she is able to assess the switching candidates in regards to their impact on the protection security and dependability when selecting the best option. If the topology has already changed due to maintenance purposes or cascading tripping as a consequence of relay mal-operation, the operator could assess the protection security and dependability for the current topology and take proper action.

Research objectives:

- The concept of distance of impact need to be developed.
- The results from the European Network of Transmission System Operators(ENTSO) that demonstrate the effectiveness and robustness of the approach in realistic user setting.
- The results of parallelization using supercomputing facilities.
- Discussion of how the computational burden can be reduced for implementation on real sized systems.

Industry partner: No

Contact details:
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Integration of TU Delft Smart Grid lab with other EU research labs

Scope: You will create state-of-the-art interfaces and supporting software infrastructure to connect the smart grid lab of TU Delft with the smart grid labs of other European universities and research infrastructures.

Problem definition: The interfaces and the supporting software infrastructure should operate at the TU Delft premises while exchanging critical information with remotely located institutions (e.g. University of Stathclyde, UK & Ricera sul Sistema Energetico, Italy). The interconnection of the labs should be done using the innovative JaNDER (Joint Test Facility For Smart Energy Networks with Distributed Energy Resources) specification and software tools.

JaNDER is a software architecture specification, supported by open source components, for the exchange of information (measurements, control signals, laboratory asset descriptions) between labs by using a secure internet connection. The use of JaNDER allows the execution of joint experiments and tests between geographically distributed laboratories across Europe.

Methodology: You will determine the best way to couple the lab software and hardware with other similar tools in other labs using the JaNDER architecture. You will investigate and set up the interfaces accordingly. You will validate the functioning of these interfaces with respect to a smart grid application defined within the project. Finally, you will discuss the opportunities for further improvement based on your experience. Knowledge of working with Linux systems or high enthusiasm for learning to work with this platform are desirable but not necessary.

Industry partner: This work is performed as part of the European project, ERIGrid, (www.erigrid.eu)

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** Improved Grid Reliability by Fault Anticipation Methods 

**Scope:** This thesis project will focus on developing algorithm which will utilize machine learning to plan and communicate corrective actions once a disturbance is detected in the power grid.

**Problem definition:** The disturbances in the grid can be identified based on the fault signatures which can cause massive power outages in the long term. 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:** You will determine the best way to use machine learning to plan and communicate the corrective actions such that the effect of any disturbance on the grid is minimized. You will implement the machine learning algorithm and perform simulations in one of the common power system tools (PowerFactory, RSCAD, etc.). Finally, you will determine the conditions for (un)successful operation of your algorithm.

**Research objectives:**

- Devise a particular set of corrective actions that are to be applied when instability is anticipated.
- Identify different ways to utilize the existing grid infrastructure to communicate the corrective actions.
- Utilize machine learning to obtain deeper understanding if/when the instability will occur.
- Test the developed algorithms within one of the common power system simulation tools.

**Keywords:** Power system, distribution system, power system reliability, fault anticipation, waveform analysis, real-time testing.

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Modeling of Decentralized Industrial Heat Networks

**Scope**: This thesis will focus on the modeling of industrial processes and their integration into heat networks. Beyond the integration on the physical level, the coordination of processes to optimize the usage of heat will be of interest.

**Problem definition**: Most industrial applications demand large amounts of heat during warm up and supply waste heat during operations. However, given the limited range over which heat can be transported and the variability of temperature levels waste heat is often merely used for district heating. Integrating energy intensive processes in a smart heat grid, creates the opportunity to utilize waste heat more efficiently. High temperature waste heat of one process can be used for the warm up of another.

Unlike district heating systems for residential neighborhoods there will not be one centralized producer and several distributed consumers. Rather every consumer at one time will also be a producer at another time. To coordinate production and consumption of heat bilateral agreements will have to be found between individual actors.

**Research objectives**:

- Develop industrial processes heat systems and a heat network in Openmodelica
- Integrating the supply and demand of heat from the industrial processes into the heat network
- Implementation of simple agent based trading; interfaced with the model through python

**Industry partner**: No

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Using distributed flexible loads to relieve network constraints

Scope: This thesis project investigates how small, flexible loads can collectively provide a dependable congestion management service.

Problem definition: Network infrastructure investment is driven by the need to cope with credible outages at times of peak load. As a result, there is a strong case to use flexible loads (refrigerators, dishwashers, etc.) to flatten demand peaks. But can we really rely on the response of unreliable small loads to manage grid security – especially in distribution networks where the numbers are small?

Methodology: Quantifying the benefits of controllable flexible loads requires a statistical approach: computing the probability that the response is sufficient. The problem must also be framed appropriately: the uncertain response of flexible loads should not be compared to a known state, but to an equally unknown behavior of the loads without a control signal. You will study aggregations of flexible loads and compute their effectiveness in avoiding network constraints in comparison with other solutions. You should be familiar with elementary probability theory. Results will be obtained using a mixture of theory and simulations (programming required, preferably in Python).

Research objectives:

- Define and study a study model on/off model (e.g. refrigerators)
- Quantify the contribution of distributed load relative to other solutions
- Depending on your skills and interests:
  - Data: analyze experimental consumer demand response data
  - Theory: develop a general ‘equivalent capacity’ framework to value flexible loads
  - Simulation: model and simulate response of complex loads (e.g. households)

Industry partner: No

Contact details:
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In post from January 1st 2018, but available for discussion now.
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:** Generation adequacy studies are based on probabilistic models of generation and load, which are analyzed using numerical or simulation methods. You will implement adequacy assessment methods (Python preferred), and determine the ‘capacity value’ of network assets in a number of common metrics (ELCC, EFC, etc.). You will define a test system and investigate whether the policy proposals would result in a fair allocation of payments to generation and interconnection owners.

**Research objectives:**

- Compare approaches and proposals for cross-border participation in capacity mechanisms
- Explore suitable mathematical and simulation methods for defining and computing capacity value derived from interconnectors and remote generators
- Perform a detailed analysis for one or more test systems, and determine whether proposals would facilitate or interfere with a fair allocation of capacity payments.

**Industry partner:** No

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In post from January 1st 2018, but available for discussion now.
Transient Models for Modular FACTS Devices

**Scope:** This thesis project focuses on developing and evaluating transient stability models for Modular Flexible AC Transmission System (M-FACTS) devices.

**Problem definition:** M-FACTS is a new technology that is increasing its presence in the grid. These devices are connected in series with the line and can be used to route the power through the network. Due to their novelty, the most common power system analysis and design tools (such as PowerFactory, RSCAD, etc.) are still lacking appropriate models for M-FACTS representation in transient stability studies. This project will look to develop such models.

**Methodology:** You will model the operation of M-FACTS devices for transient stability studies in various power system tools using available components and corresponding scripting languages. Then you will validate the developed models against the available models of conventional FACTS devices. Finally, you will perform the case studies to show the appropriateness of the developed models.

**Research objectives:**

- Develop models for representation of M-FACTS in transient stability studies
- Implement the models in one or more common power system tools (PowerFactory, RSCAD, PSSE, PSCAD)
- Validate the models against the models of conventional FACTS devices

**Industry partner:** Smart Wires

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Value of the Modular FACTS devices for managing congestion and improving reliability

Scope: This thesis project focuses on assessing reliability and of the grid with Modular Flexible AC Transmission System (M-FACTS) devices.

Problem definition: M-FACTS devices are used to route the power through the electricity network which is extremely important if the reliability of the grid is endangered. In such circumstances, M-FACTS can provide alternative paths for electricity to flow. This project will look to determine the value of M-FACTS to the system operator for managing congestion and improving reliability.

Methodology: You will investigate the congestion management capabilities of M-FACTS devices under different grid evolution scenarios (current penetration of renewables, meeting ambitious renewable targets, etc.). You will model the scenarios and investigate how different decisions on M-FACTS deployment impact the reliability of the grid over time.

Research objectives:

- Develop models of assessing the value of M-FACTS to the system operator
- Create case scenarios that shows the effect of M-FACTS on congestion management
- Discuss further opportunities for improving reliability with M-FACTS

Industry partner: Smart Wires

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IEC 61850 based system wide protection and emergency control against voltage instability

Description: Owing to the advantages on interoperability and integration, the communication standard IEC 61850 have been considered and adopted recently from local information exchanging inside one power substation to substation wide information sharing. Moreover, a reliable and efficient wide area measurement system (WAMS) is significant for the implementation of system wide protection and emergency control schemes (SWPECS). Thus in this regard, the IEC 61850 based WAMS could be very beneficial.

Research objectives: In this master project, the IEC 61850 based SWPECS is developed to prevent voltage instability induced cascading events. The objective of the project is to provide a primary investigation and analysis on the application of IEC 61850 based WAMS for SWPECS against voltage instability. Two work tasks will be included in this project:

1. Related literature reviewing, a simple transmission power network modelling, a voltage instability case simulating and simple system wide protection scheme analyzing
   In this task, the related literature and a simple transmission power network model will be provided. Voltage instability induced system wide disturbance, related stability criteria and protective control measures (generator rescheduling, tap changer regulating and load shedding, etc) should be focused and analysed. The simulation of the network model and related control models will be based on PSCAD or RSCAD.

2. Hardware In the Loop (HIL) relay testing based on RTDS, IEC 61850 and practical relays
   In this task, HIL real time blackout simulation and relay testing will be conducted in the lab. IEC 61850 network interface developing and evaluating will be focused.

This project deals with a hot topic in power system protection area, and it will be demonstrated in HIL digital way in the our powerful protection lab. Based on the progress of this project, data quality based cyber security issues could be further investigated if tasks are going fast and well.

Industry partner: No

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- Promotor: Marjan Popov (m.popov@tudelft.nl)
An adaptive protection scheme for active distribution power networks with renewable energy resources

Description: With the development and utilization of renewable energy resources (RES) in distribution power networks, the distribution power system becomes more active. But the operation conditions of distribution power networks become more complicated and unpredictable, both in Netherlands and the rest of the world. This trend brings a big challenge in the protection systems of those modern distribution networks with integration of RES. The main issue is how to efficiently regulate and adapt the protection systems of distribution networks to the variable system operation conditions caused by the integration of RES.

Research objectives: The objective of this master project is to determine an adaptive and suitable protection scheme to keep a secure and reliable operation for the active distribution power network with RES. Two work tasks will be included in this project:

1. Related literature reviewing and a simple active distribution network modelling
   In this task, the related literature and basic active distribution network will be provided. The RES modelling (PMSG based wind generator), short circuit analysis and basic protection theories (current, voltage and impedance protection) should be focused. The simulation of the network model will be based on PSCAD.

2. Case study and protection testing based on relay tester and practical relays in the lab
   In this task, diverse operation conditions of distribution networks with RES during faults will be simulated in PSCAD, while the related results will be stored as COMTRADE files. In the lab, OMICRON relay tester will be adopted to replay this simulation scenarios and testing the practical impedance relays with preconfigured adaptive setting groups.

This project deals with a hot topic in power system protection area, and provide hands-on practices in the our powerful protection lab. Based on the progress of this project, hardware-in-the-loop with RTDS could be expected if tasks are going fast and well.

Industry partner: No

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