# Topics of MSc theses in the field of power systems

Pierre Henneaux – April 28, 2019

## Introduction

Topics of MSc theses in the field of power systems are grouped in different categories:

- Probabilistic methods applied to power systems
- Numerical analysis and power systems
- Electricity markets
- Protection systems
- In collaboration with Tractebel
- In collaboration with Elia
- Other topics

## Probabilistic methods applied to power systems

### Resilience assessment of power systems

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Power systems were traditionally organized in a centralized way: generation was concentrated in large power plants, transmission systems were in charge of transferring the energy from power plants to load centers, and distribution systems supplied purely passive consumers. This organization has started to change dramatically with the massive introduction of distributed (renewable) generating units and the emergence of active consumers through demand response programs. In order to monitor and control those distributed energy resources, to balance the generation and the load and keep the stability of the electrical system, the importance of ICT is also rising in the grid. Centralized power systems are thus becoming digital and decentralized power systems, with the support of a reinforced transmission power system to balance different more autonomous geographical areas. A significant advantage of this new structure is the potential increase of its resilience to disasters such as tornadoes, earthquakes, snow storms... Indeed, transmission and distribution lines are very vulnerable to these kinds of disasters. Resorting more largely to distributed generators opens the way to a quick, potentially partial, resupply of power to consumers that are near those energy sources. The MSc thesis will aim at developing a methodology to quantify, in a probabilistic way, the resilience of a smart power system, and will aim at proposing strategies to improve the resilience.

### Application of SDDP to assess the need of seasonal storage in decarbonized systems

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A fundamental ingredient to achieve a decarbonized European energy system at the horizon 2050 will be seasonal storage. However, because it is not possible to perfectly forecast future weather conditions, impacting renewable energy sources and the electricity demand, an optimal management of seasonal storage to ensure the security of supply must rely on stochastic optimization. A specific method, called Stochastic Dynamic Dual Programming (SDDP), was developed in the nineties to solve stochastic optimization problems in order to optimally manage hydro dams in Brazil. The objective of this MSc thesis will be the adaptation of that method to assess the need of seasonal storage in decarbonized systems, such as the European one in 2050.

### Probabilistic dynamic security assessment of transmission systems

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The security of a power system is its ability to withstand disturbances arising from faults and unscheduled removal of bulk power supply equipment without further loss of facilities or cascading outages. The security analysis of the transmission grid requires both deterministic and probabilistic approaches. The "N-1 security rule" is the deterministic approach classically used by Transmission System Operators for network planning and real-time operation. This rule relies on the assumption that an electrical grid will be secure if it stays electrically stable after any single failure among the N initially active network elements. Probabilistic studies can then complement this deterministic approach to assess the residual risk of cascading outages leading to an important amount of loss of load and to identify corresponding accidental scenarios. The main goal of this MSc thesis will be the development of a dynamic probabilistic risk assessment of cascading outages, able to consider the power system dynamics (including the action of protection systems) and, hence, dynamic cascading mechanisms.

## Numerical analysis and power systems

### Hybrid EMT/RMS simulation of power systems

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Traditionally, power systems were based on synchronous generators, with typical reaction times much slower than electromagnetic phenomena. It allowed a decoupled analysis of electromagnetic transients and of electromechanical transients. The analysis of large-scale phenomena in power systems (e.g. angular stability) was based purely on the simulation of electromechanical transients. However, power electronics react much faster than synchronous generators and could entail a strong coupling between the two kinds of transients. Security and stability analyses of future power systems with a large share of power electronics (HVDC, inverter-based generation) will thus require consideration of both kinds of transients. Numerical simulation of electromagnetic transients requires small time steps, while electromechanical transients necessitate long time periods. With current simulation techniques, it would be intractable to try to simulate transmission power systems with a proper consideration of electromagnetic transients and of electromechanical transients. The industry currently makes use of co-simulation: two different simulation tools (e.g. PSS/E and PSCAD) are coupled. This solution is not fully satisfactory (no guarantee of convergence, difficult to manage). This MSc thesis will thus explore various numerical techniques (e.g. adaptive time step techniques with geographical decomposition (use of small-time steps where it is needed), approximation techniques, parallelization techniques) for hybrid EMT/RMS simulation of power systems.

### Multigrid methods for the simulation of power systems

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Multigrid methods are a class of numerical algorithms used to solve linear systems. They are usually efficient for very large systems. This MSc thesis will explore the performances of multigrid methods to simulate power systems, in both a static fashion (power flow equations) and in a dynamic fashion.

### Relaxation and decomposition techniques for stochastic optimization

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Power systems must be operated in the most economical way while ensuring the desired level of reliability. A fundamental tool allowing transmission system operators to meet that objective is the so-called Optimal Power Flow (OPF). It aims at minimizing a given objective function (e.g. operating cost) while respecting operational requirements of the power system. However, standard OPF algorithms make use only of a “best estimate” for the forecast for future power system conditions. They are then not adapted to future power systems dominated by renewable energy sources, because they are not able to consider forecast errors. The consideration of forecast errors in OPF algorithms leads to stochastic optimization problems. These problems are challenging to solve numerically, due to non-linearities, non-convexities and their large dimensions. This MSc thesis will explore relaxation and decomposition techniques to solve stochastic OPF problems.

## Electricity markets

### Optimal definition of bidding zones

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The European internal electricity market is organized on a zonal basis. Europe is divided into different bidding zones, that are geographical areas within which market participants can exchange energy without transmission capacity allocation (i.e. each bidding zone is implicitly considered as a “copper plate” from the market point of view). On the contrary, the exchange of energy between different bidding zones require transmission capacity allocation. Bidding zones are currently mainly organized based on national borders. It is not optimal. This MSc thesis will aim at proposing a methodology to define bidding zones in an optimal way for a zonal market.

### Impact of uncertainty on a flow-based market efficiency

*Contact person: P. Henneaux (pierre.henneaux@ulb.ac.be)*

The European internal electricity market is organized on a zonal basis. Europe is divided into different bidding zones, that are geographical areas within which market participants can exchange energy without transmission capacity allocation (i.e. each bidding zone is implicitly considered as a “copper plate” from the market point of view). On the contrary, the exchange of energy between different bidding zones require transmission capacity allocation. The preferred approach to calculate and allocate transmission capacity to the electricity market is a so-called “flow-based approach”. This flow-based approach tries to model more explicitly power flow constraints on transmission elements compared to the former coordinated net transfer capacity approach. However, the modeling of the flow-based electricity market to be able to simulate its behavior is not obvious. Such a modeling can be of paramount importance to assess the impact of various measures such as the development of new transmission lines, the redefinition of new bidding zones, etc. A first prototype able to compute the flow-based domain of a given network, to simulate a simplified market clearing process associated to that flow-based domain, and to simulate the redispatch within each bidding zone is under development in the framework of an ongoing MSc thesis. However, the uncertainty on renewable energy sources will be neglected in that prototype. The purpose of this Master thesis will thus be to enrich the prototype by including forecast errors. The enriched prototype will be applied to a test system such as the IEEE RTS to demonstrate its functionalities.

## Protection systems

### Ultra-high-speed line protection: algorithm performances evaluation for the distance element with a CCVT reducer and a series-compensated line

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This project is part of a contract between SIEMENS AG in Berlin and the BEAMS-Energy department of the Ecole polytechnique de Bruxelles. The goal is to develop ultra-high-speed protection relay algorithms. The target is to reach a tripping time of 4ms.  During the history of protection relays, continuous attempts have tried to decrease the algorithms time response while considering sensitivity, dependability, security and selectivity. The main difficulty will be to prove that these algorithms will reach the performances of security and selectivity for the “normal” cases, as defined in the standards, but will also be safe if the electrical conditions do not allow being secure and selective. The studied algorithms in the framework of this MSc thesis will focus on two points: (i) the impact of a CCVT reducer on the ultra-fast time-domain algorithm for the distance protection, and (ii) the adaptation of the distance algorithm for a series-compensated lines. The first step of the MSc thesis will be to study deeply the ultra-fast distance element algorithm implemented by Neriton Hoxha. The main objective of this MSc thesis will then be the improvement and/or the adaption of the existing algorithm for a high-voltage network using a CCVT reducer and a series-compensated line.

### Ultra-high-speed line protection: implementation of a fast fault detection algorithm

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## In collaboration with Tractebel

### Frequency reserves in RES-dominated power systems

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When the share of variable Renewable Energy Sources (RES) in a power system is important, it is challenging to maintain the frequency stability for two main reasons: the inertia is low, and the load/generation balance is constantly impacted by fluctuations of RES. The sizing of frequency reserves and the requirements on the deployment time must then rely on both probabilistic and dynamic approaches. This MSc thesis will aim at providing a methodology to size frequency reserves in RES-dominated power systems, and to allocate the reserves between the different load-frequency control areas for multi-area power systems.

### Estimation of the contribution to primary frequency control in a longitudinal system subject to large amplitude interarea oscillations

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Upon loss infeed the various units contributing to the spinning reserve release according to their prime mover and governor speed control characteristics. The assessment of the compliancy to a given criteria based on active power measurement might require filtering the response to correctly assess the increase of the mechanical power at the output of the virtual shaft composed by all the units in a subsystem. The MSc thesis will consist in developing filtering techniques and/or an estimate of the mechanical power. The data will be generated on a simplified power system model and the developed estimates compared to the mechanical power.

### Automatic identification of the share of rotating machines (motors) behind a distribution feeder based on PMU recordings

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Air conditioning devices impact negatively the power system (voltage) stability. In power systems dominated by these devices (e.g. power systems in Golf countries), it is crucial to use load models reflecting accurately the share of rotating machines (mainly induction motors) often located within distribution systems (in the low voltage part, so not directly observable). Thanks to recording devices installed in the power system, more and more measurements (U/I/P/Q) of the behavior of the system at the medium voltage level are available. Because the system is permanently subjected to small disturbances, the objective of the MSc thesis will be the identification of the share of motors based on a linearized model of the system composed by a distribution feeder and using optimization methods. For that purpose, the MSc thesis will first aim at understanding the involved electrical phenomena and their modeling based on a simple example, will then develop the identification techniques based on data obtained through simulations (without measurement noise on one hand, and with artificial addition of noise on the other hand), and will finally apply these techniques on real measurements coming from countries with a large share of air conditioning.

## In collaboration with Elia

### Decision-making under uncertainties in grid development – optimization of grid reinforcement in the presence of a large amount of Distributed Generation (DG) units

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The amount of distributed energy resources (DER) has been increasing in the recent years, namely photovoltaic (PV) panels and wind turbines. These new resources are mainly considered as renewable energy resources (RES) but can include also combined heat and power (CHP) units, decentralized storage units, flexible and active loads… connected at both Low-Voltage and Medium-Voltage levels. These units affect directly the distribution system operator (DSO) operation and planning. However, the aggregated effect of DERs can also affect, and will affect more and more in the upcoming years, the transmission grid operation and planning. The deterministic approach classically used for the network planning calculations assumes that the data (annual power demand, annual power generation, power demand growth…) are known with a quite good certainty. RESs, such as wind turbines typically, behave rather differently from conventional generation facilities, since they are intermittent. RES generators introduce therefore uncertainties that cannot be disregarded. The maximum/minimum load conditions of the electrical system are no longer always the most critical cases to be studied, in order to ensure a secure grid operation. The application of strict deterministic criteria would strongly limit the amount of connectable generation to a given grid infrastructure. Furthermore, systematically reinforcing the network in order to absorb the last MWh produced by generators located in unfavorable areas is not efficient i.e. neither economically viable for the community nor acceptable from an environmental impact point of view. In order to increase the amount of DERs likely to be connected, an Active Network Management (ANM) scheme can be envisioned: if specific conditions of generation and load cause congestion on the grid, this congestion is solved by curtailing optimally the production of some units. At some point, however, the transmission system operator can decide to plan a grid reinforcement, in order to accommodate in the future a larger amount of DG units in a specific part of the grid. Such reinforcement takes 4 to 5 years to be carried out, given the heavy administration associated with such a process. In the meantime, the actual landscape of newly connected DG units to the corresponding part of the grid is likely to evolve in a non-fully known way. In a similar fashion, drops in the non-residential part of the load could be observed, entailing larger congestion risks than expected at the time the reinforcement had been decided. The present thesis will aim to develop a methodology for the optimization of such grid reinforcement in an unknown evolution of the characteristics of the electrical system.

### Battery storage for grid deferral

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Today, grid planning is mostly based on deterministic criteria. One of the best known criteria is the worst case N-1 principle which ensures the correct functioning of the system after the outage of any single element. In a situation where the flows on grid assets can be predicted with high certainty, this approach has proven its strength through its simplicity while still being able to capture sufficient information for good decision-making. More recently, the increasing share of variable and difficult-to-forecast electricity generation have led to a situation where the confidence level for electricity production forecasts is strongly reduced. This evolution, combined with the fact that the capacity factor and amount of time that renewables (PV, Wind, Hydro…) run at nominal output is often lower than conventional generation (Nuclear, coal...) has resulted in an increased risk of investing in an asset that is almost never used to its full capacity. Indeed, if the worst case only occurs in case an element is out (situation N-1) with the generation running at nominal capacity (often for a limited time and low probability), chances are that it would economically not make sense to make the investments. This begs the question whether or not it is necessary to invest in a grid that is capable of permanently functioning in worst case N-1, or if we should install temporary capacity in the form of storage that can handle the worst case for a limited but sufficiently long time. After a literature study the first step in the project is to select criteria that could be used to evaluate the economic and risk-based aspects needed for making such a decision. In a second step the algorithms to calculate these criteria should be selected and implemented for simplified cases. In a final step, the student is to test this strategy on an actual part of the electrical transmission grid, followed by a discussion of other aspects important in the decision-making process such as public acceptance and robustness. If sufficient time is left, proposals on how to evaluate these additional criteria are to be delivered. This project will be performed in collaboration with Elia System Operator

## Decision-making under uncertainties in grid development – impact of the experts' preferences and the value of lost load (VoLL) in the expert elicitation process

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To ensure the electrical transmission grid fulfills its function to satisfaction regular investments are to be made. To choose which investments are needed, it is important to detail the costs and benefits of the possible actions. For the electrical grid the benefits typically entail an increase in reliability and thus a reduced cost from losing load/generation during incidents. Typically, the cost associated to such an incident is evaluated by multiplying expected the amount of energy that has to be shed over the lifetime of the proposed grid by a fixed, universal value of lost load (VoLL). Reducing the effect of an incident to an amount of energy (MWh) however risks being a serious oversimplification of the actual consequences as it fails to accurately take several important aspects of an outage into account (type of load shed, location, time, duration, expected reliability, …). In addition, studies have shown that in practice experts do not evaluate the risk of an incident purely proportional to the probability of occurrence. A possible way to overcome these shortcomings and to more accurately quantify the costs experts give to specific incidents is the use of expert elicitation processes. Expert elicitation consists of interviewing experts in a structured fashion to elicit from them an educated guess of certain parameters and is often used in situations associated to rare events (nuclear safety, seismic hazards, …). The adaptation of this field of knowledge to the study of (possible) electrical incidents could greatly improve the grid development process. The main goal of this project is to create an improved model that can be used to evaluate the risks linked to incidents and by extension grid variants. To this end the state on the art on multidimensional definitions of risks and the use of expert elicitation processes are to be considered.

## Other topics

### Co-simulation of power systems and communication networks

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The need for more flexibility in power systems due to the increased penetration of renewable energy sources leads to a larger use of ICT technologies to control power systems (e.g. smart grids). However, delays can occur in ICT systems, and these systems are also not perfectly reliable. In particular, the use of IP-based or Ethernet-based systems will have an impact on the overall performance and reliability of the electrical network, in terms of delay, bandwidth, and real-time reaction of electrical protections. It will thus become more and more important to simulate in a coupled way power systems and ICT systems. This MSc thesis will explore the implementation of co-simulation techniques aiming at doing that, by coupling a simulator of power systems like Eurostag and a simulator of ICT systems like NS-3.

### Simulation of integrated energy systems

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The large-scale use of renewable and intermittent energy sources in the power system (wind, solar) entail a high need for flexibility. Indeed, the generation from renewable energy sources can change quickly while, at any time, the load and the generation must be balanced in the power system. If this flexibility is currently provided by classical thermal generators (mainly based on fossil fuels) and by storage (pumped-storage, and, on a smaller scale, battery storage), it could be also provided by other energy systems. For example, the low cost of heat storage provides an opportunity to shift electricity demand. It is thus expected that, in a near future, energy systems will be strongly integrated and inter-dependent. In that context, the purpose of this MSc thesis will be the development of a model to simulate the operation of integrated energy systems.

### Simulation of HVDC grids in planning studies

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Power systems are planned according to specific planning criteria, in order to ensure the desired level of reliability. The demonstration that the planned power system meets these planning criteria is usually performed by simulation. For example, the power system planner has to demonstrate that the system can withstand a fault followed by the disconnection of the faulty element while continuing to satisfy operational criteria and without load shedding (N-1 security criterion). As it is not possible to model in details large power systems in such simulations, different models with different levels of simplifications must be used by the power system planner to address the different phenomena and planning criteria. For AC grids, the different models that are relevant for the different phenomena are well known. This is not the case for HVDC grids. This MSc thesis will thus aim at progressing in the determination of simulations that must be performed and models that must be used to demonstrate that an HVDC grid complies with the required planning criteria.