TECHNICAL UNIVERSITY OF DENMARK
DEPARTMENT OF ELECTRICAL ENGINEERING
CENTRE FOR ELECTRIC POWER AND ENERGY
ENERGY ANALYTICS & MARKETS GROUP

Overview of available projects:

1. Synergies between electricity, gas and heat markets
2. Investment decision under uncertainty for power-to-gas technology
3. Co-optimization of energy and reserve markets
4. Multi-stage strategic investment in CCGT and wind power units via progressive hedging
5. Impact of unit commitment constraints on generation expansion decisions under wind uncertainty
6. Probabilistic forecasting of solar power generation at the distribution grid level
7. Distributed learning in renewable energy forecasting
8. The Renewable Energy Scenario Generation (RESGen) platform
9. Population games in electricity markets
10. Wind producers and honesty in stochastic energy markets
11. Calibrating operation models in electricity markets

NOTA: Other projects can be tailored to the students' specific skills and interests!

More information on the various activities in the group can be found on the DTU CEE youTube Channel: https://www.youtube.com/playlist?list=PLwKjKt8EU3S2w2T7duSMNCxaRymIMj07Z

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Synergies between electricity, gas and heat markets

Supervisors: Pierre Pinson, Christos Ordoudis, Lesia Mitridati
Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

Over the last years, high shares of renewables are integrated in the energy systems resulting in significant operational. Power generation from renewable energy sources is intermittent and hard to predict, especially in cases of wind and solar power. The penetration of renewable energy production in the total energy system will mainly increase through the electricity sector, which is currently undergoing exceptional changes. However, there is strong interaction among the various networks of the total energy system that can help in reaching higher shares of renewables and their more efficient use. The already existing infrastructures, such as power, natural gas, heat and storage systems are highly developed in European countries, as well as Denmark, though there are mainly operated in an uncoordinated manner. The operation of the energy system need to be revised towards a collaborative and optimally operated system in order to increase the overall efficiency.

In parallel, a significant increase has been noticed both in the natural gas share of the generation mix through gas-fired power plants (GFPPs) and in the utilization of combined head-and-power (CHP) plants to produce heat for the district heating network. Taking into account the coupling of the energy systems through these units and the introduction of heat and gas storage facilities results to the challenge of optimally operating the systems under the minimum cost. Various uncertainties need to be taken into account, such as wind power production, natural gas availability and heat demand. The increased power and heat generation from GFPPs and CHPs creates strong links between the electric power, natural gas and heat systems. GFPPs constitute a significant fraction of the natural gas demand, which affects the total gas consumption and the flows in the natural gas network. In addition, CHPs may also consume gas and need to meet the power and heat demand. Gas market prices and the type of contracts may affect the economic dispatch of the units in the electricity and heat market. For this reason, a combined operation of the three markets is important, as synergies exist and potential improvements need to be examined.

Objectives

In that context, the main objective of this M.Sc. project is to investigate synergies and ways of aligning the electricity, natural gas and heat markets in the scope of accomplishing an improved operation of the system.

Methodology

From the methodological point of view, the interdependency of electricity, gas and heat markets can be formulated as an optimization problem by including the constraints that compose the electricity, natural gas and heat models aiming at minimizing the total cost of operating the system. The link between the two markets via the GFPPs will be included in the model. Given time availability, renewable energy production, natural gas availability and heat demand uncertainty may be introduced in the model to examine how the scheduling of the units will be affected. The optimization models may be implemented in GAMS, Python or Matlab depending on the background of the successful candidate.

Expected results

The expected outcome includes relevant literature review, the formulation of the optimization problems and their implementations as well as the evaluation of the results.

Prerequisites

Power systems operation, sustainable energy, energy systems modelling, energy markets, basics of optimization

Investment decision under uncertainty for power-to-gas technology

Supervisors: Pierre Pinson, Stefanos Delikaraoglou, C. Ordoudis
Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context
Over the last years, the large scale integration of renewable energy sources, e.g., wind and solar power, has introduced new challenges in power system operation due to their intermittent and partially predictable generation. In the meantime, a significant increase has been noticed in the natural gas share of the generation mix. More specifically, the share in EU has almost tripled from 8% in 1990 to 23% in 2010. Moreover, power-to-gas (P2G) technology is becoming increasingly popular in recent years, allowing for large-scale energy storage and facilitating the integration of renewable energy sources.

Gas fired power plants (GFPPs) constitute a significant fraction of the natural gas demand, which affects the total gas consumption and the flows in the natural gas network. The increased power generation from these units creates a strong interdependence between the electric power and natural gas systems, which can be further reinforced by the utilization of P2G technology. This tighter coupling between these two elements of the energy system, promotes further the need for integrated operational approaches to increase the overall system efficiency. P2G technology can additionally help to bridge geographical distances at the gas system as the surplus of renewable production can be transformed to gas and stored at the optimal sites. For this reason, siting of these units is also of high importance.

The aim of the transmission system operator is to invest in P2G in order to optimize the long-term efficiency of the integrated energy system. For this reason, the optimal siting and sizing of P2G technology has to be investigated, taking into account both the electricity and gas networks. The objective is to minimize the total investment cost plus the operating cost of the system in the presence of the uncertain renewables' infeed.

Objectives
In that context, the main objective of this M.Sc. project is to investigate the investment decision of P2G technology under renewable energy uncertainty in order to increase the overall efficiency of operating the electricity and natural gas systems.

Methodology
From the methodological point of view, the investment problem can be formulated as a multi-stage stochastic programing problem aiming at minimizing the total investment and operational cost of the system. The optimization model should incorporate, on a reasonable level of detail, the technical constraints of both electricity and natural gas models. In addition, renewable energy uncertainty will be introduced in the model to examine how the investment decisions are affected. The optimization models may be implemented in GAMS, Python or Matlab depending on the background of the successful candidate.

Expected results
The expected outcome includes relevant literature review, the formulation of the optimization problems and their implementations, as well as the evaluation of the results.

Prerequisites
Power systems operation, sustainable energy, energy systems modeling, energy markets, basics of optimization

Co-optimization of energy and reserve markets

Supervisors: Pierre Pinson, Athanasios Papakonstantinou, Tiago Soares
Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context
Energy and reserves are two common products traded and cleared in the traditional electricity markets. The clearing of both products in the market can be done in two distinct ways, sequentially or simultaneously. Both ways of clearing are used in the electricity markets. However, the simultaneous clearing of energy and reserve was adopted in many electricity markets (for instance in the US), since it can be economically more efficient than the sequential approach, especially in power systems close to its own limits/capacity.

With the current proliferation of wind power in electricity markets, traditional methods for clearing the market products should be improved, since intermittent power production can decrease the system reliability and thereby, increasing the levels of reserve needs. Furthermore, wind turbine technology and wind farm control has been evolving in such way that they now allow wind power plants to provide additional products besides energy only. Thus, wind power producers are now willing to participate in the provision of reserve products in electricity markets. These changes in the electric power systems should be considered, for instance, by developing new methodologies for co-clearing the energy and reserve market and able to deal with uncertain energy production and provision of reserves in the system.

Objectives
In this scope, the main goal of this M.Sc. project is to develop a new model for co-clearing energy and reserve markets, accounting for the participation of wind power in both market floors.

Methodology
For modeling the proposed problem, optimization techniques can be used. Usually, the common problem of co-clearing the energy and reserve is modeled based on a deterministic approach. However, the inclusion of intermittent production requires the need of stochastic approaches to deal with the uncertainty in the system. This problem can most likely be modeled as a two-stage stochastic problem, where the first-stage is the co-clearing of the energy and reserve in the day-ahead market, while accounting for the realization of the uncertainty in the second stage. The model should be formulated in such way that allows the wind power producer to participate in both energy and reserve markets. The optimization models may be implemented in GAMS, Python or Matlab depending on the background of the successful candidate.

Expected results
The expected outcome of this project includes a literature review on the problem of co-clearing of energy and reserve market with wind power participation, as well as, the formulation of the optimization problem and its implementation. The resulting model can be compared to a benchmark consisting of a traditional market model for energy and reserves..

Prerequisites
Power systems operation, sustainable energy, energy markets, basics of optimization.

Multi-stage strategic investment in CCGTs and wind power units via progressive hedging

Supervisors: Pierre Pinson, Jalal Kazempour, Luis Baringo (UCLM, Spain), Antonio Conejo (The Ohio State University, US)

Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

One of the most complicated decisions that an electricity producer competing in a market has to make is to decide on its generation-capacity investments. Such a producer needs to decide on the technology, sizing, siting, and investment year of each generating unit to be built, with the purpose of maximizing its expected profit. Such decisions are comparatively more complex for a strategic producer that seeks to alter the market-clearing outcomes, i.e., clearing prices and quantities to its own benefit, through the following actions: i) strategically selected offering prices, ii) strategically selected offering quantities, and iii) strategically selected investment decisions. Note that the first two strategies correspond to short-term decisions, while the last one refers to long-term decisions. On one hand, the strategic producer faces diverse sources of uncertainty (e.g., rivals' actions, future investment costs, future load levels) that make its decision-making process complex. In addition, the maturity of non-dispatchable wind-power (WP) units make essential to consider them as investment options. However, the inherent uncertainty and variability of WP production bring more technical and computational complexity. It is also important to represent the dynamic of investment decisions that take place at different points in time, which further complicates the modeling details.

Objectives

This thesis develops a multi-stage stochastic model for a strategic producer that allows it to appropriately characterize the market functioning and all potential uncertainties. This way, the strategic producer is able to decide on its generation investment actions (long-term decisions) along with the offering strategy in terms of price and quantity (short-term decisions) for all the units within its generation portfolio including both existing and newly built units. Combined cycle gas turbines and wind-power units are considered in this thesis as investment options due to their competitive advantages. To make informed decisions, all potential uncertainties plaguing the investment and offering decisions are classified as long- and short-term uncertainties and appropriately modeled in the proposed model using a structured set of long-term, market, and wind-power production scenarios.

Methodology

A stochastic multistage bi-level model is needed to assist a strategic producer in making informed offering and investment decisions. The upper-level (UL) problem of such a bi-level model represents the profit-maximization objective of the strategic producer, while the lower-level (LL) problems represent the clearing of the market under different operating conditions, time periods, and realizations of the uncertain parameters. The simultaneous solution of both problems (i.e., the solution of the complementarity problem) results in the optimal offering and investment decisions of the strategic producer. The proposed model is recast as a mixed-integer linear programming (MILP) problem. The resulting MILP problem may be solved in GAMS, Python or Matlab depending upon the background of the successful candidate. One main concern is that the proposed model becomes computationally expensive (and even intractable) if many scenarios and time periods are considered. To overcome such an issue, a decomposition technique, namely progressive hedging, is needed to be applied.

Expected results

The expected results include relevant literature review, the formulation of the optimization problems and their Implementations.

Prerequisites

Power systems operation, energy systems modeling, energy markets, basics of optimization

Impact of unit commitment constraints on generation expansion decisions under wind uncertainty

Supervisors: Pierre Pinson, Jalal Kazempour, Amin Nasri (Sweco, Sweden), Antonio Conejo (The Ohio State University, US)

Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

The electricity generation expansion planning (GEP) is one of the most complicated decision-making problems in power systems, which determines the technology, capacity and location of new generation units to be built. It is common in the literature to ignore the unit commitment (UC) constraints of the conventional generation units, e.g., ramping constraints and minimum production (Pmin), within GEP decision-making problems. However, as more variable and uncertain wind power is being integrated to power systems, those UC constraints cannot be ignored. Under wind uncertainty, the dispatch of conventional generators becomes more volatile, so that UC constraints are often active. The exclusion of those constraints may result in inefficient GEP decisions in wind-integrated power systems.

Objectives

For a power system with given future wind capacity, this thesis develops a stochastic GEP decision-making model to determine the future conventional GEP decision, while enforcing the UC constraints of all existing and candidate conventional generation units. This model provides a tool to compare the GEP decisions with and without enforcing each UC constraint. This tool allows us to evaluate the importance of each of those constraints.

Methodology

The main technical core of the model is a large-scale two-stage stochastic programming problem. The first-stage provides the deterministic GEP and daily day-ahead UC decisions, while the second-stage models the real-time operation to adjust wind power imbalances under each scenario. Due to computational issues, Benders' decomposition is implemented to decompose the original problem to a number of smaller problems, one per day, hour and scenario. The proposed model is finally recast as a mixed-integer linear programming (MILP) problems. The resulting MILP problems may be solved in GAMS, Python or Matlab depending upon the background of the successful candidate.

Expected results

The expected results include relevant literature review, the formulation of the optimization problems and their Implementations.

Prerequisites

Power systems operation, energy systems modeling, energy markets, basics of optimization

Probabilistic forecasting of solar power generation at the distribution grid level

Supervisors:	Pierre Pinson, Jakob Messner
Group:	Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

While Denmark has traditionally invested more in deploying wind power generation capacities, the role of solar power in generating renewable power in increasing at a steady pace. While wind farms tend be large and feeding the network with their power production at medium and high voltage levels, solar power capacities tends to be smaller and spreader at lower voltage levels of the overall network, typically at the distribution grid level. Generating power at the distribution grid level, which may be consumed locally or going up to higher-voltage levels is something fairly new and that creates new challenges in distribution grid operation and management. One crucial problem is that of predicting the production from solar panels for the coming minutes, hours and days. Solar power generation has particular features due to the natural course of the sun, cloud passages, shadowing effects, air pollution, etc. In addition, when solar capacities are spread in a small area, one may naturally want to exploit all data available in space and in time to obtain forecasts of the highest quality. This requires the design of new forecasting approaches, from simple statistical models to advanced machine learning techniques. Besides, forecasts are to be issued and evaluated in a probabilistic framework, since then comprising an optimal input to a wide range of operational decision problems.

Objectives

In that context, the main objective of this M.Sc. project is to proposal and evaluate novel approaches for solar power forecasting at the distribution grid level, considering medium to large number of sites (from 10s to 100s). A test case for a real word setup in Evora, Portugal, will be considered.

Methodology

In the first stage, one may build on existing models in the literature for predicting solar power production at each and every sites individually, considering power measurements and possibly weather forecasts. These methodologies will then be generalized to the vector case, i.e., considering all sites at once. Parametric and nonparametric approaches to probabilistic forecasting will be implemented and compared.

Expected results

The expected results include relevant literature review, the proposal of a suite of forecasting approaches to be evaluated on real-world data, as well as new insight on forecasting at the distribution grid level.

Prerequisites

Power systems operation, sustainable energy, forecasting, basics of optimization, statistics or data-mining

Distributed Learning in Renewable Energy Forecasting

Supervisors: Pierre Pinson, Jakob Messner
Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

Wind and solar power generation is spreading rapidly, inducing a number of challenges in power system operations and electricity markets. Forecasting is seen as a crucial input for nearly decision-making problems related to wind and solar power management. Forecasts may take various forms, while being either deterministic or probabilistic. Many academics and companies have developed solutions for wind and solar power prediction with lead times between a few minutes and several days ahead over the last 10-15 years.

One of the main challenges in forecasting renewable energy generation today is to adapt to the availability of large amounts of data, with high temporal resolution and for many sites. This is while the modeling and forecasting methodologies should make optimal use of this data at minimum computational costs. The availability of such large amount of data may also be seen as an opportunity for a change of paradigm in the way forecasting is done and considered. While forecasting has mainly been a centralized task so far (say at the level of a portfolio manager or system operator), the proposal of the thesis is to induce a paradigm change by considering that the whole forecasting problem should be distributed, as in problem of learning on a distributed sensor network.

Objectives

In this context, the main objective of this MSc project is for the student to propose novel approaches for distributed learning with application tor renewable energy forecasting, building on recent development in distributed optimization and network science. For the application of the methods and the validation of the proposal, different case studies may be considered, e.g., in Europe, Australia or the US.

Methodology

For the present M.Sc. thesis project, emphasis will be placed on various approaches to distributed learning, combining ideas from distributed optimization and network science. In the first stage, the forecasting problem will be formulated in such a way that it will be possible to decompose it and share it. Known methods will be applied for that purpose. An additional complexity will arise when aiming to make this distributed learning as cheap as possible, by making it recursive and adaptive, while still being distributed. It is aimed to figure out how this learning distribution should be optimally done, in an effort to minimize the potential needs for measuring and communicating information at all potential sites considered (these may be thousands or more!). As an ambitious last step, the method will be generalized to the case of probabilistic forecasting.

Expected results

The expected results include relevant literature review, the formulation of the methods for distributed learning and application to renewable energy forecasting, their implementation as their evaluation for real-world test cases.

Prerequisites

Power systems operation, forecasting, basics of optimization, statistics or data-mining

The Renewable Energy Scenario Generation (RESGen) platform

Supervisors: Pierre Pinson, Jakob Messner
Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

Wind and solar power generation is spreading rapidly, inducing a number of challenges in power system operations and electricity markets. Forecasting is seen as a crucial input for nearly decision-making problems related to wind and solar power management. Forecasts may take various forms, while being either deterministic or probabilistic. Many academics and companies have developed solutions for wind and solar power prediction with lead times between a few minutes and several days ahead over the last 10-15 years. However, there is no commonly accepted open-source platform that would permit to generate such forecasts in a comprehensive, transparent and reproducible manner, to be used as input to operations and planning studies considering future penetration levels for such renewable energy sources. This is while there is an increasing need for such a platform and forecasting tools. Our group at DTU Elektro, CEE, has worked on developing an open-source platform, with two setups for the Western US and for they the whole European power system. Future plans are to extend that platform so that it may be used for as many locations as possible around the world, by both scientists and practitioners.

Objectives

In this context, the main objective of this MSc project is for the student to contribute to the development of this open-source platform, combining development of methods to improve the forecasts and their implementation. Modeling, visualization and verification aspects will be considered. Different case studies may be considered, e.g., in Europe, Australia or the US.

Methodology

For the present M.Sc. thesis project, emphasis will be placed on probabilistic forecasting approaches, permitting to inform about the whole range of future power production levels. These forecasts will take the form of both probability distribution functions and space-time scenarios. The most interesting part of these developments will focus on proposing fully data-driven techniques allowing to adapt the modeling and forecasting techniques to any site (and aggregation of sites), by adaptively estimating clear-sky models for the case of solar power, and spatio-temporal dependence structures for both wind and solar power generation.

Expected results

The expected results include relevant literature review, the formulation of the methods for issuing the probabilistic forecasts and scenarios, their implementation in the platform as well as their evaluation against a various benchmarks.

Prerequisites

Power systems operation, forecasting, basics of optimization, statistics or data-mining

Population games in electricity markets

Supervisors: Pierre Pinson, Athanasios Papakonstantinou
Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

The deployment of stochastic renewable energy sources (RES) e.g. wind and solar power, has been steadily increasing, bringing significant economic and environmental benefits. As renewable generation approaches grid parity, stochastic producers are asked to participate in electricity markets under the rules applied to conventional producers. Although now they may face regulation costs due to imbalances between their day-ahead market offers and real-time production, they can also employ trading strategies in the day-ahead markets that may offset the cost of imbalances.

There has been an increasing scientific interest in addressing such issues with stochastic optimization methods being the most prevalent. Although such approaches bring significant contributions, they have limitations. First, the stochastic producers rely on knowledge that is unlikely to be available to them, such as complete information of the power system's attributes and access to the predictive distributions of all other stochastic producers, while assuming that they accurately model real-time production. Second, they assume that only a single producer is strategic and capable of devising an optimal strategy, with the rest following without a reaction. That is, they do not capture the inherent dynamics of participating in a market, with the exception being the formulation of the competition among stochastic producers as an equilibrium program with equilibrium constraint. However, such techniques are computationally demanding with reduced tractability, often too complex to be implemented in real-world real-time basis.

Objectives

In this context, the main objective of this MSc project is to analyze the behaviour of stochastic producers in electricity markets focusing on the collective impact of the individual actions.

Methodology

We model the interactions among stochastic producers as Minority Game, a class of game-theoretic problems that can be used to study market competition among self-interested agents. In a Minority Game, a population of agents has to decide between options A and B with those belonging on the minority group by the end of the game considered as the winners. Naturally, the fact that those belonging in the minority group derive more benefits is very appealing in financial markets, given that market complexity is summarized under the famous mantra: “Sell when everybody is buying and buy when everybody is selling”. This can have applications in power systems, either to model electricity market interactions or congestion in the grid. *In both cases it is possible to bypass the complexity often associated with electricity markets and grid operation by designing intuitive rules that capture the principle of the Minority Game.*

Expected results

The expected outcome includes relevant literature review and the formulation and improvement of rules based on well-known game-theoretic problems such as the El Farol Bar problem (EFBP). The developed rules will be evaluated on a test system focusing on several aspects of the market clearing i.e. market prices, congestion in network nodes, scheduled and dispatched energy.

Prerequisites

Power system operations, electricity markets, basics of optimization, basics of probability theory, python, gurobi are preferred (or matlab, GAMS).

Wind producers and honesty in stochastic energy markets

Supervisors:	Pierre Pinson, Tue V. Jensen
Group:	Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

With increasing amounts of renewable energy comes a need to explicitly price the costs associated with their uncertainty and variability. The natural setting for evaluating these costs is a stochastic market clearing, where the market operator clears the market considering the expected costs of operation in a set of scenarios. From the system operator's perspective, stochastic market clearing leads to lower overall system costs and increased systemic robustness, especially in scenarios with high renewable production.

However, stochastic market clearing presents two challenges to the market operator: Firstly, it is necessary to generate scenarios for wind production. These scenarios represent the simultaneous production for multiple wind turbines, and must be constructed based on forecasts submitted by single wind turbines. Secondly, the prices in stochastic markets are not simple to interpret, and no consensus exists on how loads and generators should pay and be paid.

These two issues combine to form a larger issue; a wind generator participating in a stochastic market must submit partial scenarios to the market operator. Depending on the scenario generation method and payment scheme, the wind generator may attain higher profits by supplying the market operator with false or incomplete forecast information. This project seeks to examine to which extent this problem occurs for currently proposed payment schemes.

Objectives

With this background, this project aims, under stochastic market clearing, to quantify how the remuneration and scenario generation method impact the profits earned by stochastic producers. Further, to examine whether these producers have (first-order) incentive to reveal their true private information to the market operator.

Methodology

To properly evaluate the efficacy of a stochastic market setup requires building a chain of tools. The chain would go from the systems' underlying true wind distribution at one end, through the producers' reporting of their strategic scenarios, using these reports in a scenario reconstruction procedure, evaluating the reconstructed scenarios under stochastic market clearing, clearing the real-time system via the underlying truth, and revealing the final settlements for market participants.

Each link in this chain presents opportunities for modeling operational procedures. The stochastic market clearing, for instance, would be modeled in an optimization framework in, e.g., Python, MATLAB or GAMS depending on the preference of the candidate, with multiple options for the desired level of detail (zonal, nodal) and which products to consider (ramping, reserve allocation, etc.). Time permitting, a more complete treatment of various links in the chains can be considered.

Expected results

The expected results include a review of remuneration schemes for stochastic markets, definitions of simple scenario reconstruction methods, definition of a stochastic market clearing model, and a comparison of the final outcomes of these under variations of the input scenarios.

Prerequisites

Energy system modeling, energy markets, basics of optimization, some familiarity with statistics is recommended.

Calibrating operation models in electricity markets

Supervisors: Pierre Pinson, Stefanos Delikaraoglou
Group: Energy Analytics & Markets, Centre for Electric Power and Energy, Department of Electrical Engineering

Context

The liberalization of the electricity sector lead to a paradigm shift on power system operation. Prior to the establishment of electricity markets, planning and operation of the power system was managed by vertically integrated monopolies with full control and information of the underlying the economic and technical constraints.

In the existing decentralized environment, many operations that were previously undertaken by a single entity are now internal decisions of multiple market players. To ensure the efficient coordination of these agents within the technical limits of the power system, electricity markets become more and more complex. This high complexity is further exacerbated by the large-scale integration of variable and partially predictable renewables, since markets have to cope also with the uncertainty of this stochastic in-feed.

In this complex environment, a methodological framework that enables the in-depth comprehension of market operation, should consider a number of technical and economic aspects. From the technical perspective, factors such as outages, must-take resources (e.g. CHP), reserve requirements and forecast uncertainty may have significant impact on the market outcome. In the meantime, economic aspects as market power, imports/exports from/to neighboring systems and fuel price fluctuation are influential drivers of the market-clearing prices.

Objectives

In that context, the main objective of this MSc project is to formulate a Unit Commitment (UC) model that replicates adequately the market-clearing in NordPool, with primary focus on the Danish market zones. This tool, if properly calibrated, can reveal potential discrepancies between the theoretical and actual market operation and serve, in the future, as an advanced basis for demonstrating the interest of novel methodologies and ideas.

Methodology

From the methodological point of view, this MSc project involves the following main steps:

i. Study and document the existing market design of NordPool spot market considering also the functionality of more complex products, e.g., block bids.
ii. Integrate these features into a UC model.
iii. Calibrate the UC model such that it approximates sufficiently the historical market outcomes. Advanced statistical or optimization methodologies, e.g., inverse optimization may be employed.

Expected results

The expected outcome includes relevant literature review, the formulation of the optimization problems and their implementations, as well as the evaluation of the results.

Prerequisites

Power systems operations, sustainable energy, energy systems modelling, energy markets, basics of optimization