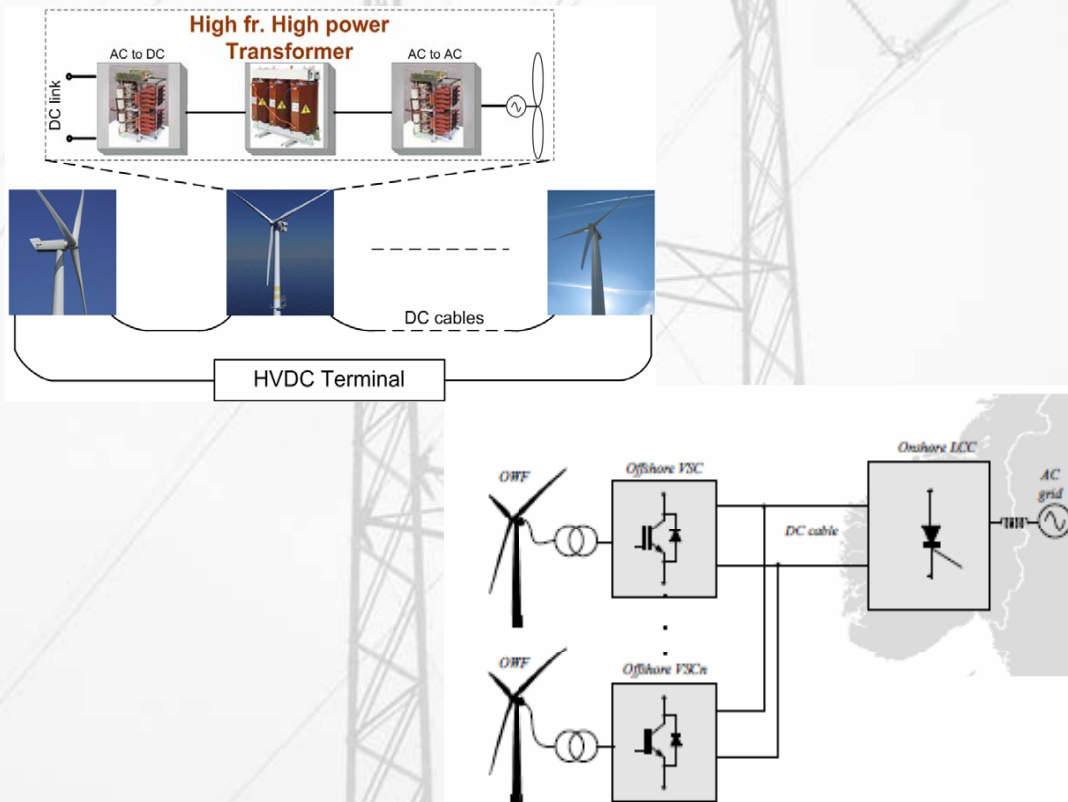


PhD projects

Department of Electric Power Engineering

February 2011



An overview over PhD Projects 2011

at

Department of Electric Power Engineering
Faculty of Information Technology, Mathematics and Electrical Engineering
Norwegian University of Science and Technology

This report gives an overview of current PhD research projects at the Department of Electric Power Engineering.

Currently 42 students are registered in our PhD program. This number has been steadily increasing for several years, reflecting the increased general interest in energy and electric power from renewable resources. The department has 11 professors, and three associate professors and six assistant professors. In addition to the scientific and administrative staff, the department houses a mechanical workshop and an electro technical laboratory.

The research activity at the Department is mainly covered by the following three fields:

- Power Systems
- Electrical Power Technology
- Energy Conversion

The PhD projects presented here focus on topics from all these areas. The research projects are both theoretical and practical and based on extensive use of our computer and laboratory resources. The projects are also influenced by our collaboration with industry and our neighbour institution SINTEF Energy Research AS. Since the PhD projects represent the main part of the professors' research, this folder also gives an overview of the entire research activity at the Department.

The nominal duration of PhD program is three years of full-time research, of which a half year is devoted to post graduate courses. A typical PhD project, however, lasts for four years, where the additional year is booked within university/educational duties.

For further information about the research projects presented, please contact the individual researcher given by name in this folder. For more information on previous projects, please contact the Department.

NTNU, 1 February 2011

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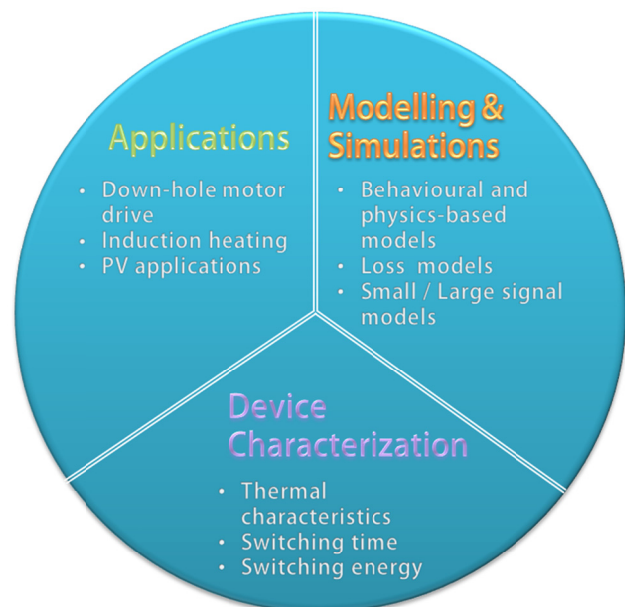
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SiC Power Devices for High Performance Energy Conversion Systems

With continuance growth of power electronics based systems; driven by the increased share of renewable energies within energy market as well as the need for more efficient, less CO₂ solutions, a significant improvement of these conversion systems is desirable. Moreover, new industries, where other forms of energy are conventionally in use e.g. hydraulic systems, are now considering electrification as an alternative. However, today's power device technology (Silicon-based devices) is not able to fulfill such desires knowing that Si-based devices have already reached their maximum physical limits. SiC-based power device technology is a potential replacement for Si-based devices due to the superior features they possess. The high temperature stability of SiC devices makes it possible to operate at higher ambient temperatures with less cooling requirements. This can benefit applications where temperate is the main challenge like deep oil and gas wells and space exploration. Adding the ability to fabricate more compact, high efficiency conversion systems, PV inverters and electric vehicle could hugely benefit from this technology.

This PhD project focuses on understanding different aspects of the fast growing SiC technology. Thus trying to answer the question of; how can we use newly developed SiC devices in today's technologies. The basic step to start with in such type of studies, after literature review, is naturally to characterize electrically and thermally the targeted devices. The outcome of this lays not only on acquiring better understanding and verification of theoretical hypotheses. It also reveals several challenges that circumfused targeted future applications. With help of mathematical modeling, findings of characterization process are employed to gain one more vital piece of information. Expectedly, a foreseen of SiC devices being employed in real application is in hand. The pie graph shows these three interconnected areas which form the scope of this research project.



RESEARCH SCOPE

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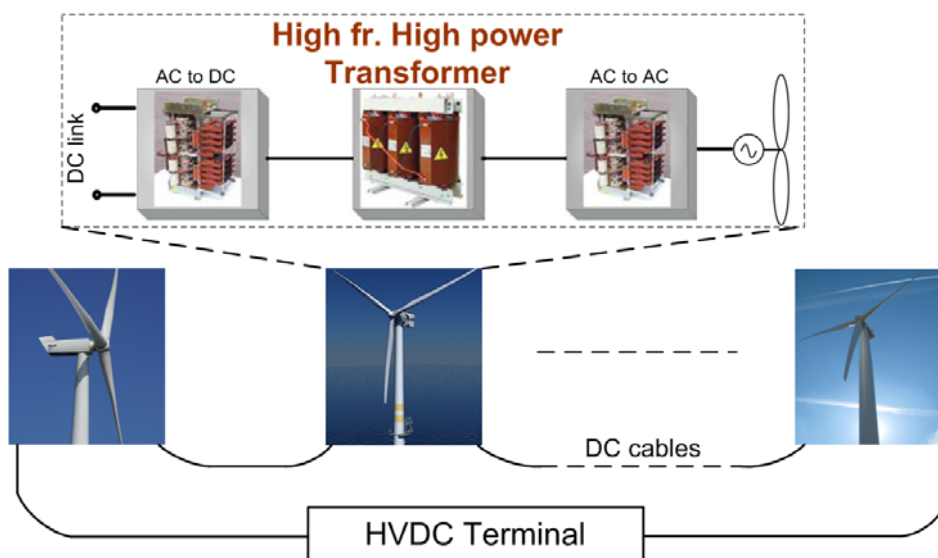
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Simulation and design of high frequency high power transformers

Over the last decades, the worldwide interest in renewable energy sources has risen drastically. At this stage the generation of electrical power via wind turbines is one of the most promising renewable sources. Primarily, in Europe the installed power has risen drastically so that wind power is today, after hydro power, the second largest renewable energy source and is still growing most rapidly of all the renewables with respect to the installed power rating per year. Wind energy is typically converted to electrical energy by electrical induction machines and AC/AC converters in combination with a power frequency (50Hz) transformer and AC/DC rectifiers. This is a physically large and heavy construction that is challenging in a floating wind generator structure.

The idea is further to use a high frequency transformer to feed a more traditional AC/DC converter and insure galvanic isolation between the AC and DC side of the wind generator system. A high frequency transformer solution seems beneficial since the required core cross section is inversely proportional to the frequency of the applied flux. Increasing frequency can thus save weight and cost and enable a solution where the entire energy conversion system is placed in the nacelle close to the wind turbine. This requires fundamental research on the behaviour of the transformer at frequencies in the range of 500 Hz to 10 kHz. Transformers at 400 Hz are used today in ships and airplanes to save space and weight, but to go above 1 kHz requires new solutions both regarding core material and handling of capacitive effects and core losses. Increased copper losses at increased frequency could also pose a challenge.



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System Impacts of Large Scale Wind Power

The European Commission proposal for 20% renewable energy by 2020 paves the way for a massive expansion of wind energy and a new energy future for Europe. To reach the goal wind energy is a key technology and large scale integration is required both onshore and offshore. This represents heavy challenges to the power system requiring new ways of designing and operating the system. Especially large scale offshore wind power will require attention to new focus areas. The wind may be more stable offshore, but there will be less geographical smoothing effect, so wind variations will still be a key issue. Power transmission and grid connection represent other main challenges for realisation of large scale wind power, and especially for offshore wind farms.

The influences and impacts of large scale wind power production on the Nordic system and on single parts of the EU have already been discussed and are well covered. According to these analyses, feed in fluctuation caused by wind speed variations, may affect the reserve requirements as well as the system reliability on a short and long term basis. Using the interconnected European grid may offer advantages in balancing the variable energy production from renewable energy and reduce reserve requirements in the different areas. The variability of wind power production as well as the zero output occurrences are reduced in a large interconnected system, due to the spatial separation between the production units, while the output predictability can be increased.

The scope of this fellowship is how to handle a growing amount of wind power and how to find an efficient and secure design and assure a stable operation of the overall system. The objective is to assess the variations in wind power production on a short term basis, including gradients and smoothing effects depending on geographical separation of the wind farms and how these effects may affect the system operation (operation planning, balancing control and reserve management).

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Modelling of households' electricity consumption

The purpose of the Electricity Demand Knowledge project is to increase the knowledge about electricity consumption for specific consumers like households and businesses. This includes knowledge about electricity consumption (kWh) and peak demand (kWh/h) for various groups of consumers and electrical appliances. More knowledge about consumption is necessary to be able to develop methods to influence and reduce consumption.

The present PhD study will contribute by using mathematical and statistical methods for the estimation of total electricity consumption and the specific consumption for purposes like room heating, lighting, water heating etc. The study will focus on households.

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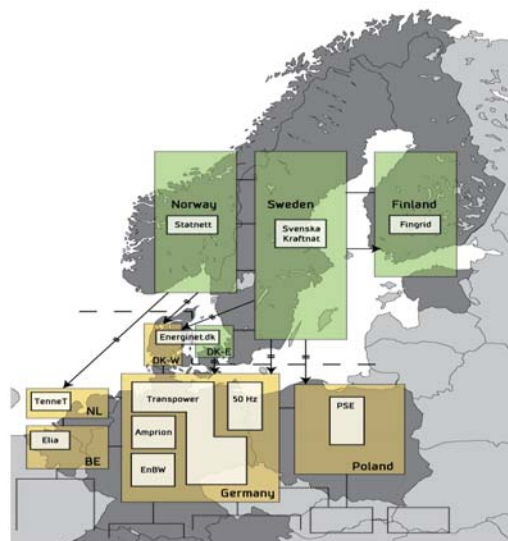
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Balance Management in Multinational Power Markets

Besides the ongoing process of market coupling in continental Europe, reserve procurement is going to become more complicated to handle efficiently in a huge integrated system. The need for adequate and optimal reserve resources is increased by strongly increasing amounts of intermittent renewable energy resources such as wind power notably in northern Europe. The exploitation of the favourable properties of hydropower plants and especially Nordic hydropower with large reservoirs as regulating resources and the newly commissioned HVDC between Nordic and Central European power system are drivers to exchange balancing services between two systems.

An integration of regulating markets can facilitate the mutual procurement of regulating resources and is a way of using existing cross border capacity more efficiently. The focus of research work is to design the scientific foundation for a framework for efficient, market-based balancing of power system that can be implemented in multinational power market. The framework should minimise the system costs and maximise social value by co-ordinating the dispatch of all available reserve resources.



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Using Scandinavian pumped hydro to integrate German wind power: a real options analysis

Germany has a target of 27% renewable energy by 2020, increased from 10% currently. With heavy reliance on renewable power sources such as wind and solar, Germany will have to increase gross electricity imports or install local quick-ramping generation capacity or energy storage to balance variable renewable power output. This research will examine optimal investment strategy in wind-balancing resources from a German perspective.

Net Present Value (NPV) is often used to plan investment in electricity generation projects, with revenue calculated from the expected values of future electricity prices and a positive NPV indicating that the project is expected to be profitable. However, NPV does not account for the benefit of waiting to gather more information; with uncertain future electricity prices, there could be a substantial advantage to waiting and observing price trends before deciding whether to invest. The field of real options provides tools to assess optimal investment strategies in energy projects, accounting for uncertainty in future prices and the value of waiting for additional information.

This research will use real options to examine optimal investment strategies in HVDC transmission to Scandinavia versus local natural gas capacity to integrate wind power in Germany. The first stage of the project will consider a pumped storage facility in Scandinavia and an HVDC transmission line that connects the facility to the German electricity market (EEX). Annual profit of this system will be modeled as a stochastic process for which real options can be applied to find optimal project investment timing. The next stage of the project will examine local natural gas-fired generation as another method of balancing German wind power, and model the switch from gas to pumped hydro for balancing power as an exchange of two risky assets with an optimal price level under which to make the exchange.

Results of this project will help define the optimal investment strategy in assets to integrate German wind power. Despite its location-specificity, results and methodology of this study could also inform investment decisions in storage versus natural gas capacity to integrate intermittent renewables in other locations.

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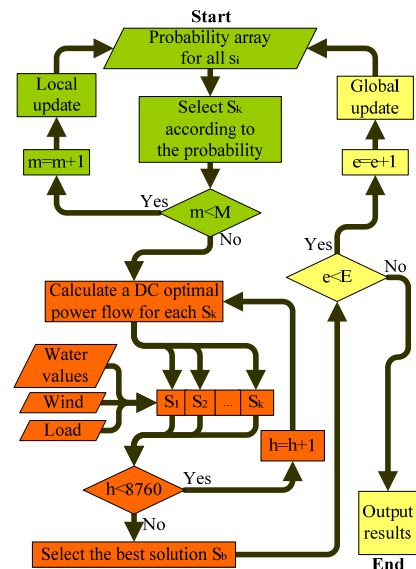


Planning Power Transmission For Wind Power Integration

A significant number of new methods for TEP have been proposed and tested by researchers and TSO. It is still a task to meet particular challenges with TEP problems, especially when it comes to coordinate new transmission lines for wind power integration. The successful large scale wind power integration requires a redesign of TEP scheduling. For this the TSO needs improved TEP tools including the nature of wind power integration.

The project involves the development of an algorithm for transmission expansion based on ant colony optimization (ACO), which belongs to the group of swarm optimization among artificial intelligence methodologies. The flexibility of the method allows a higher grade of detail when including wind power integration into TEP modelling. The ability to include any heuristic information makes it an attractive tool for implementation into more comprehensive power system models.

The flow chart shows the method of operation of the ant colony based tool which is developed during this PhD project. It is programmed in Matlab and includes a DC optimal power flow performed by Matpower.



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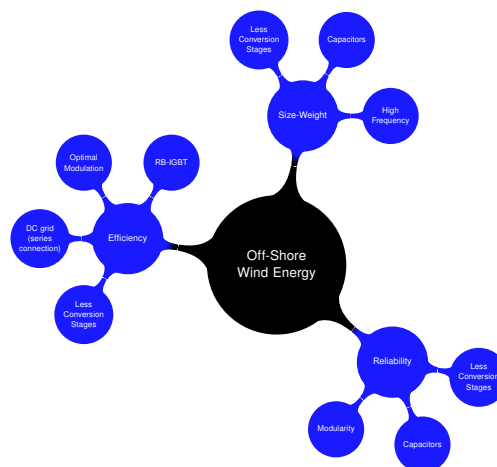
Reduced Matrix Converter for series Connection of Off-shore Wind Farms.

WIND energy is a promising technology for electrical power generation because of its well known environmental advantages over conventional generation systems. In recent years, there has been an increasing interest in offshore wind farms because of their reduced visual impact and high performance of energy production. However, offshore wind farms deals with new challenges which must be faced to make them a feasible alternative.

- Size and weight reduction: each component placed offshore represents high investment costs due to the transportation to the emplacement from shore, and the offshore platforms. Therefore, increasing the power density is an important objective from investment point of view and the maintenance since it reduces the cost of spare parts transportation.
- Efficiency: long distances are expected in offshore wind farms, since the longer the distance to shore, the higher and more constant the generated power is. Therefore, losses must be minimized not only in the converters but also in the transmission lines. HVDC is the most suitable technology in these conditions, but the offshore grid topology and the converters themselves must be optimized for their particular conditions.
- Reliability: Maintenance and replacement of components represent high transport costs. Accordingly, the reliability of the components themselves as well as the grid topology must be optimized.

Matrix converter is a direct AC/AC conversion system which fulfills the three above mentioned requirements, because of the less stages of conversion, the use of high frequency, the possible use of new semiconductor devices and the absence of a bulky electrolytic capacitor, which is a reliability issue in conventional converters. In addition, the control is performed in just one stage of conversion.

On the other hand, series connection produces lower grid losses, since it operates at the same transmission current and generation voltage. However, it carries with technological challenges which needs to be further studied: variation in the wind velocity causes variations in the output power and therefore in the output voltage. As a result of that, a wide variation capability of output voltage is required in each turbine and an optimal power flow control must be developed.



The objective of this research is to face the three challenges mentioned previously by using a new topology of matrix converter and series connection of wind turbines (see figure above). The project studies not only topologies and new modulation strategies but also the coordinated operation of the complete system by a non linear optimization model. The general approach of the project consist of a theoretical investigation, which will be complemented with investigations on an experimental prototype.

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Integrated converter design with generator for weight reduction of offshore wind turbines

Recent years have shown an increasing interest in offshore wind power. This is due to better, more stable wind conditions and less environmental impact than onshore. As a result of the offshore conditions, few, large turbines have been pointed out as more beneficial than many small. However, larger turbines means higher current ratings, and therefore it is crucial to perform the transformation to higher voltage in the nacelle. But a distribution transformer would add significantly to the top weight, and hence increase the overall cost of the turbine

Therefore, the focus of this research project is to design a converter, which together with an ironless axial flux permanent magnet (AFPM) - generator, will eliminate the need for a distribution transformer. The design of the converter includes an evaluation and identification of a suitable converter topology and the synthesis of a control system which guarantees proper operation of the generator drive. The converter- and control system should also have a structure which provides the generator drive with redundancy, and ensure continuous operation even if some parts of the system fails.

Additionally, while medium voltage AC-grids have been applied to offshore wind farms so far, recent research has pointed out the possible advantages of a DC-collection grid. To follow up this research trend, the converter will be designed for a DC-collection grid, and the control system should contribute to the stability of such a grid.

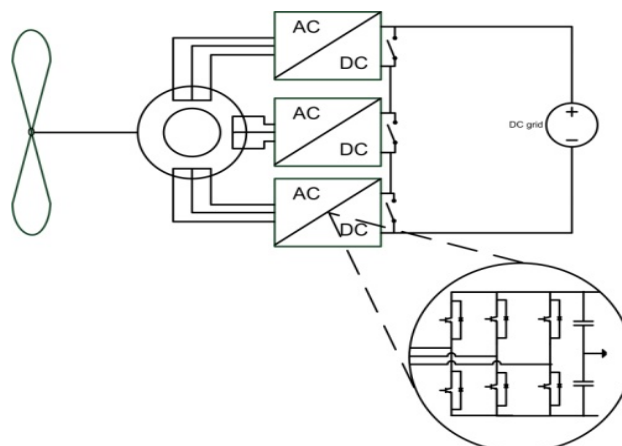


Fig: Example of generator/converter system, here with 3 converter modules

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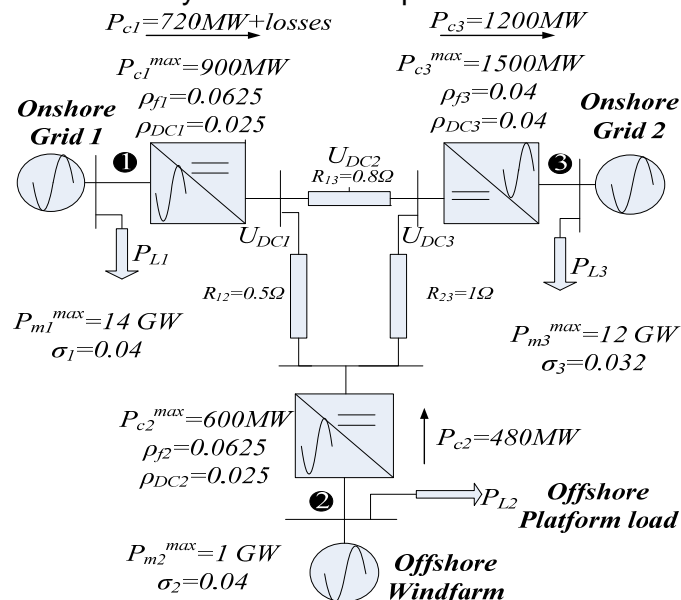


Control and Operation of Multiterminal VSC-HVDC(MTDC) for Offshore Systems Application

With increased interest for environmental friendly renewable energy, offshore wind power has been attracting the attention of researchers and energy developing companies as a promising source of future electricity. Considering the long distance from onshore involved with such offshore wind farm sites, it will be necessary to find a robust grid integration solution for transmitting the power generated to points of power consumption onshore. On the other hand the development of voltage source converters in the high power range has made multiterminal HVDC (MTDC) a technical possibility in recent years. In the case of the North Sea, the presence of offshore loads at oil & gas platforms can make it attractive to consider offshore MTDC interconnecting the wind farms, the oil & gas platforms and onshore national grid.

MTDC is a technology still under development and there are some important aspects, such as control, operation and protection of MTDC, which should be resolved in order to employ the technology for practical use.

The focus of the research is to find out best ways of controlling MTDC and to investigate how an MTDC connected offshore/onshore systems can be operated in a market oriented environment.



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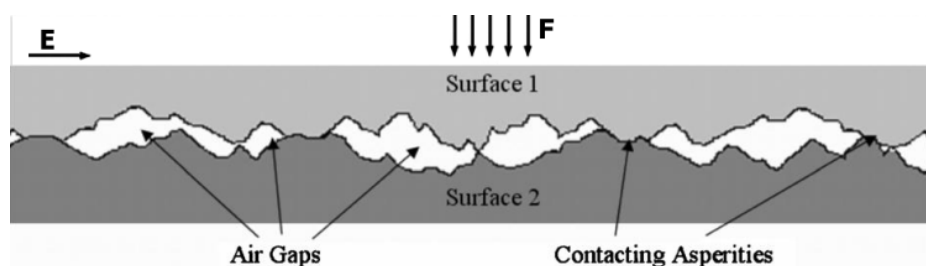


PD characteristics and Breakdown Strength of Solid |Solid Interfaces

This project investigates the breakdown strength and partial discharge (PD) of solid-solid interfaces, analytically and experimentally. The electrical insulation of many high voltage devices consists of a combination of different solid dielectrics. Consequently the electrical strength of these apparatus is not only determined by the breakdown strength of the each solid material but also by the dielectric properties of solid-solid contact areas. The contact area between different insulating materials is called "interfaces". Interfaces are found, for instance, in power cable joints, high voltage outdoor composite insulators and subsea power connectors. Normally, interfaces are critical areas because of their weak physical structure and, additionally, the combination of two solid dielectrics enhances the risk of air gaps or cavities at the interfaces.

Cavities or areas with a low material density in the contact area have much lower breakdown strength than the solid dielectrics and, consequently, these regions are preferred starting points and propagation paths for electrical discharges, as depicted in the figure. As a result, the electric field at the interface should be chosen to be as low as possible at normal voltage. The relative permittivity mismatch between the solid dielectric and air may intensify the electric field inside the cavities, too. The existence of defects (contaminant and water droplets) can also influence the electric field distribution due to their high permittivity and conductivity. The breakdown strength of the interface is reduced if the electrical stress is applied parallel to it. In this case, the initiation of PD and, consequently, the short circuit of some air gaps result in rise of voltage across the residual part of interface. Assuming cascade phenomena, these regional short circuits of voids lead to an electric breakdown of the whole interface.

This study argues that material properties, contact pressure and surface roughness govern the partial discharge inception stress and breakdown strength of interface. The main contribution of this work is the analysis of the contact between two surfaces, the estimation of void's dimension and verification of theoretical results by measurement.



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Wind Energy Conversion using High Frequency Transformation and DC Collection

The offshore wind farms are growing in size and being placed farther away from shore. From that perspective, HVDC collection and transmission system will become more advantageous, if not the only alternative, as important losses in long AC cables are eliminated. The BARD 1 wind farm (400 MW), 100 km off the coast of Germany, is currently under construction and is the first offshore wind farm that will be connected via an HVDC transmission system.

In parallel the semiconductor industry is making ever improving progress and are now producing switching devices, the reverse blocking IGBT, that increase substantially the efficiency of matrix converter. As a consequence, the matrix converter is rising up as a strong candidate for wind energy conversion due to its many advantages: independently controllable sinusoidal input current and output voltages, potentially high reliability and small size and weight due the elimination of the DC link capacitor needed in conventional back-to-back converter. There exist many different possible matrix converter topologies: conventional matrix converter, indirect matrix converter, sparse matrix converter, reduced matrix converter, etc...

The matrix converter in combination with a high frequency transformer for galvanic isolation and an efficient AC to DC converter yields an overall energy conversion system compact enough to fit inside the nacelle of the wind turbine. In this research work the three above-mentioned technologies will be combined to conceive a state of the art wind energy conversion system that is suitable for small or large offshore wind farms that are located far from shore.

A total of three PhD students will be working on this project, funded by the Norwegian Research Council and the RENERGI Program. My specific research work will be to select and make simulation models and eventually a prototype of the optimal matrix converter topology in terms of efficiency, reliability, volume and cost as well as the AC-DC conversion system.

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Electrical Treeing in Syndiotactic Polypropylene

Syndiotactic polypropylene (s-PP) is being considered as an alternative extruded high voltage cable insulation, particularly for high temperature cable applications. Cross-linked polyethylene (XLPE) is normally used, but its operation temperature is limited to 90 °C. s-PP has melting point at 130 °C and low dielectric losses. In capacitors it is common to use isotactic polypropylene (i-PP), but this material has a high elasticity modulus which would make extruded cables stiff and hard to handle. s-PP has lower elasticity modulus, reducing these problems.

Electrical tree growth is the main pre-breakdown mechanism in polymeric insulation materials. It is typically initiated at a field-enhancing void or impurity, a situation which in experiments is approximated by using a needle-plane geometry. The formation of an electrical tree is characterised by three main phases: Initiation, propagation and breakdown. For the experiments moulded samples with needle-plate distance of 1.05 mm is used, applying 8-12 kV 50 Hz AC voltage. Two main types of trees are observed: Branched trees with either one or multiple branches to the ground electrode before breakdown. The latter tree type is shown in Figure 1, where the width of tree can grow to 2-3 times the needle-plane distance.

The focus of this work is to study electrical tree growth in s-PP, quantifying it in terms of tree structure, propagation rate and time to breakdown. In addition, the purpose is to examine a possible correlation between mechanical properties, morphology and electrical tree growth. For comparison samples of s-PP was made with two different cooling rates, which significantly effects the tensile strength and morphology. However no significant difference in time to breakdown was found. A quality of i-PP is included in the study, which have 50% higher tensile strength than s-PP. Generally the time to breakdown in s-PP was lower than for i-PP, and there was more variation in the results. The effect of higher and lower frequencies will further be included in the study.

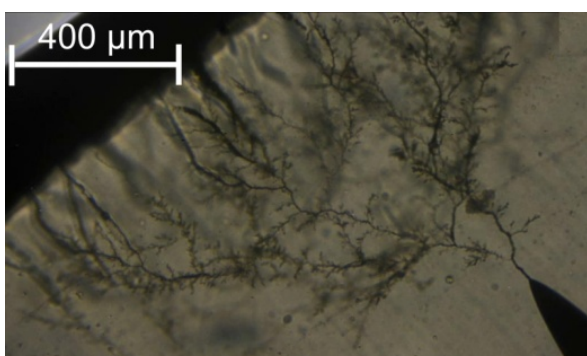


Figure 1 Electric tree with multiple branches to the ground electrode, grown in s-PP.

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Control and Energy Management of a Hybrid PV/Battery/Genset for Microgrid Application

Increasing demand for energy, decreasing conventional fossil-fuel energy sources, and environmental concerns are driving forces toward renewable energy sources. About 1.5 billion people across the world, which is about 25 % of the world population, do not have access to electricity. Majority of these people are in the developing countries, mainly in South Asia and sub-Saharan Africa. These countries are blessed with sunshine throughout the year and hence Photovoltaic (PV) hybrid energy systems are a sustainable energy source of electricity since it ensures sufficient and continuous electricity supply.

The Microgrid (MG) concept assumes a cluster of loads and micro-sources operating as a single controllable system that provides electricity to its local area. This overcomes the insufficient supply by Solar Home Systems (SHS) or the operation cost and emission problems of diesel generators operating alone.

The focus of this research work is to develop the control strategies for the optimal operation of the microgrids, the goal being to meet the customer demand by proper sizing of the hybrid system (PV panels, batteries and genset) , minimize the operating costs, minimum CO₂ emission, improve the performance, and increase the lifetime of the system. Main tasks are extracting the maximum power from PV panels, controlling the battery charging and discharging, operating the genset in its most efficient operating range, Controlling the inverters and power flow in a microgrid.

The research involves simulation using PSIM and Matlab/Simulink and building a prototype to show the effectiveness of the developed control strategies. The system is digitally controlled due to advantages offered by digital control compared to analog control.

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Balance Management in Multinational Power Markets

With begin of the 1990s privatization and deregulation became a big topic in Europe and electricity markets started to develop. The Initialization took place in England and Wales (1989), followed by Norway (1990) and many other countries further on. The European directives 96/92/EC and 54/EC aim to the integration of electricity markets in the member states. Regulation 1228/2003 furthermore explicitly includes cross-boarder issues.

The Nordic electricity market (Nord Pool) is a common market ever since, as it was first joined by Sweden and later by Finland and Denmark. In continental Europe coupled and common markets are developing, most notably to mention the CWE-ITVC (including Nordic and central-western Europe), which achieves a market coupling as far as from northern Norway down to southern France.

With a European wide need for sustainable energy resources, especially resulting in an increasing share of wind power, a higher balancing potential in the grid is needed. Moreover there will be new HVDC cables connecting Scandinavia to continental Europe. These developments can provide Norway with its high share of hydro power production the possibility to become a supplier of balancing resources to the continental thermal based system. Considering this aim, besides having a common day-ahead market, it will also be necessary to integrate regulating power markets. Thus the project objective is to *design the scientific foundation of a framework for efficient, market-based balancing of power systems that can be implemented in multinational power markets.*

While the project objective is formulated in a general way, the actual focus is on the exchange between southern Norway and northern continental Europe. In order to simulate the exchange of balancing resources and investigate a possible outcome a model for a system wide procurement of balancing resources as well as their activation is developed. The EMPS model, developed at SINTEF, is used as the basis, describing a common European day-ahead market. It evinces that there is a high potential of regulating resource exchange, resulting in a significant reduction of the costs for reserve procurement and the system balancing.

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Electrical Systems for Offshore Wind Parks: From the Generator to the Grid Connection Onshore

Increasing demand of environment-friendly energy has forced the developed world to work towards tapping renewable energy resources like solar (thermal & photovoltaic), wind, wave, tidal, fuel cells, hydrogen etc.

Large scale, deep sea wind power generation projects bring High Voltage Direct Current (HVDC) transmission into perspective. It is well established that underground or submarine power transmission via cable above a certain distance is technically impossible due to excessive reactive loading. This led to development of HVDC in the mid 50s and has seen enormous growth since then.

The conventional converter topology for AC/DC power conversion is referred to as Line Commutated Current Source Converter (CSC). The technology is well developed and the majority of high voltage high power links constructed in the world employ this technology. There are certain inherent problems associated with the current-sourced topology and the focus of this research is to address a few of these. These are listed below:

1. The manufacturing, installation and maintenance costs of offshore supporting platforms for converter station equipment are directly proportional to their weight and volume. The converters, being line commutated, have slow switching speeds thus inducing lower order harmonics into the ac system meaning bulkier filters.
2. The commutation mechanism for these types of converters makes the current lag the voltage in the ac system regardless of whether the terminal is acting as a rectifier or an inverter making the terminal a sink of reactive power requiring large capacitors for compensation.
3. CSC stations are not capable of self starting as they require ac voltage for AC/DC conversion.
4. CSC terminals are prone to commutation failures which may cause the converter terminal and consequently the link to shutdown. In an area with harsh climate conditions and almost impossible access during most part of the year, this scenario has to be avoided.

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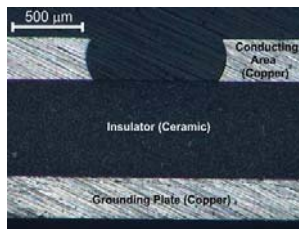


Insulation of Electrical Converters with Transformer Oil for Subsea Applications

The use of IGBTs and IGBT modules has become quite common in the last decades and their behaviour is well studied. Especially medium voltage applications have benefited from these devices. One reason for this is that they are well suited for parallel operation. This has led to development of a broad variation of IGBT modules. But there is little experience of operating power electronics under pressure, available solutions for subsea applications consist of large pressure vessels with atmospheric pressure inside. To minimize the size and weight and consequentially the costs of such equipment it is considered to insulate the power electronics in transformer oil instead of silicon gel or epoxy and expose it to the hydrostatic pressure.

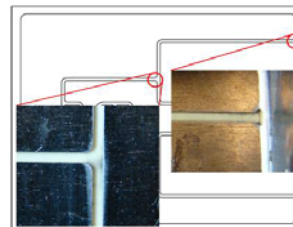
The base plate of an IXYS module was selected, it is a typical module applied in frequency converters under development for subsea use. It has narrow insulation gaps (0,85 mm) between the conducting areas and also an irregular geometry such that high fields can be expected. The electric field has been calculated with the finite element method (FEM) for cross sections of the base plate at an expected highly stressed region. One base plate was cut for examination with a microscope to obtain the exact geometry.

The base plate has gap formations resulting in homogeneous as well as inhomogeneous fields. In addition the interface between ceramics and the oil needs to be considered. Therefore test objects representing semi-homogeneous fields by a sphere gap and inhomogeneous fields by a needle-plate arrangement were chosen. High voltage experiments were done on the base plate as well as on the test objects made on PCBs.



Left side: Cross-sectional cut of module

Right side: Specific areas for pd activity on the module plate



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Impact of Short Term Effects on Long Term Hydro Scheduling

The project objective is to consider what adaptations are necessary to prepare mid- and long-term hydro power scheduling tools for a power system with increased production volatility combined with an increased level of restrictions on production.

Increased production volatility is likely to be caused by an increasing amount of non-regulated renewable power production and/or increased exchange capacity with European power systems.

An increased level of restrictions is caused by local environmental concerns, e.g. as prescribed by the EU Water Framework directive.

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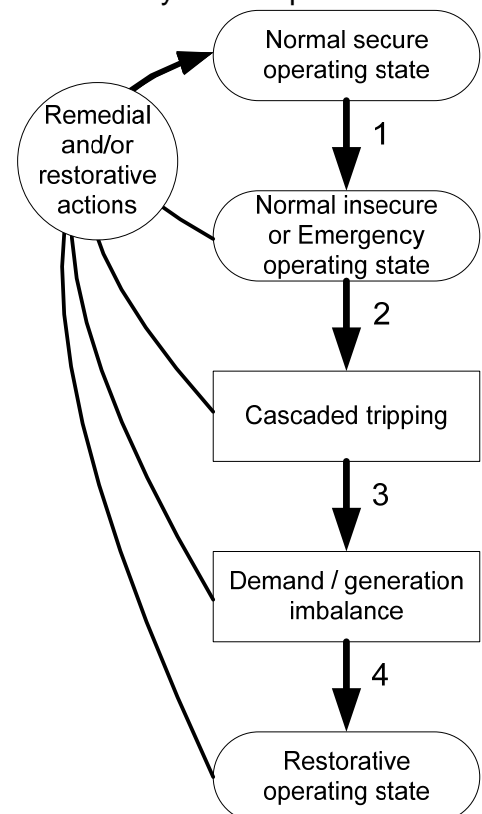


Models and methods for risk analysis of extraordinary events

Power system operation and management requirements are escalating due to society's increased dependency on electricity as well as a continued evolution of the power system. A reliable supply of electricity is recognized as vital for the society, to which extraordinary events pose a severe threat.

An extraordinary event refers to a disturbance in the power system with a potentially high societal impact and a low probability to occur, often resulting in a wide-area interruption or a total blackout of the power system. Due to their unpredictable nature, difficulties arise to economically justify major reinforcements of the power system to prevent extraordinary events from occurring. Increased insight into and understanding of these events is an important step in order to develop and assign appropriate remedies to limit the consequences of future events.

Wide Area Monitoring Systems (WAMS) is identified as a field where applications could be efficiently utilised in order to increase the system security to extreme contingencies without major economical investments. The enhanced information made available by a WAMS enables improvements in many fields related to monitoring, control, and protection of the power system. Hence, development of applications in wide area monitoring, protection, and control is a topic of high interest.



Generalised sequence of extraordinary events

The PhD study is funded through the Knowledge-Building (KMB) project “Vulnerability and security in a changing power system”.

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Load Current Interruption in Air

Load Switches for medium voltage are old and comparably simple devices. At Universities this has for long time, not been a prioritized research area and very little information is published directly related to this topic. However, there is now a growing interest from industry to establish a more fundamental understanding of the processes involved in current interruption in order to further develop today's products. The main focus is to make a switch compact and cheap as well as environmental friendly. By using air as interruption media it is challenging to make it compact and therefore it is needed to develop more precise and accurate design rules.

My research has an experimental approach where each parameter which plays a role in the process is studied separately. If the interruption process for a specific current will succeed or not depends on;

- Cooling performance of the switch
- Voltage transients after interruption
- Contacts separation speed
- Geometry of interruption chamber
- Materials used in the product

To study these issues, very high demands is put on the laboratory circuit. The circuit has to handle power up to 30MW as well as being able to tune the current and voltage transients independently of each other. No such circuit existed when I started my project, not here in Trondheim and not what we know about, anywhere else either. The last 1,5 years I have spend my time on building this circuit. I estimate it will be finished before Easter this year.

In parallel to this activity I also run experiments on ablation materials. These plastic materials have shown to have high rate of degassing when exposed to an electric arc. The result is that the arc looses energy and is cooled. For example can an arc chamber made of POM compared to PTFE, quench an arc with double as high current. We are focused on a wide range of plastics and additives in our research and have so far got promising results for publication.

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Evaluation, classification and grouping of operational states

The SINTEF Energy AS project “Integration of methods and tools for security of electricity supply analysis” has as main objective to establish a comprehensive methodology for security of electricity supply analysis, by integration of system reliability analysis with the power market analysis. The different parts of this security of supply analysis can be seen in figure 1.

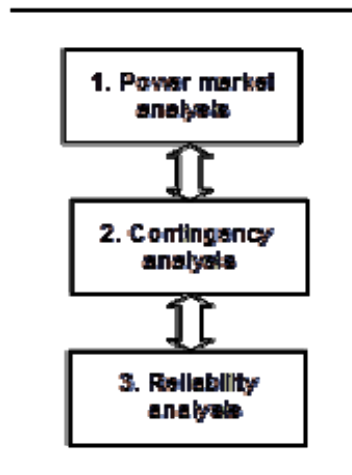


Figure 1: Methodology for security of supply analysis

The power market model combine generation and power market scenarios into a set of operational states, described by generation, load and network topology. These operational states are then transferred to the contingency analysis, where the consequences of different contingencies are determined.

The set of operational states is very large, and to run a full contingency analysis for a large power network is not feasible, especially if higher order contingencies are included in the analysis. The objective of my PhD study is to reduce the number of operational states that needs to be analysed in the contingency analysis, while maintaining an adequate base for the reliability analysis.

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Stochastic short term optimization of hydro power production

Stochastic optimization tools for hydro power production has been subject to research and put to industry use among Nordic hydro power producers since the 70's. The deregulation of the power market in the 90's created increased need for short term optimization tools. This led to the development of the deterministic optimization tool SHOP (by Sintef Energy research) and the implementation of this tool in industry.

The increased integration of intermittent new renewable power sources in the power system and the increased transfer capacity and trade across national borders imposes new challenges to short term scheduling: More volatile prices and increased activity in intraday, balancing and capacity markets. Stochastic optimization models creates more robust strategies given uncertain scheduling conditions and are therefore preferred in this setting.

My research focuses on price uncertainty and bidding strategies in the day-ahead spot market, intraday market and markets for ancillary services. Research topics include:

- Probabilistic forecasts for price
- Decomposition methods
- Quantification of the gains of stochastic methods versus deterministic
- Bidding strategies for multiple markets with similar or related products, but different time horizon

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Correct Street and Roadway lighting

At all times and every condition

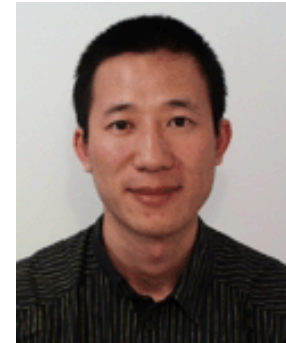
During the last decade an increasing focus on energy efficiency has led to a global initiative to reduce use of electrical energy in all public and private sectors. Norway has close to 1,3 million street and road lighting fixtures, representing an annual electrical consumption of around 0,8-0,9 TWh. The main goal of this PhD is to find the possible energy saving potentials in these installations, and establish the best street lighting control approach for the future.

This PhD study investigates the current status of Norwegian street lighting installations and compares it to the neighbouring country Sweden, concerning lighting quality and lighting levels. This is done by two field studies, one on Norwegian roads (CIE selected papers, CIE x034, pp 75-79, 2010) and a comparative study of Swedish roads (Light and Engineering, edition 3, 2010). As the status is investigated in the first two studies, the possible use of new technology for lighting and control of lighting are investigated to analyze how to provide “Correct Street- and roadway lighting - at all times and every condition”. This is done by two field studies, one investigating the “Use of LED for Street- and roadway lighting”. The last field study is based on the weather influence on the needed contributions of artificial lighting to maintain a stabilized Luminance level on the road surface. Lighting of roads is done as a “worst case scenario” design and is mainly not designed as dynamical installations. By controlling for the current scenario concerning weather and surface condition, it is investigated how to best adapt a dynamically control scenario for a street lighting system.



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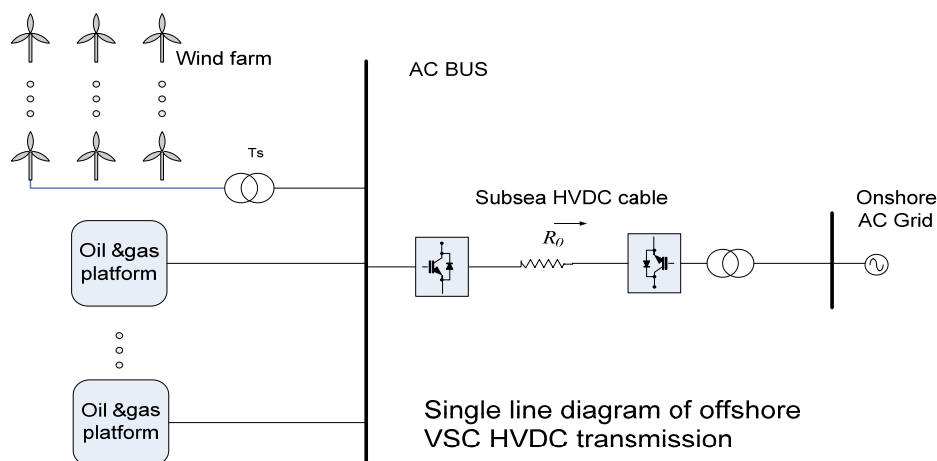
Deep-sea Wind-farm Electrical System and Power Transmission

The main purpose of PhD thesis is to answer the question that how the converter interfaced offshore wind generation can support grid, which highlight both offshore wind energy transmission solutions and grid assisting functions such as reactive power support & inertial control.

In the first stage of project, investigation on offshore wind farms transmission solutions will be excuted with focuses on the two HVDC transmission solutions: Voltage Source Converter (VSC) HVDC and Line-Commutated Converter (LCC) HVDC. The below aspects need to be considered: A: Fault or short circuit response and dynamic stability (mainly for VSC, shown in figure 1), B: Power quality including flicker and harmonics.

In the second stage of project, the investigation will be aimed to propose the wind farm level control strategy, which is able to deliver ancillary grid support functions such as active power regulation, reactive power support and inertial control function. First, the thesis will summarize the development of wind farm models, for designing and verification of voltage and frequency control strategies. Second, the performance of ancillary grid support functions during normal operation and various faults conditions will be investigated and improved. At last, the economic and technical issues of wind farm's reactive power ancillary service will be investigated, which clarify the possibility for the future implementation.

In the year 2011, Bing presented the conference paper titled 'Faults mitigation control design for grid integration of offshore wind farms and oil & gas installations using VSC HVDC' at the SPEEDAM International Symposium with issue date: 14-16 June 2010. And Bing has acquired 34.5 ECTS from the 4 PhD courses in study plan and has completed 87% of 1 year teaching duty.



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Advanced Control of Power Converters

Introduction

The demand for clean and sustainable energy is increasing at a rapid rate with the ever growing population of the world. This is not only true for the more developed western world, but the growing economies in the developing world. Although renewable energy sources hold great promise, but with the present day solar or wind technologies, the conventional energy sources like oil, gas and coal have to be utilized for at least next couple of decades. It is thus essential that these existing energy resources of the world are harnessed in an environment friendly manner. However, many of the world's major existing oil and gas reservoirs located either onshore or in shallow water offshore are in decline. With increase in the consumption of oil and natural gas, more innovative solutions for tapping the energy resources located in more challenging locations have to be taken up. One such step in this direction is the exploration of oil and natural gas in under sea locations remote from the shore. This requires lot of engineering expertise because of the extreme working conditions and the need for a fail safe operation. The downtime of failure for these critical products can be enormously high. Reliable and fault tolerant operation is thus an important criterion for designing these products.

Mathematical modeling and design of control system for power electronic converters connected in subsea power system, different converter topologies, optimal modulation and control algorithms will be investigated. For subsea applications both ruggedness and low losses are of vital importance. Making design for high reliability and high efficiency are two important challenges. Advanced and fault tolerant control methods will be applied to the control of power converters in order to minimize harmonic components, control resonances and to increase the reliability. In such cases explicit Model Predictive Control (MPC) can be applied. This method, in addition to other suggested control algorithms, such as virtual flux, virtual adaptive impedances and active damping will be investigated in the sub project. Due to the weak power grid in offshore power systems it is important to have a control system for the power electronic converter which is very robust and can "ride-through" large disturbances in the power grid.

Multilevel inverters have a high number of power semiconductors, and consequently, the possibility of a failure is much higher. Hence, the identification of possible faults and the operation under faulty conditions are of great importance. Due to the high number of components, the

detection of a fault can be complicated in principle. However, the availability of powerful microprocessors made it possible to develop very intelligent methods for fault detection. To allow for operation under fault condition, some methods include additional hardware and modify the topology. They also modify the software, particularly the modulation strategy.

Evaluation and power circuit topologies for fail tolerant and fail safe operation will be investigated and suitable controller architecture will be suggested. Laboratory prototypes for relevant applications will be specified and established in cooperation with PEC, (Power Electronic Center, Siemens).

Project Background

This PhD project is initiated and funded as part of the SIEMENS-NTNU OIL AND GAS OFFSHORE PROJECT, which is a cooperative project between Power Electronic Center of Siemens and NTNU.

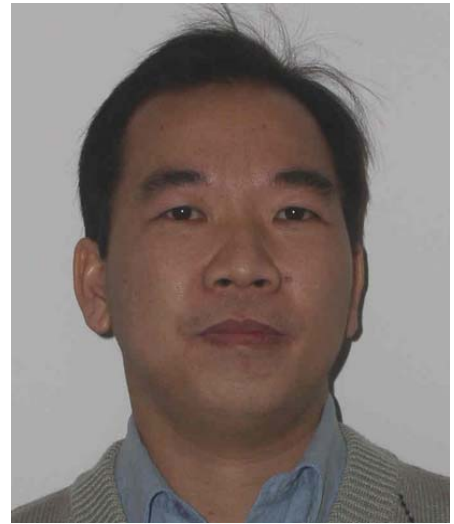
Completion Date

The PhD project is assumed to be concluded in the early of 2014 spring semester. 24.01.2014 has been stated as ending date.

This project is supervised by Prof. Lars Norum from the Department of Electrical Power Engineering at NTNU.

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Experimental studies on streamers of electrical prebreakdown and breakdown phenomena in long electrode gap

Today most of the dimensioning rules for transformer dielectric insulation are empirical and based on long experience and less on basic scientific understanding. However, most of the present understanding related to prebreakdown and breakdown phenomena in insulating dielectric liquids are of qualitative nature. In other words, the basic phenomena leading to electrical breakdown is presently very well documented but not yet fully understood.

In addition, the branching mechanism of streamer has still been unknown as well as the nature of streamer in fast event, the exact electric field at the head of streamer, and streamer mechanism for fast mode have been other unanswered questions. Therefore, the investigation streamer in each compositions of transformer oil in long gap and then compares among them in order to get more understanding is very essential.

This research will focus on examining streamer initiation and propagation in slow modes and fast modes for dm gap as well as electric field calculation at the head of streamer and electric field distribution in inter-electrode gap space are also studied. In addition, the effect of additives on streamer, the mechanism of enhancing or reducing of streamer branches, and the development of streamer mechanism are other topics of research.

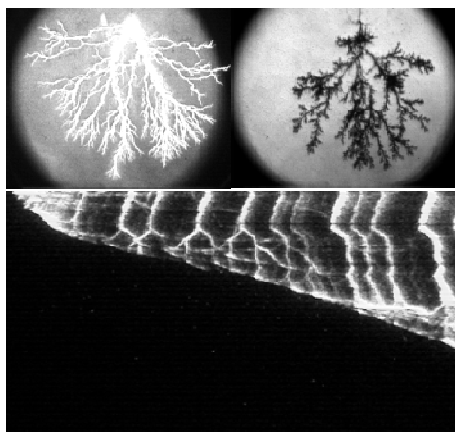


Figure 2. streamer images.

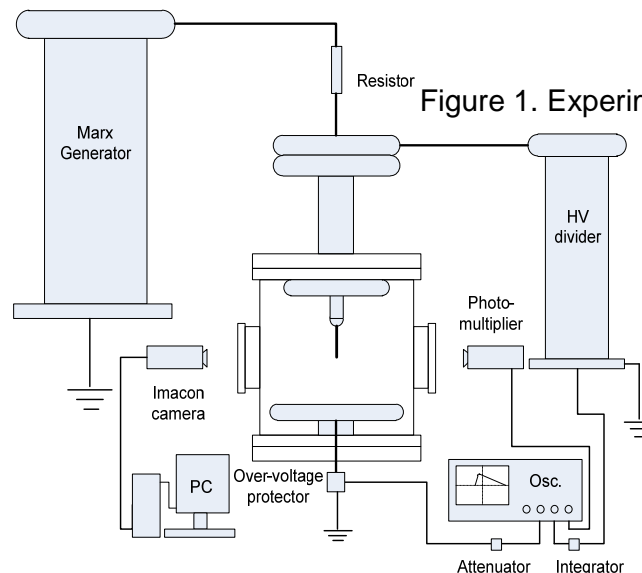


Figure 1. Experiment setup.

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New Concepts for Converters and Control of Photovoltaic Systems

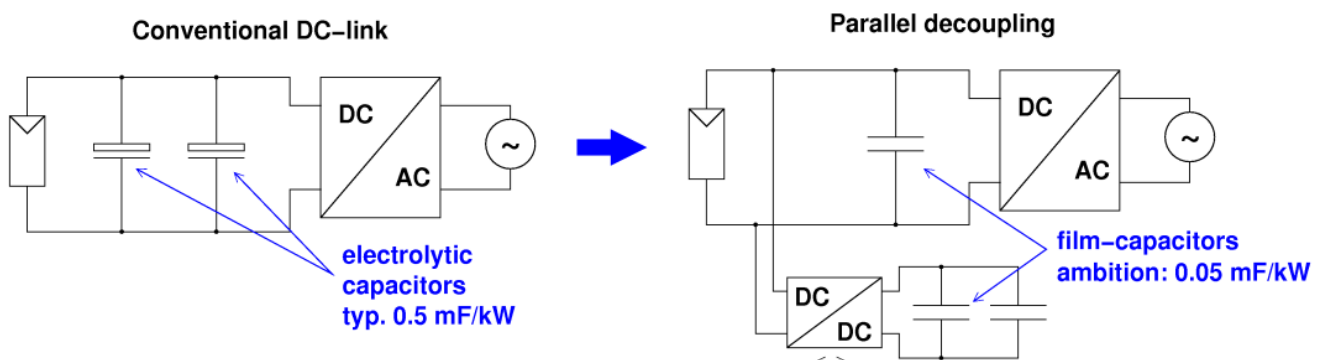
Photovoltaic systems for electricity production have become a popular source of clean, renewable energy. The number of PV-installations is quickly growing and PV delivers a considerable percentage of the energy production in some countries already. Converters are a central part of all PV-systems and they are produced by industry in all power ratings.

Still, a lot of optimization and adjustment to new technological needs can be done on the converters. Some working areas are: Reduction of the specific price per kW, increase of reliability and lifetime, safety improvements and additional functions like interfaces to energy storage elements or backup-functionality.

Safety on the DC-side of PV-installations is one of the main aspects of my project. In state-of-the-art installations the occurrence of an electrical arc due to a fault in a DC-connection of the system cannot be detected. This can lead to damage or fire. As a countermeasure, an arc-detector which can be integrated into the PV-modules is developed in the project.

Another part of the project is the increase of reliability and lifetime of single-phase inverters by reduction of the DC-link capacitance. When this capacitance is small enough, the very reliable film-capacitors can be used instead of their electrolytic counterparts with limited lifetime. For this aim an additional converter stage is introduced, which decouples the capacitors from the DC-link.

The same concept of parallel decoupling can also be used for longer term energy storage in a battery. The result could be a "smart" PV-system which can deliver power on demand and more independent from the current irradiance condition.



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Modelling of European energy markets for low emission scenarios

This research work is part of a multi-disciplinary project called LinkS. The LinkS project combines global top-down climate related research and bottom-up regional energy system design. The main objective is to develop an integrated decision support framework for more sustainable energy infrastructures.

The LinkS project's starting point is a set of emission mitigation scenarios which are studied using a global energy-economy-climate model called GCAM.¹ This model calculates supply, demand and prices for energy and agricultural products and the emission of 16 climate gases and the effects of these emissions on the climate system.

One issue with the GCAM model is that the results are on a highly aggregate level (the world is, at the moment, modeled as fourteen regions) and it does not model any infrastructure within each region. To see how the GCAM projections play out in detail, demand and price forecasts from GCAM will be used as input for SINTEF's EMPS² model. The particular strength of the EMPS model in this setting is that it incorporates the stochastic nature of power generation from renewable energy sources.

Mitigating climate gas emissions will inevitably increase the share of power production from renewable sources which will require transmissions of large amounts of power and gas across Europe. By using the EMPS model it will be possible to verify the feasibility of the GCAM results, provide adjustments for the projections and unveil where investments in transmission systems will be necessary along the projections.

¹ GCAM - The Global Climate Assessment Model

² EMPS - European Multi-area Power market Simulator

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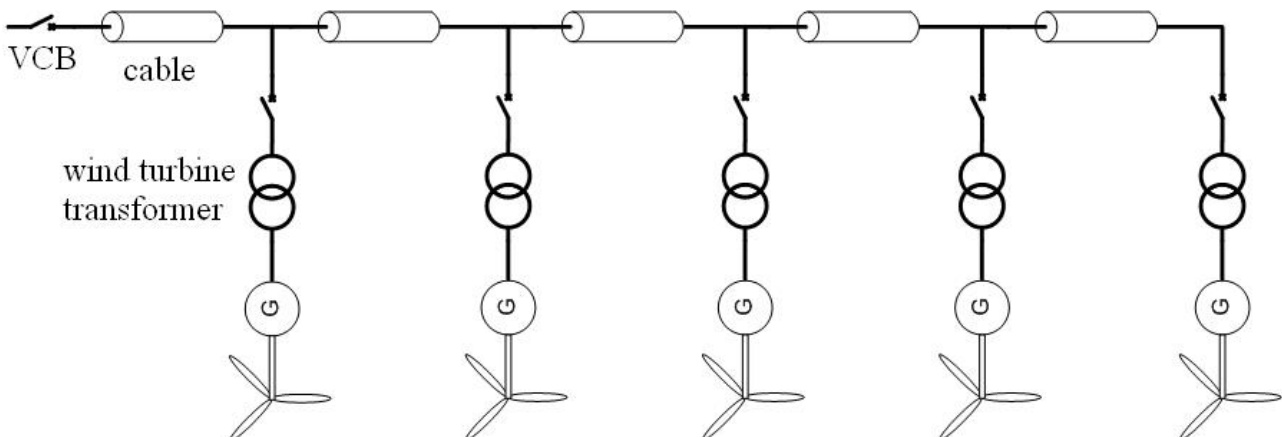
Switching Transient in Offshore Wind Farm

In order to connect the offshore wind turbines, large undersea cable connections are required. Since each wind turbine has a step-up transformer, a row of Offshore Wind Farm (OWF) composed of cable-transformer sections which are linked in series.

Wind Turbine Transformers (WTTs) can be exposed to dielectric failures, internal insulation damage as well as external one due to overvoltages, e. g. energization overvoltages, earth fault, current chopping, and voltage escalation of VCB during disconnection.

The aims of this PhD study are:

- 1- Study and simulation of transient phenomena in a row of OWF and focus on the potential of resonance phenomena with the help of black box modelling of WTTs. In this phase, the external overvoltage on transformer terminals are investigated in different transient phenomena for various OWF configurations.
- 2- Development of the High Frequency (HF) modelling of WTTs based on gray box models such as Multi Transmission Line (MTL) model and Finite Difference Time Domain (FDTD) model and the analysis of resonance overvoltages along transformer winding. A 500 KVA transformer with probes along the winding is applied to validate the HF model of WTT with experiments.



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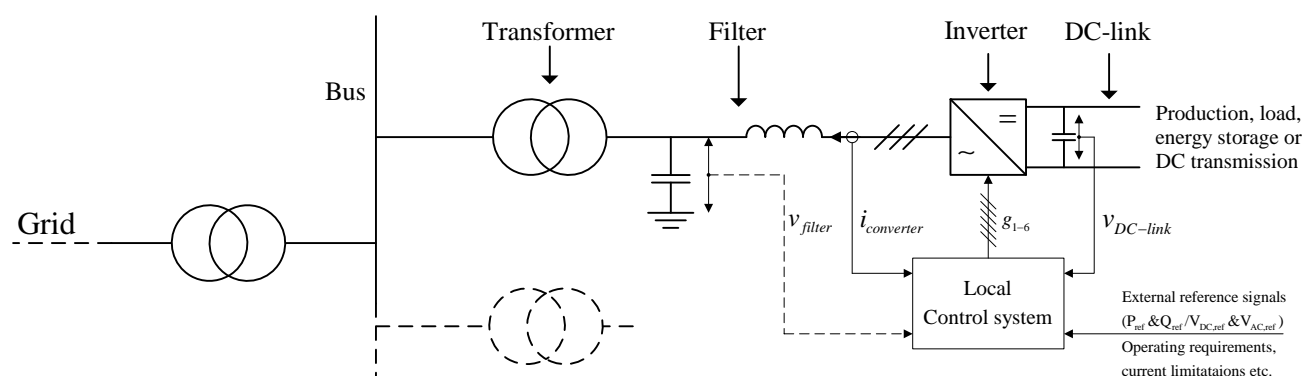
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Control of Voltage Source Converters in weak grid conditions

The development in power semiconductors and digital control techniques, together with increased utilization of renewable energy sources, is leading towards widespread use of three-phase Voltage Source Converters (VSC's) in the power system. The applied control strategies will therefore have significant influence on not only the performance and stability of individual grid interfaced VSC's, but also on the power grid in areas dominated by power electronic converters. Especially for challenging operating conditions, like in weak power systems or during voltage sags and unbalanced conditions, the control of VSCs can have crucial influence on the nearby power system. Due to the high controllability, there is however a significant potential for implementing controller functionality that can improve the system performance or stability.

Local control systems for regulating currents, voltages, and/or active and reactive power in a VSC can be made to operate with any power factor, and the same control structure can thus be used for many different applications. This work has therefore been following a general approach, where the purpose has been to study limitations to stable operation of the converter, without limiting the studies to a particular application. A corresponding structural overview of a system with a VSC connected to a power system is shown in the figure below. Currently, the main focus is on investigating methods for converter operation based on the concept of "Virtual Flux," and a generic method for "flux" estimation under unbalanced voltages and variable grid frequency has been developed. It has also been investigated how the estimation of "Virtual Flux" can be utilized to extend the range of stable operation of the converter by changing the point of synchronization to the grid. This approach can be followed both for traditional control system implementations based on voltage measurements and for grid-voltage-sensor-less control. The developed technique for estimation of "Virtual Flux" is intended for combination with different strategies for control of instantaneous active and reactive power. This will be a basis for developing and comparing control techniques that can maintain a wide stability range of the converter and at the same time support the operation and power quality of the grid.



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Hydrogen Assisted Distributed Renewable Energy Systems based on Photovoltaic Energy

Depletion of fossil fuels and growing awareness of impact of environmental pollution have motivated immense interest towards alternative energy micro grids and distributed generations (DGs). Wind and solar are two major renewable energy sources suitable for DG application. The advantages of installing distributed generations near load sites are many: serving both utilities and consumers by eliminating the need for long distribution infrastructures, raising environmental standards, increasing supply reliability, peak shaving and ancillary services.

Traditionally, off-grid (stand-alone) power systems based on wind and solar are often operated in combination with diesel generators and/or long term storage batteries for backup. To solve the problem of low energy density of batteries, and low efficiency, high O & M cost and environmental impact of diesel generators, a solution based on hydrogen energy for long term storage and peak shaving battery with reduced capacity for short term storage is an attractive alternative. Especially in remote area power systems, replacing diesel generator with hydrogen produced locally from renewable energy like wind and solar is likely to be cost competitive on purely economic grounds. This is mainly because heavy costs of diesel fuel transportation and maintenance in remote areas are eliminated. However, due to high capital cost, installation and use of renewable energy based hydrogen power systems remain a challenge. The key to implementation of these environmentally sound technologies is, therefore, the ability to reduce costs. One way to reduce a fair share of this cost factor lies in developing optimal/near optimal operating strategies which increase output and prolong life time by reducing cost of performance degradation and loss of efficiency (of fuel cells and electrolyzers). The focus of this PhD study is modeling, control and optimal/near optimal operating strategies in fuel cell assisted photovoltaic (PV) power systems. Hydrogen storage solution as weak grid support and for short term fluctuation smoothing in high PV penetration grids is also treated in this PhD thesis.

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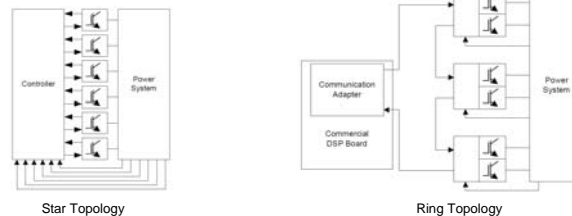


Integration of Electrical Power, Propulsion and Control in Future Energy Efficient Marine Power System (Advanced Control of PE Converter)

It is predicted that the future marine electrical systems will be intensely different from today's systems. In order to achieve top speed and maximum acceleration, the demand for highly reliable electrical power supplies continues to increase. A reliable local power distribution system with multiple primary and secondary energy sources with several back-up energy storages should be design for the future marine power system. In order to reduce the complexity, cost and power loss in the distribution system Electronic Power Distribution System (EPDS) is proposed for the future with the power electronics converters interface between energy generation, distribution and consumption.

Future research may be focused on system architecture design and optimization while standardizing the power electronics converters. Power Electronics Building Blocks (PEBB) is introduced to reduce cost and design effort while improve the system reliability by standardization the power electronics converters. The key functional component for PEBB is the power electronics controller, where Digital Signal Processor (DSP) or FPGA are commonly used. The conventional way of the control interface between the controller and the gate drivers is known as star topology where a number of wires are needed for the switch commands, fault signals and all the sensor values. Ring topology is proposed to significantly reduce the number of wires, installation cost and noise interference.

This research will mainly design and implement a high speed reliable control architecture to meet the future EPDS in marine power system with PEBB. A power converter prototype will be developed at the end of the research for marine/subsea application. The proposed control architecture will be designed in a user-friendly and standard form mostly will expend from ring topology. It is expected that the proposed control architecture is fully decoupled between software and hardware with minimum engineering effort.



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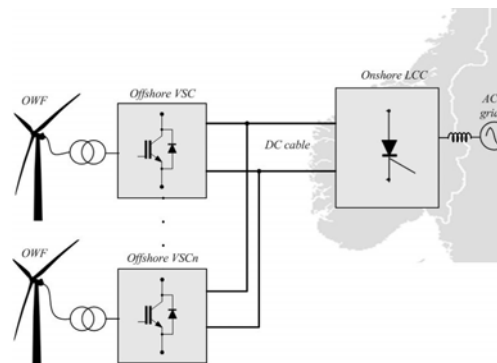
Use of HVDC VSC and LCC options to incorporate offshore wind or wave power to the Norwegian grid

Because the increase environmental concerns around the world, there has been a significant development in renewable energy in the past decade, among the available options for renewable it is recognized that large size offshore wind farms are well placed to accommodate the future increase in the wind energy generation. High Voltage Direct Current (HVDC) transmission may be the only feasible option for connection of a wind farm if the distance exceeds 100-150 km, therefore is a good option for offshore wind farms.

There are two different HVDC transmission technologies, i.e. voltage source converter (VSC HVDC) using controllable switches like IGBTs and line-commutated converter HVDC (LCC HVDC) using controllable switches like thyristors. The principal characteristics of VSC transmission are: (i) active and reactive power exchange can be controlled flexibly and independently; (ii) no commutation failure problem; (iii) no communication required between two stations, and etc. However, VSC transmission does have higher power loss compared with an LCC HVDC system. Typically, the power loss at full load for the two converters is about 3.5 % for VSC transmission and 1.5 % for LCC HVDC. LCC HVDC can be used at very high power levels, the reliability and availability of LCC HVDC have been demonstrated by more than 30 years of experience. However, it is necessary to provide a commutation voltage in order for the offshore LCC HVDC converter to work properly.

Hybrid HVDC consist of VSC and a LCC connected on the same DC link as it shown in Fig. 1. Hybrid option is aimed at combining advantages of both HVDC technologies. Among the advantages: LCC can handle high power level, so several VSC can be connected to one LCC making the investment more economical. Because the switching mechanism. LCC have lower losses compared with VSC, therefore hybrid HVDC should have lower losses than VSC HVDC. LCC has a much lower cost than a VSC, Hybrid will also less expensive. Despite it is intended that one LCC supports the entire HVDC, LCC reliability has been proven for many years, so the hybrid concept is expected to be very reliable.

In this work is expected to identify improved solutions for the transfer of offshore wind or wave power to the onshore AC grids using hybrid option, composed by VSC and LCC HVDC. The project will also clarify some of the system aspects when using VSC-HVDC or LCC-HVDC.



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Magnetic Forces and Vibrations in Wind Power Generators

Offshore wind energy will play a vital role in future world energy markets specially in US, UK and North Europe. There are a lot of challenges in developing offshore wind installations requiring strong R&D activities. One of the most important challenges in offshore installations is mechanical forces acting on wind turbine structures due to wind and also ocean waves. In addition, difficulties in access to the wind turbines and maintenance problems must be considered.

Direct-driven permanent magnet generators can reduce maintenance and increase system reliability in offshore installations by eliminating the gearbox. Direct-driven generators have a large diameter and short stator length and therefore moderate mechanical stiffness. This problem is very important especially in offshore applications, when large units are preferable.

The focus of this research work is on how to reduce the magnetic forces and vibrations in direct-driven permanent magnet generators. The magnetic flux in the airgap of the electrical machines contains harmonics and sub harmonics producing the magnetic forces and in special cases may cause critical vibrations in the generator. The main aim of this project is mitigation of magnetic vibrations in generator. The work will focus on winding arrangements and rotor and stator geometry in the design procedure.

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Effect of Moisture on Space Charge Accumulation in Polymeric HVDC Cable Insulation

The use of polymeric insulation materials for submarine HVDC cable systems has been introduced quite recently, with the first cable installed in 1999. Previously, oil-filled and mass-impregnated cables were the only practical alternatives, but the low production and maintenance costs of polymeric cables and the development of specialized HVDC polymers, extruded HVDC cables have become viable.

Submarine power cables are often equipped with a metal or polymeric water blocking sheath. Metal sheaths are excellent water barriers, preventing water from entering the underlying polymeric semiconductors and insulation. However, in cases where the metal is cracked or where a polymeric water barrier is used, water will migrate into the insulation system. The amount of water absorbed and the rate of absorption depends on the type of polymers, both in the insulation and the sheath, and the temperature of the system.

In a polymeric DC cable, space charge, i.e. net positive or negative charge distributed in a region of space, will accumulate. Space charge accumulation occurs when there is an imbalance between injected and transported charge in an area, causing a buildup of excess charge. The presence of space charge in the insulation will cause a distortion in the local electric field. At HVDC cable service conditions, which include temperature gradients and polarity reversals, this field distortion may cause the local electrical field to exceed the breakdown strength of the insulation, leading to insulation breakdown. While the occurrence of space charge in polymeric insulation is a well-known phenomenon, very little has been done to examine the effect absorbed water may have on charge accumulation and transport.

The goal of this PhD project is to investigate the effect of moisture on space charge accumulation. Both the space charge distribution and the conductivity in polymeric materials with varying water content will be of interest. The results of the research will give an indication on how critical the prevention of water intrusion into polymeric HVDC cables is, and possibly yield design criteria on water barriers for such cables.

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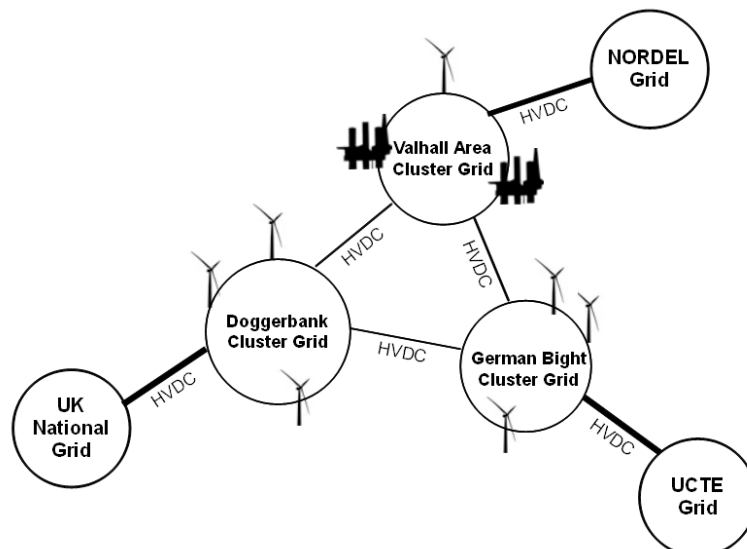


Development and Operation of the North Sea Super Grid

Due to the current focus on offshore renewable energy installations there will be a need for connecting these installations to the onshore grids. Electric supply of oil installations from onshore is also focused due to the environmental perspective. The paneuropean electricity market highly demands stronger interconnections for efficient balancing of regional fluctuations due to the increasing share of volatile electric power sources in Europe. The North Sea Super Grid (NSSG) will evolve in the future to address these issues.

With the distances involved to these candidate installations, HVDC (High Voltage Direct Current) will be of major importance. The wind farms which are now under construction are realised with internal AC grids. The NSSG will therefore consist of both AC and DC and could be seen as a hybrid (AC+DC) grid, but the share of those technologies is not known yet.

The focus of this research work is on how to design such an offshore network which must be operated in parallel with the existing AC onshore grid. Reliability, technical performance, robustness and flexibility will be of major importance. Other issues to consider are the protection and sectioning of the system in case of component fault. With the large future plans for offshore renewable installations it is of crucial importance to minimize the worst case amount of disconnected power. The results could be partly also relevant for a possible redesign of the Krigers Flak wind park connection and the Desertec project.



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Electromagnetic data communication along a steel pipe in layered media

This project aims at improving the understanding of electromagnetic data communication along steel pipe completions through layered rock formations. The long term goal is to develop a mathematical model to predict the communication range based on real resistivity and rock layer profiles. The second part of the project will comprise development and validation of the theoretically obtained results. The work will also include a practical part to validate the theoretical models developed in the project.

It is known that electromagnetic data communication based on extremely low frequent signalling along the production tubing or along well casings has an interesting potential for wireless communication in oil wells. Work in this area have almost exclusively been focused on exploiting this principle in Measurement While Drilling systems, using the drill string as a waveguide for either acoustic or electromagnetic signals. However, using the same principle to achieve wireless communication from reservoir sections of producing wells has received much less attention. In such a scenario, the available power for transmission is usually much lower. Then, it is of interest to have a more accurate characterization of the downhole wireless channel. In particular, to characterize the influence of changing rock formations and their inherent conductivities along the well, since this greatly affects signal loss in the system. With better channel knowledge, advanced signal processing techniques can be applied to extend range and/or improve signal-to-noise ratio (SNR) for future systems based on this communication principle.

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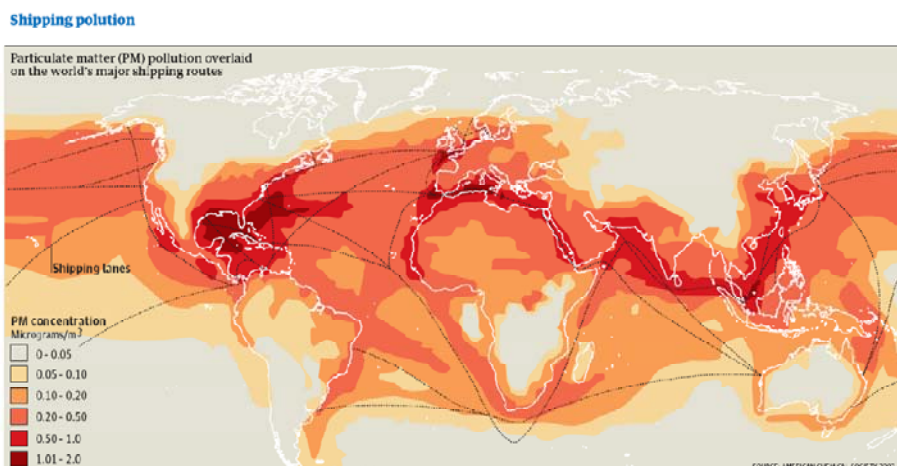
Integrated Marine Electrical Power and Control Systems

Environmental concerns and rising cost of oil have intensified the need for low emitting and fuel efficient vehicles. The shift to electric propulsion from conventional mechanical propulsion in marine vessels aligns with this need. Reduced fuel consumption, possibility of utilizing light high speed diesel engines, less propulsion noise and less space consuming are some of the advantages of electric propulsion in marine vessels.

Electric propulsion has also facilitated a hybrid utilization of energy sources and storages. Operation in all-electric mode is a main advantage of hybrid ships, which makes it possible to have zero emission sailing when ship is approaching or leaving harbor. In this mode the speed is low and energy storage can take over to supply propulsion motors. This can affect the local air quality which is becoming a major concern at harbors and nearby cities. As indicated in the figure the impact of shipping on local air quality is significant.

The operation of energy storage in hybrid propulsion is not limited to all-electric mode. During the normal operation it can also be utilized effectively so that ICEs operate at their optimal efficiency work point. This is normally done by charging the storage when load is below the optimal value and discharging it when load is beyond optimal.

The focus of this research is on design a new control system for hybrid electric ships based on power electronics giving the advantages of zero emission operation and optimal efficiency. The important point is to adopt an effective strategy for power and energy management, in such a way that the ship runs at an overall optimum operating point. Proper hybrid topology, appropriate modelling of the power system, stability control, and reliability are other major concerns. Finally, an experimental system is to be implemented to validate the methodology by practical results.



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Dynamic modelling, estimation and controller of linear electric machines

There is a clear evidence that percussive drilling (even without rotary) can often produce higher rate of penetration (ROP) than conventional means, such as rotary drill or diamond drill, especially in some hard formations such as siliceous granite, sandstone, limestone, dolomite, etc. The down the hole (DTH) hammer driven by tubular reciprocating translational permanent magnet synchronous motor (RTPMSM) will be a good option for such applications. My project is to develop the dynamic modelling, estimation and controller of linear electric machines for this application. The self-sensing controlled tubular RTPMSM is aiming at providing more efficient power transfer and higher reliability for percussive drilling in oil and gas industry with the high temperature and high pressure conditions. The movable secondary shown in Fig.1 will be driven by electromagnetic force between permanent magnet and primary winding. And this electromagnetic force will be amplified by the system. Therefore, the huge impact force converted from electric power source by RTPMSM to the hammer bit will be used to collapse the rock.

The equivalent model is shown Fig. 2. RTPMSM contains an inner oscillating subsystem and an outer oscillating subsystem. The RTPMSM connecting to the drill cylinder by an external spring consists of a casing with primary winding, a movable secondary with laminations of permanent magnets and iron, two gas springs inside of each end of the casing, an external spring connecting with drill cylinder. The very high pressure at the gas chamber results in a high oscillation frequency of the system. The movable secondary driven by the alternating electromagnetic force moves back and forth at the forced resonant mode. The casing oscillates under forces from the inner subsystem and impacts the hammer bit at its maximum speed when the movable secondary moves up and down. The electromagnetic force is produced by the interaction between the permanent magnets and the primary winding carrying alternating current.

In order to make the hammer bit collapse the rock, the first control objective for the tubular RTPMSM is to oscillate the casing set. The system is a mass-spring oscillatory system so that the trajectory of the driving force---electromagnetic force should be with the alternating waveform and its frequency should be equal to the natural frequency of the system. The second control objective for the system is to produce the impact force, which is high enough to collapse the rock. The third objective is to optimize the input voltage in order to maximize ROP and minimize the losses. Different input voltages with the same amount of energy input, such as cosine, rectangular, and harmonic waveforms can be used to oscillate this system in order to obtain certain ROP. But the system will have different efficiencies with different input voltages.

Simulation result in Fig.3 shows that the electromagnetic force is amplified by RTPMSM. Fig.4 shows the rate of penetration of the system.

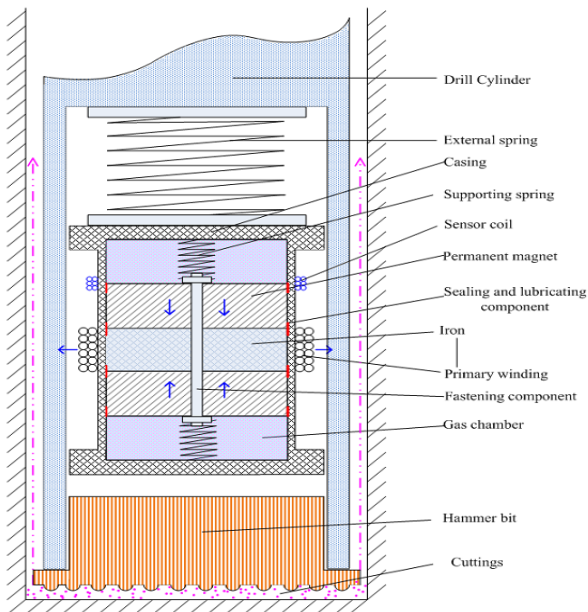


Fig. 2 System topology of DTH hammer driven by tubular RTPMSM

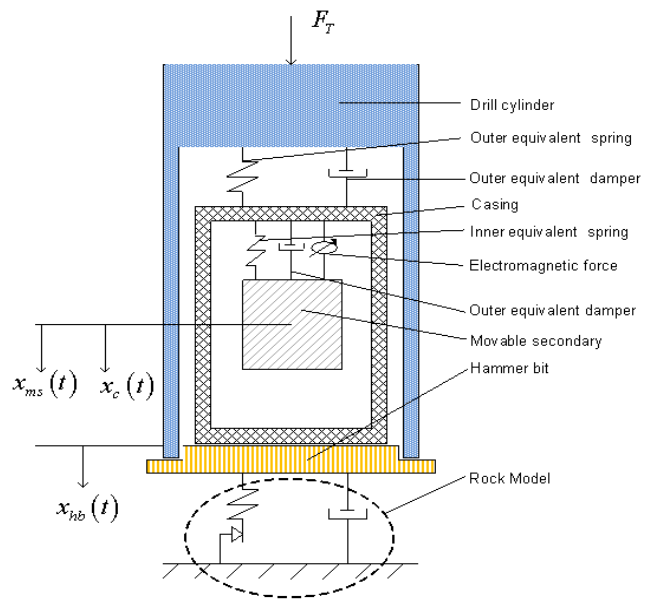


Fig. 1 Equivalent model of DHT hammer system

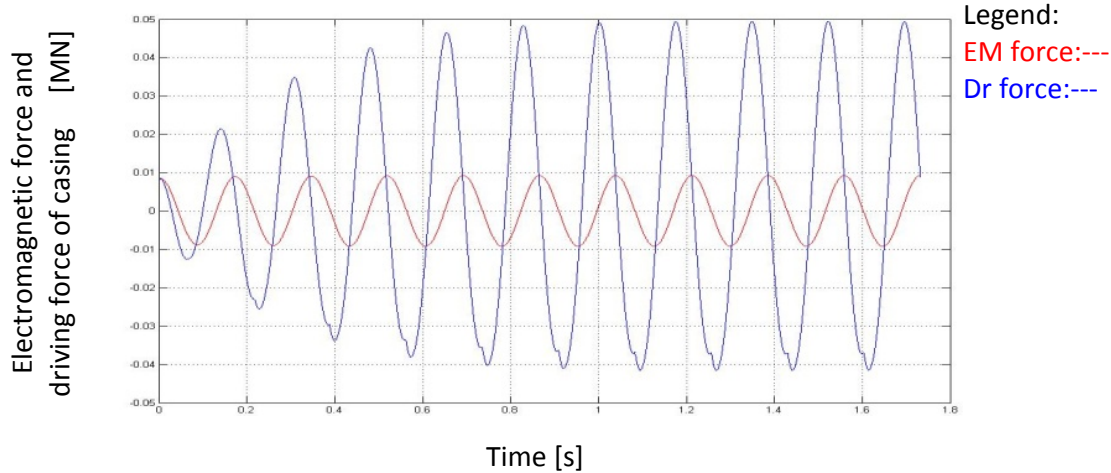


Fig.3 Force amplification with cosine wave input voltage

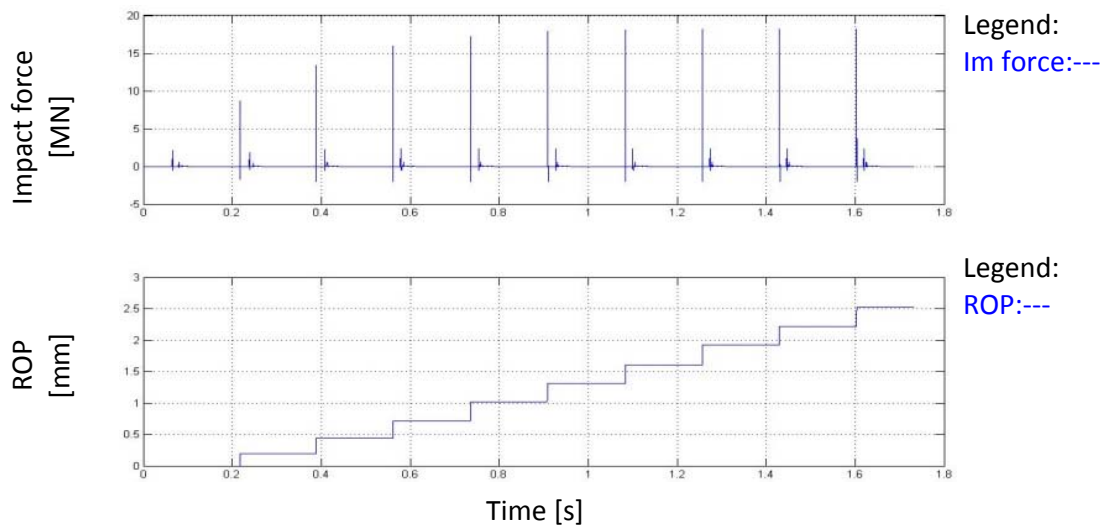


Fig.4 Impact force and ROP with cosine wave input voltage

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Coupled 3D models of permanent magnet generators with very large diameters and with a special focus on losses

Generator is the key component of the WECS. For offshore application, the design of generator should take into account all of the offshore features: harsh environment, large unit preferred, high reliability required and compact design desired. Furthermore, generator design is a highly multidisciplinary task that involves knowledge from electromagnetic, thermal design and so on. PM machine is very promising in offshore wind application. So far, a lot of research has been conducted on the radial flux machine and machine up to 4MW is now available in the commercial market.

Ironless AFPM machine is very promising in term of torque density and high efficiency, and it can be a competitive solution to meet the demand for large power (4-10MW) high performance generator in offshore wind application. However, there are insufficient knowledge on high power ironless AFPM, such as how to choose the slot/poles combination, how this combination influences the machine parameters, losses and torque, and how to accurately predict the machine performance with the latest modeling approach without making the expensive prototype.

The focus of this research work is to research and develop the 3D modelling approach in design of 10MW ironless axial flux permanent machine. Accurate modeling approach is to be studied, especially in losses/torque calculation. System level modeling approach and coupling modeling of EM-Thermal field is to be studied.

In this research, an analytical method for sizing of the ironless AFPM machine is to be developed. 3D FEA that is commonly regarded as the most accurate approach is to be adopted. In order to reduce the solving time in FEA, high performance computing (HPC) platform will be established for this research.

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Year	Name	Title
Febr. 2011	Krøvel, Øystein	Design of Large Permanent Magnetized Synchronous Electric Machines – Low Speed, High Torque Machines – Generator for Direct Driven Wind Turbine – Motor for Rim Driven Thruster
	Chen, Anyuan	Investigation of PM machines for downhole applications
2010	Chiesa, Nicola	Power Transformer Modeling for Inrush Current Calculation
	Danielsen, Steinar	Electric Traction Power System Stability Low-frequency interaction between advanced rail vehicles and a rotary frequency converter
	Nordgård, Dag Eirik	Risk Analysis for Decision Support in Electricity Distribution System Asset Management
	Greiner, Christopher Johan	Sizing and Operation of Wind-Hydrogen Energy Systems
2009	Eek, Jarle	Power System Integration and Control of Variable Speed Wind Turbines
	Kulka, Arkadiusz	Sensorless Digital Control of Grid Connected Three Phase Converters for Renewable sources
	Guidi, Giuseppe	Energy Management Systems on Board of Electric Vehicles, Based on Power Electronics
2008	Pedersen, Per Atle	Forces Acting on Water Droplets in Electrically Energized Oil Emulsions; Observations and Modelling of Droplet Movement Leading to Electrocoalescence
	Østrem, Trond	Reliable Electric Power Conversion for Connecting Renewables to the Distribution Network
	Skjellnes, Tore	Digital Control of Grid Connected Converters for Distributed Power Generation
	Næss, Bjarne Idsøe	Operation of Wind Turbines with Doubly Fed Induction Generators During and After Line Voltage Distortions
	Belsnes, Michael Martin	Optimal Utilization of the Norwegian Hydropower System
	Helseth, Arild	Modelling Reliability of Supply and Infrastructural Dependency in Energy Distribution systems

Year	Name	Title
2007	Di Marzio, Giuseppe	Secure Operation of Regional Electricity Grids in Presence of Wind Power Generation
	Gullvik, William	Modeling, Analysis and Control of Active Front End (AFE) Converter
	Andreassen, Pål	Digital Control of a Zero Voltage Switching Inverter for distributed Generation of Electrical Energy
	Hoff, Erik Stjernholm	Status and Trends in Variable Speed Wind Generation Topologies
	Løken, Espen	Multi-Criteria Planning of Local Energy Systems with Multiple Energy Carriers
	Ericson, Torgeir	Short-term electricity demand response
	Mauseth, Frank	Charge accumulation in rod-plane air gap with covered rod
2006	Maribu, Karl Magnus	Modeling the Economics and Market Adoption of Distributed Power Generation
	Catrinu, Maria	Decision-Aid for Planning Local Energy Systems. Application of Multi-Criteria Decision Analysis
2005	Hellesø, Svein Magne	Dynamic analysis and monitoring of power transmission cables using fibre optic sensors
	Lund, Richard	Multilevel Power Electronic Converters for Electrical Motor Drives
	Bjerkan, Eilert	High Frequency Modeling of Power Transformers - Stresses and Diagnostics
	Vogstad, Klaus-Ole	A system dynamics analysis of the Nordic electricity Market: The transition from fossil fuelled toward a renewable supply within a liberalised electricity market
2004	Øvrebø, Sigurd	Sensorless control of Permanent Magnet Synchronous Machines
	Kristiansen, Tarjei	Risk Management in Electricity Markets Emphasizing Transmission Congestion
	Korpås, Magnus	Distributed Energy Systems with Wind Power and Energy Storage
2003	Botterud, Audun	Long Term Planning in Restructured Power Systems: Dynamic Modelling of Investments in New Power Generation under Uncertainty
	Ettestøl, Ingunn	Analysis and modelling of the dynamics of aggregate energy demand

Year	Name	Title
2002	Kolstad, Helge	Control of an Adjustable Speed Hydro Utilizing Field Programmable Devices
	Norheim, Ian	Suggested Methods for Preventing Core Saturation Instability in HVDC Transmission Systems
	Warland, Leif	A Voltage Instability Predictor using Local Area Measurements. VIP++
	Ruppert, Christopher	Thermal Fatigue in Stationary Aluminium Contacts
2001	Larsen, Tellef Juell	Daily Scheduling of Thermal Power Production in a Deregulated Electricity Market
	Kleveland, Frode	Optimum Utilization of Power Semiconductors in High-power High-frequency Resonant Converters for Induction Heating
	Myhre, Jørgen Chr.	Electrical Power Supply to Offshore Oil Installations by High Voltage Direct Current Transmission
2000	Oldervoll, Frøydis	Electrical and thermal ageing of extruded low density polyethylene insulation under HVDC conditions
	Doorman, Gerard	Peaking capacity in Restructured Power Systems
	Hystad, Jan	Transverse Flux Generators in Direct-driven Wind Energy converters
	Pleym, Anngjerd	EMC in Railway Systems. Coupling from Catenary System to Nearby Buried Metallic Structures.
1999	Gjerde, Oddbjørn	Systemanalyser av skipselektriske anlegg
	Evenset, Gunnar	Cavitation as a Precursor to Breakdown of Mass-Impregnated HVDC Cables
	Hvidsten, Sverre	Nonlinear Dielectric Response of Water Treed XLPE Cable Insulation
	Pálsson, Magni Tor	Converter control design for Battery Energy Storage systems applied in autonomous wind/diesel systems
	Warland, Geir	Flexible transfer limits in an open power market. Congestion versus risk of interruption.
1998	Hans Kristian Høidalen	Lightning-induced overvoltages in low-voltage systems.
	Selvik, Eirik	Information models as basis for computer-aided tools.
	Huse, Einar Ståle	Power generation scheduling A free market based procedure with reserve constraints included.

Year	Name	Title
1997	Bjørn Harald Bakken	Technical and economic aspects of operation of thermal and hydro power systems.
	Ole-Morten Midtgård	Construction and assessment of hierarchical edge elements for three-dimensional computations of eddy currents.
	Qing Yu	Investigation of dynamic control of a unified power flow controller by using vector control strategy.
1996	Gerd Hovin Kjølle	Power supply interruption costs: Models and methods incorporating time dependent patterns.
	Tom Fagernes Nestli	Modelling and Identification of Induction Machines
	Bjørn Sanden	XLPE cable insulation subjected to HVDC stress. Space charge, conduction and breakdown strength
	Gisle Johannes Torvetjønn	Switchmode Powersupplies Optimum topologies and magnetic components
1995	Lars Arne Aga	A Laboratory Platform for Theoretical and Experimental Research on Rotor Flux Oriented Control of Motor Drives.
	Knut Styve Hornnes	A Model for Coordinated Utilization of Production and Transmission Facilities in a Power System Dominated by Hydropower
	Rolf Ove Råd	Converter Fed Sub Sea Motor Drives
1994	Snorre Frydenlund	A study of voltage stresses in ARC furnace transformers due to switching operations
	Anne Cathrine Gjørde	Multifactor Ageing of Epoxy - The Combined Effect of Temperature and Partial Discharge
	Arne Nysveen	A Hybrid Fe-Be Method for Time Domain Analysis of Magnetic Fields Involving Moving Geometry
	Feng Xu	Power System Security Assessment. Identification of Critical Contingencies and Outage Distance by a Zone Filter
1993	Bjørn Alfred Gustavsen	A study of overvoltages in high voltage cables with emphasis on sheath overvoltages.
	Svein Thore Hagen	AC breakdown strength of xlpe cable insulation
	Olve Mo	Time Domain Simulation and Modelling of Power Electronics Circuit. Development of a Simulation Tool
	Terje Rønningen	Internal faults in oil-filled distribution transformers. Fault mechanisms and choice of protection.
	Gorm Sande	Computation of Induced Currents in Three Dimensions

Year	Name	Title
1992	Per Hveem	Computer Aided Learning, Simulations, and Electrical Motor Drives.
	Ståle Johansen	Energy resource planning a conceptual study of a multiobjective problem.
	Astrid Petterteig	Development and Control of a Resonant DC-link Converter for Multiple Motor Drives
	Bendik Storesund	Resonant overvoltage transients in power systems
1991	Jonny Nersveen	Kvalitetskriterier og helhetlig planlegging av innendørs belysningsanlegg.
	Torbjørn Strømsvik	Kraftelektronikk som kilde til forstyrrelser i fordelingsnettet.
	Alf Kåre Ådnes	High Efficiency, High Performance Permanent Magnet Synchronous Motor Drives
1990	Eilif Hugo Hansen	Bruk av kunstig lys og lysmanipulering for styrt produksjon av laksefisk.
	Guijun Yao	Modelling, Dynamic Analysis and Digital Control of PWM Power Converters