Risø DTU

Test Facility for Grid Connection Characteristics of Wind Power Plants

Final report

Risø-I-Report

Test Facility Project
Test Facility Report Risø-I-3100(EN)
Publication date : 1st May 2011

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Risø DTU
National Laboratory for Sustainable Energy

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Abstract (max. 2000 char.):

This is the final report of the EUDP-supported project entitled "Test Facility for Grid Connection Characteristics of Wind Power Plants". The project investigates various technical options for a test facility to emulate different electrical grid conditions at the site of the forthcoming National Test Centre for Large Turbines at Østerild, in Denmark. The test facility will provide wind turbine manufacturers with the opportunity to test turbine properties to a greater extent than presently possible. This will enable both turbines and standards to be developed to assist the integration of increasing wind power in power systems around the world in the future.
Following the assessment of technical concepts the project focuses on the chosen solution and considers the organisational and business case for running the facility. A budget cost for the establishment is formulated, together with a funding plan.
Finally, an implementation plan is presented that will carry the project forward through to establishment and operation .

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Preface

This interim report describes the first phase of a project dealing with the development of an advanced test facility in connection with the National Test Centre for Large Wind Turbines at Østerild, which will enable the wind power industry to develop and test new grid connection solutions, and to validate the grid connection characteristics of wind power plants.

The project was initiated in the context of the Megavind working group dealing with "Integration of wind power in the energy system". The project is endorsed by the Megavind Steering Committee and is in excellent agreement with the Energy Authority and Megavind strategy in that area.

A very strong project team has been assembled to include manufacturers (Vestas, and Siemens Wind Power), energy companies (DONG and Vattenfall), component manufacturers (ABB and Siemens) and academia (DTU and Aalborg Universities). The project is managed by Risø DTU National Laboratory for Sustainable Energy whose experience and contacts enable them to co-ordinate the interests of such a diverse group. The project is carried out in communication with the Danish TSO Energinet DK.

The project is partly funded by the Energy Authority ("Energistyrelsen") through its Energy Technology Development and Demonstration Programme EUDP file no.: 64009-028 and partly by the companies / institutions participating in the project. The quite significant contribution from EUDP is gratefully acknowledged by the project group.

The very active participation in and contribution to the work in the project group by the industry and the developers clearly demonstrates the strong interest and commitment of the stakeholders to the objectives of the project.

The interim report describes the outcome of the work as per 1st February 2011 with emphasis on the details in the functional requirements of the test facility and with outlines of the possible technical solutions and organisation of the test facility.

Due to the proprietary nature of the information provided by the commercial stakeholders this Interim Report is issued as Confidential with a distribution limited to the stakeholders and the Energy Authority (ENS).

1 Introduction

This interim report describes the first phase of a project dealing with the development of an advanced test facility in connection with the National Test Centre for Large Wind Turbines at Østerild, which will enable the wind power industry to develop and test new grid connection solutions, and to validate the grid connection characteristics of wind power plants.

The background for the project is that grid compliance and grid connection characteristics are becoming increasingly important for modern wind power development. During the expansion of wind power in the last century, grid compliance was mainly concerned about the impact that wind power had on the local voltage quality for neighbouring electricity consumers. This lead to requirements being set for power quality characteristics, which could be tested with dedicated power quality measurement equipment. Today, wind power has reached a much larger scale in many power system areas, and thus wind power has an increasingly significant impact on power system operation and control on a national and international level. This development has resulted in the need for specific requirements for the wind power plant's behaviour both in normal operation conditions and under fault conditions when the grid is disturbed. Therefore, simple power quality measurement equipment alone is no longer sufficient to perform a power quality test. These days, a grid compliance test also requires test equipment that can emulate grid disturbances in order to test the response of the wind power plant to these disturbances.

The rapid development in wind power has led to frequent updates of the grid code requirements from transmission system operators (TSOs), especially with regard to the grid compliance of large wind farms. These new requirements have pushed the wind power industry to develop the electrical design and control of wind turbines, and also to provide solutions that include auxiliary equipment besides the wind turbines. Furthermore, with the targets that have already been set for wind power development internationally, there will be even more focus on wind power grid compliance in the future.

At present, a power quality test according to IEC 61400-21 [4] requires that the test equipment emulates voltage dips at the wind turbine terminals to validate the simulated response of a wind turbine to such grid disturbances. For that purpose, the wind power industry currently uses mobile test equipment based on voltage division with impedances ("short circuit" test equipment). This equipment has very limited functionality, determined by the current requirements of TSOs for the test and validation of wind turbine response to voltage dips.

In addition to the power quality requirements modern grid codes specify, in detail, the responses requested of wind turbines and wind farm control systems which include frequency response, voltage control, significant reactive power capabilities, voltage dip and swell capabilities, response speeds, ramping rates, etc., all of which are features that need to be developed, tested, validated, incorporated in computer simulation tools and, it is expected at some point, certified.

This project was initiated in the context of the Megavind working group dealing with "Integration of wind power in the energy system". It endorsed by the Megavind Steering Committee and is in excellent agreement with the Energy Authority and Megavind strategy in that area.

The purpose of the project is to develop an advanced and comprehensive test facility that will enable the wind power industry to develop and validate a much wider range of grid connection characteristics of wind power plants than is possible at present. The test facility will be based on modern power electronics solutions, aiming at maximum flexibility to enable the more advanced testing of characteristics that are expected to be required in the future. For optimal benefit, the grid test facility shall be located at the Danish national test station for large wind turbines at Østerild, ensuring that it will be available for the development and test of all aspects of turbines of future wind power plants. Furthermore, this location will assist in the testing of the impact that grid disturbances have on mechanical loads on the wind turbine structures, because the wind turbines at the test station will normally be instrumented for mechanical load tests as well.

The test facility shall fulfil the present needs for validation according to relevant grid codes, but it shall also be able to facilitate the tests of more advanced characteristics in the future. The project will specify these characteristics in more details as described in the report. A supplementary literature survey relevant to such a test facility is included in the appendices.

The approach of the project is based on active collaboration between the stakeholders in a very strong project team that has been assembled to include manufacturers (Vestas and Siemens), energy companies (DONG Energy and Vattenfall), component manufacturers (ABB and Siemens) and academia (DTU and Aalborg Universities). The project is managed by Risø DTU National Laboratory for Sustainable Energy whose experience and contacts enable them to co-ordinate the interests of such a diverse group. The project is executed in communication with the Danish TSO Energinet DK.

During the course of the project monthly meetings of the project team have been held in addition to exchanges between the participants of documents and other inputs via email. The work has been undertaken in the following four work packages (WP's), all of them headed by Risø DTU:

WP1: Functional specifications of the Test Facility

WP2: Possible functional solutions

WP3: Possible organisational solution

WP4: Proposed implementation plan

This interim report describes the outcome of the work as per Feb 1, 2011, with emphasis on the details in the functional requirements of the test facility and with outlines of the possible technical solutions and organisation of the test facility. The final report will present the results from all WP's including the implementation plan.

2 Functional description of the Test Facility

2.1 Introduction

The basis for this functional description is the range of tests that are relevant for the Test Facility to conduct. The description is a compilation of tests that are relevant now and the expected needs in the future. It should be noted that not all the technical concepts for the Test Facility would be able to fulfil all the requirements. This assessment of the different options is part of the performance versus cost evaluation exercise.

These can be categorised as follows:

1) Tests that are required today by regulators, customers and, particularly, grid codes (references [1] - [4]) worldwide.
2) R&D performance tests that manufacturers would like to carry out
3) Performance/control tests that wind farm developers/operators would like to carry out
4) Future tests that can be foreseen

The description focuses on the main equipment capabilities but auxiliary functions such as instrumentation, measurement, data logging, computer hardware & software are also important. Also included is the issue of the switchgear arrangement required. This matter revolves around flexibility (and, in no small part, safety): how many turbines can be connected to the various test facilities whilst leaving the remainder undisturbed and connected to the ordinary grid.

The Test Facility shall be able to satisfy both the current requirements for the testing of wind power plants and at the same time be sufficiently flexible to be able to meet the needs of future grid codes. In addition, the Test Facility should be able to support the development and testing of new wind turbine concepts with attention to the ability to emulate extreme grid conditions. The importance of the equipment's flexibility and capacity should be seen in the light of the fact that most TSOs update their grid codes every few years, so facilities built to handle specific grid codes will quickly be out of date. To guard against being outdated this facility should be able to accommodate turbines up to 16 MW installed capacity, operating at a power factor of 0.9. This represents what the manufacturers currently consider to be the size limit of the largest turbine permitted at Østerild.

Whilst not a test in itself, the computer simulation of a wind turbine and its various systems is an essential part of the design and development process by a manufacturer. However, wind farm developers and owners also use simulations, as do the transmission system operators and other authorities. It is therefore important that the simulation models are verified as to their accuracy and performance. To enable this, the Test Facility should provide the users with sufficient flexibility and comprehensive measurement of parameters to be used in the validation of their simulation models. So, whilst not a specific test, the test facility equipment should be able to exercise those (electrical) parameters that give the most problems when modelling the behaviour of a wind turbine. There should be sufficient data collection (measurement and logging) to provide a comprehensive set of data that can be used for validating a model. The model could represent the whole turbine or one or many sub-systems.

2.2 Description of tests for a single wind turbine

This chapter describes the relevant tests that are typically carried out with regard to the development and testing of wind turbines. These tests are done to assess the performance of an individual turbine and the technically ideal Test Facility should be able to handle all the tests.

It is envisaged that the Test Facility will be used to investigate a wind turbine's static and dynamic performance under specific grid situations, including both normal and disturbed grid conditions. The facility should provide the ability to change these electrical external conditions and so as to investigate the impacts on both the electrical and mechanical systems in the turbine.

Furthermore, tests will be carried out for the demonstration or certification of wind turbines, including the fulfilment of applicable grid codes.

In the following sections, the tests of the turbine under normal operating conditions are described first where the turbine follows the external conditions and make limited performance adjustments as necessary. This is followed by those tests during disturbed grid conditions where the turbine is to play an active part in contributing to changing the external conditions.

2.2.1 Active and reactive power control (normal grid conditions)

A wind turbine's generation of active power shall be able to be changed using an external set point. This functionality (response time, ramp rates, etc.) can be verified by measurement of the active power generated. The corresponding conditions are applicable for the wind turbine's control capacity for production and/or consumption of reactive power with reference to the specified PQ chart.

Changes in the set point can be verified without access to a test facility as the function can be activated via the wind turbine's internal control system, through SCADA equipment or a Power Plant Controller. However, without a special test facility, the range of the power tests - particularly with regard to reactive power – is limited by the restriction on voltage changes allowed at the public grid connection point. A test facility can be used to widen the possible test range because the voltage can be kept within the normal range even in cases of extreme reactive power production / consumption.

For disturbed grid conditions see section 2.2.11

2.2.2 Voltage control (normal grid conditions)

There are often requirements for wind turbines that concern voltage regulation at the connection point, where the wind turbines should take part in maintaining voltage stability. Wind turbines should thus be equipped with an ability to control reactive power to ensure that voltage variations are kept within defined limits under normal operation.

In order to validate that a wind turbine can control the voltage, the test facility should be able to emulate a grid which is subject to a voltage change. A simple way to do this is to emulate a grid with a Thévenin equivalent, i.e. an ideal voltage source in series with a resistance and a reactance. A change in the ideal voltage should then cause the wind turbine to change reactive power and thereby mitigate the voltage change. The ideal voltage should be able to change rapidly (typically within a few line periods) in order to validate the dynamic response of the wind power plant voltage control.

2.2.3 Voltage amplitude changes (normal grid conditions)

A wind turbine's production of active and reactive power should only be affected to a limited extend by voltage amplitude changes in the grid as long as these voltage changes stay within the wind turbines normal operating range.

In order to test how the wind turbines power is affected, the test facility should be able to emulate fast voltage changes within the normal operation range (nominal voltage ± 10-15%). Typical voltage changes are up to ± 4%.

2.2.4 Voltage unbalance (normal grid conditions)

The European voltage standard EN 50160 requires that the voltage unbalance in a power system is less than 2% for 95 % of the time. The 2% is a typical value, which is as a result of the fact that asynchronous machines will most often disconnect due to high negative sequence currents if the voltage unbalances are larger than 2 %. In some rural grids, higher voltage unbalances are common.

The test facility should be able to emulate relatively high voltage unbalances, preferably up to 4%. Such a test facility could be used to great advantage for the verification of the impact of voltage unbalances on a wind turbine's performance and the electrical & mechanical loadings.

2.2.5 Operation at alternative system frequencies (normal grid conditions)

Wind turbine manufacturers supply wind turbines all over the world, which is why turbines are developed for both 50 and 60 Hz frequencies. It will be useful to do the mechanical load and power curve verification on a 60 Hz prototype in Denmark. It is therefore appropriate that the Østerild Test Centre is able to carry out extended tests with the above power system frequencies.

In order to meet this test, the test facility should be able to provide normal grid conditions with two different system frequencies: 50 Hz and 60 Hz.

2.2.6 Harmonic emission assessment (normal grid conditions)

According to IEC 61000-3-6 [6], the harmonic emission from a sum of distorting installations can be calculated from the current distortion of the individual installations. This is used in IEC 61400-21 [4] as a method to assess the harmonic emission from a wind farm, based on a wind turbine type test measuring the current harmonic emission from a single turbine. This approach has shown to overestimate the harmonic emission significantly in many cases, because the measured current harmonics depend strongly on the grid resonances and background harmonics from other sources in the grid where the type test is performed.

In order to make a neutral test of the harmonic emission from the wind turbine, the current harmonic emission should be tested in an ideal grid where the voltage harmonics are zero. Such conditions (zero voltage harmonics) can only be obtained within a limited bandwidth, i.e. only for lower harmonic orders.

2.2.7 Grid resonances (normal grid conditions)

The purpose of this type of test is to investigate the resonance interaction between the wind turbine controller (sub-synchronous and low order below 7^{th} harmonic and the grid.

For this purpose, the test facility should not only be able to emulate an ideal grid free of voltage harmonics, but it should also be able to emulate a grid with frequency dependent impedance.

2.2.8 Voltage fluctuations caused by the turbine (normal conditions)

IEC 61400-21 [4] requires the testing of flicker emission from wind turbines during continuous operation and due to switching operations. In both cases, it is assumed that the current flicker emission from the turbine is independent on the voltage flicker. This assumption is more robust than the similar assumption for harmonics (see 2.2.6 above), but also the current flicker emission from a wind turbine depends on the voltage fluctuations on the wind turbine terminals.

The test facility should be able to emulate an ideal grid corresponding to the equivalent grids specified in IEC 61400-21. This means that the grid should be specified as a Thévenin equivalent with an ideal voltage source in series with a resistance and a reactance as in section 2.2.2.

2.2.9 PQ capabilities at different voltages and frequencies (normal)

This programme of tests is aimed at exploring the actual range of turbine performance, rather than fulfilling a specific requirement. It is thus dependent on the capabilities of the test turbine rather than on any particular grid codes as the actual performance limits of the turbine may well be better than required by the grid codes. The test facility can be used to define exactly how much better they are which is an exercise that, at present, is a simulation task.

A wind turbine’s power control quality should be able to be tested under these various voltage and frequency conditions, for example, different combinations of high/low voltage with high/low frequency when applied to continuous operation. Long term tests such as these at the lower voltage limits are useful to test thermal limits of the turbine’s sub-systems.

2.2.10 Frequency control & inertia response (disturbed grid conditions)

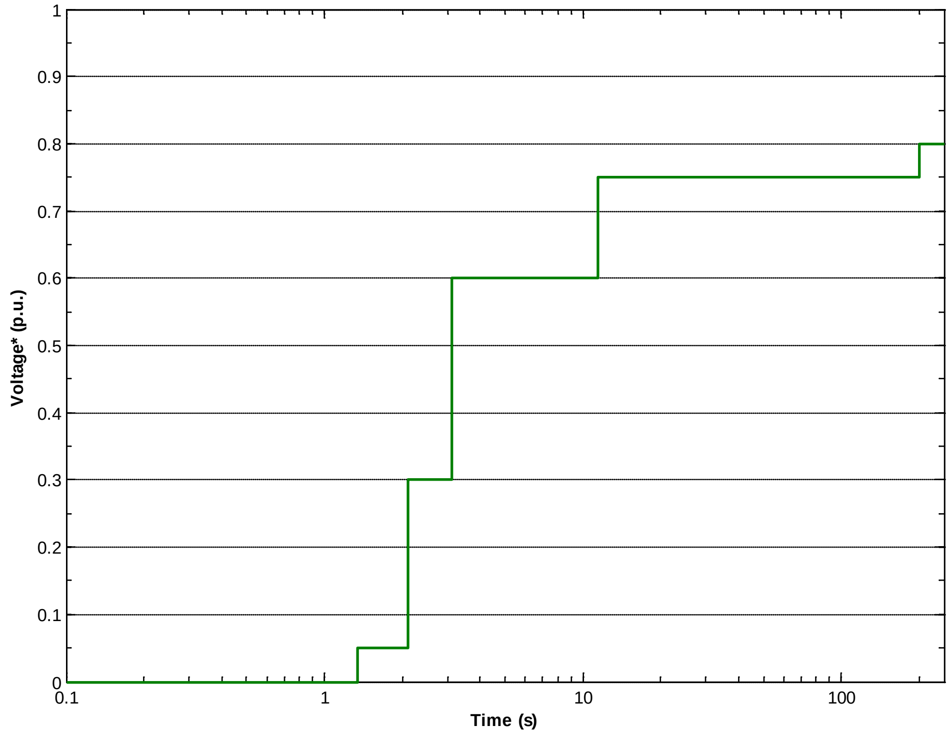
With a change in frequency in the power system, a wind turbine’s production of active power should be able to be controlled (frequency control) with respect to a defined characteristic with the aim of stabilising the frequency. This functionality (response time, ramping, dead band, etc.) can be verified through measurement of the active power generated.

A test facility can be used to emulate a frequency-weak grid and so a wind power plant’s contribution to the stabilisation and limitation of frequency variations in such a system can be documented. For example, it can be documented that wind turbines can:

- support the frequency when a power station falls out
- contribute to the mitigation of the frequency variations that follow wind speed variations in island systems that have a large proportion of wind power.
- support specific services of relevance for frequency control – more specifically the virtual inertia which may possibly appear in future grid codes.

2.2.11 Low Voltage Ride Through: LVRT (disturbed grid conditions)

A wind turbine shall be able to tolerate a voltage dip without decoupling from the grid where the parameters of the voltage dip (amplitude and duration) are specified in the relevant grid codes. Many studies have been performed to compare grid code requirements to LVRT, but these requirements have been subject to frequent revisions. A profile of showing possible future wind turbine LVRT capabilities is shown in Figure 1.



*Voltage at wind turbine LV terminals

Figure 1 Combination of various low voltage ride through profiles

During and after the voltage dip the wind turbine's production of active and reactive power should be controlled according to the grid codes. Some grid codes additionally require a double voltage dip ride through capability.

There are also corresponding requirements for the wind turbine's short circuit contribution (symmetric/asymmetric) when there is a fault in the surrounding electricity grid.

Apart from the testing of a wind turbine's required LVRT characteristics, the short circuit trials can correspondingly contribute by verifying a wind turbine's electro-mechanical and system wise properties – for example loading impact of mechanical/electrical components together with the verification of internal systems for control and protection.

The LVRT requirements are under continual development, notably the requirements for the wind turbine's ability to deliver reactive current during faults. Furthermore, there are requirements for controlling (response time, ramping, etc.) of the short circuit current. In order to verify these requirements it should be possible to reproduce the following types of short circuit events/faults:

- Three phase short circuit
- Two phase short circuit (phase-phase and possibly 2F-0)
- One phase short circuit to ground

2.2.12 High Voltage Ride Through: HVRT (disturbed grid conditions)

A wind turbine shall be able to tolerate overvoltages of a certain size and duration without decoupling from the grid. The required overvoltage size and duration are often specified in the relevant grid codes and a combined profile of known HVRT requirements is shown in . During and after the overvoltage period, the wind turbine's production of active and reactive power should be controlled according to the grid codes.

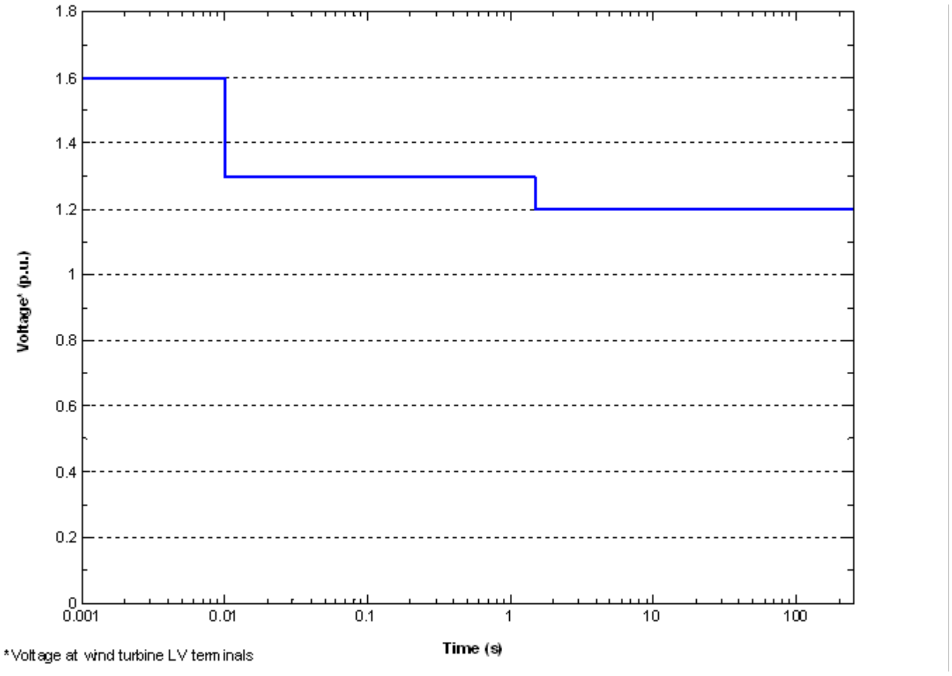


Figure 2 Combination of high voltage ride through profiles

2.2.13 Operation during frequency variations (disturbed grid conditions)

In accordance with various grid codes, a wind turbine shall remain grid connected in cases of frequency variation in a power system. Conversely, it is normally required that wind turbines disconnect if frequency variations exceed defined limits.

If the frequency variation (amplitude/duration) exceeds the setting for the wind turbine's internal frequency protection systems this should result in the disconnection of the wind turbine. The frequency tolerance and protection functions of a wind turbine can be verified through measurement. Finally the turbine's other systems should be tested for frequency tolerance, including the back-up systems, etc.

2.2.14 Voltage phase angle jumps (disturbed)

A phase angle jump most commonly occurs when one of a pair of parallel lines is disconnected. The test facility should be able to produce phase angle jumps at least to 20° so that a wind turbine's performance under these conditions can be tested.

2.2.15 Protection strategies (disturbed)

If the voltage amplitude or frequency exceeds the limits set by the wind turbine's protection system, then the wind turbine should trip. The test equipment should be able to provide external conditions that change rapidly enough (and to a suitable extent) that the turbine protection equipment is tested. IEC 61400-21 [4] describes a procedure for offline testing of the protection system, i.e. with the wind turbine stopped, but with a suitable test facility these tests can be carried out online, i.e. with the turbine connected and producing power.

2.2.16 Start and stop scenarios (disturbed)

The test equipment should be able to handle start and stop (including emergency stop) scenarios, giving sufficient measurement outputs.

2.3 Tests at a wind farm level

Whilst the ability of a turbine to fulfil a certain grid requirement is of utmost importance, it is generally at the high voltage interface with the public grid that the grid codes are enforced. From a developer's point of view the performance of the whole wind farm is, therefore, crucial and here the test facility equipment should also be able to perform certain functions to help assess and develop compliance.

2.3.1 Virtual wind farm emulation

The idea behind this test set-up is to operate one real turbine and include in the test a simulation of the remainder of a wind farm, with the inclusion of the wind farm controller.

A substantial part of the grid code compliance at wind farm level is achieved by the central wind farm controller which is measuring at the connection point and sending active/reactive power references to the wind turbines (for example frequency control and voltage control). So for assessment of wind farm compliance it is essential to include the wind farm controller in the test, either by simulation or by physical hardware. Turbine performance alone is not enough.

The proposed set-up is to use one actual turbine at the test centre, simulate the remaining turbines and have the test facility emulate the properties of the substation and grid connection. There are many possible combinations of the use of actual versus simulated components in this set-up but one arrangement is shown below in Figure 3.

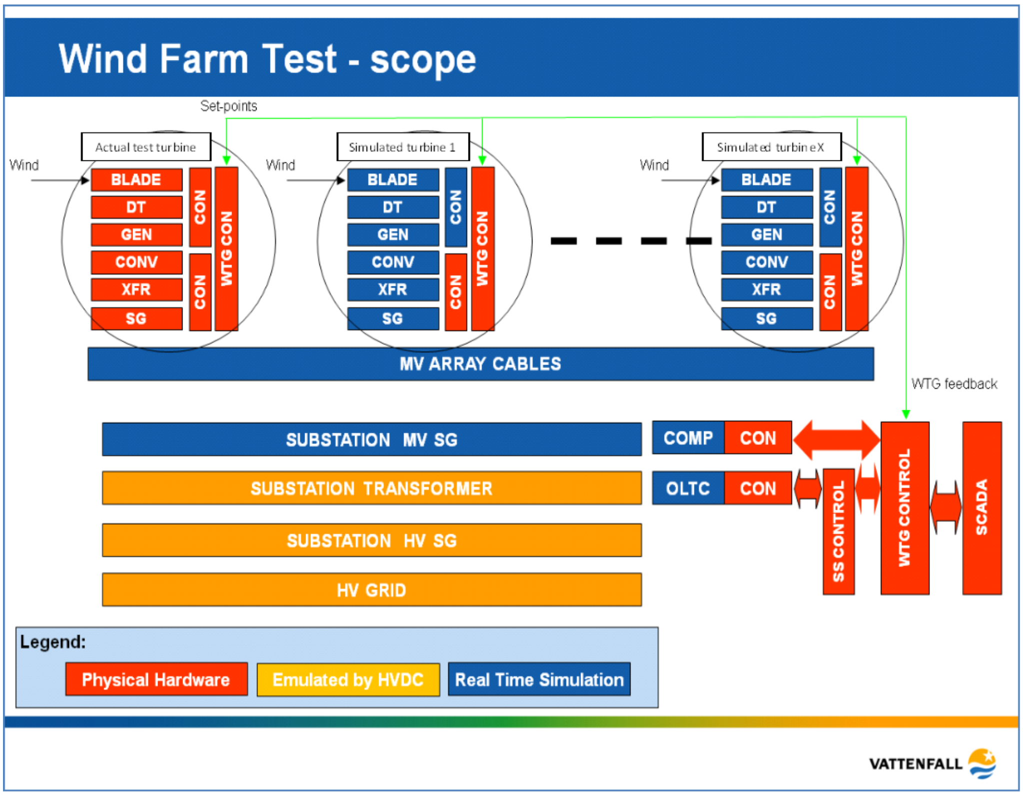


Figure 3 Actual hardware and simulated equipment for whole wind farm tests

Items shown in red are hardware-in-the-loop equipment: the actual test turbine, the WTG controllers of the simulated turbines, and the wind farm level controllers (sub-station/wind farm/SCADA). The remaining turbines in the wind farm are then real time simulations (shown in blue) and the grid connection equipment and the grid itself are replicated by the test facility equipment.

2.3.2 Operational tests on SCADA and SCADA-interface systems

Of further interest to those managing the contracts for developing a wind farm is the ability to have a hardware-in-the-loop simulation of the wind farm where the communication interfaces between various contacts/equipment can be tested in real time.

An example of this is shown below in Figure 4.

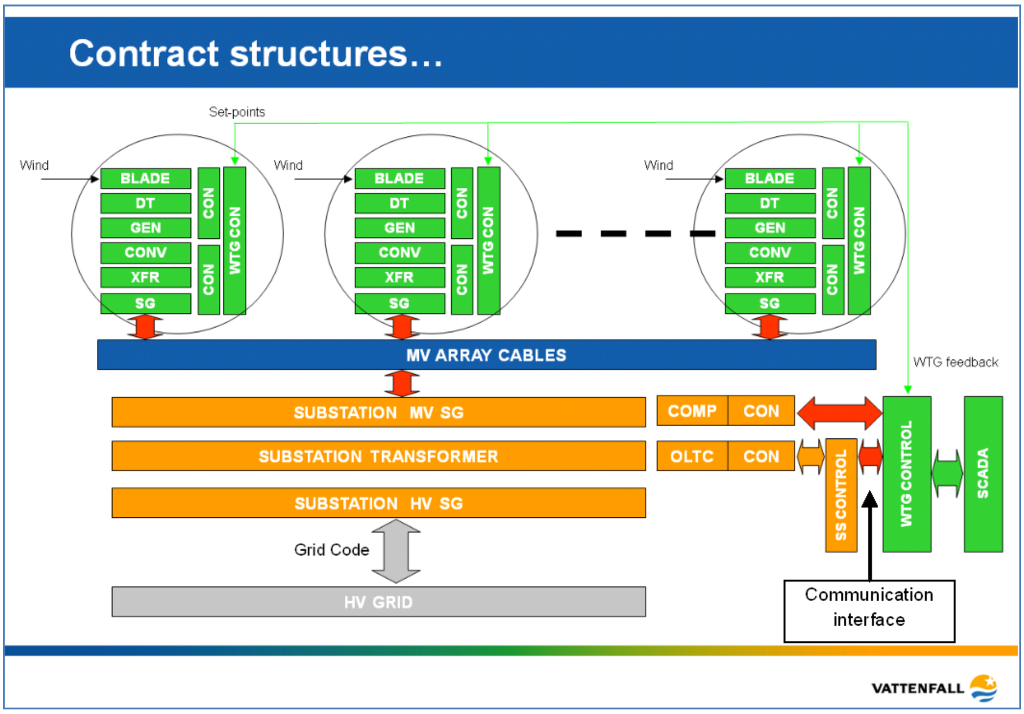


Figure 4 Example of contract interfaces showing the communication interface to be tested

The colour blocks indicate equipment provided by different contractors and there are, therefore, interfaces between them that could benefit from testing prior to deployment at the actual wind farm construction site. In particular, the communication interfaces between the "WTG Control" (the controller at the wind farm level) developed by the wind turbine manufacturer and the sub-station controller from the switchgear/transformer manufacturer as indicated on the diagram above can be tested in real time.

2.3.3 Compensation equipment model verification

The Test Facility can also be useful for validation not only of individual turbine models but also models of the interaction of compensation equipment (such as mechanical switched capacitors, SVC or STATCOM) with either single wind turbines or whole wind farms.

2.3.4 Tests of Power Plant Controllers

A wind turbine, or a group of wind turbines, is expected in the future to have a Power Plant Controller in order to ensure overall control and supervision of the wind turbine's production (active and reactive power) together with a number of supplementary functions.

At present requirements for the following control functions are known:

1. Frequency regulation
2. Balance regulation
3. Production limiting (absolute, delta, ramp)
4. Voltage regulation
5. Reactive power regulation
6. Low Voltage Ride Through – plant level

A significant number of grid codes describe requirements for more complex control functions which, in the long term, should be tested.

Depending on the implementation (principally for frequency measurement) of the frequency control (1) it can be essential to use a test facility whereby the electrical frequency can be varied – refer to Section 2.2.12.

The testing of the control functions (2-5) do not require access to special test facilities as the functions can be verified by measurement. These functions (response time, ramps, etc.) can be verified through measurement that can be done without access to a special test facility since the functions can be activated via the wind turbine's SCADA system or Power Plant Controller.

It should be mentioned that verification of a power plant and its associated control functions can be done by simulation (real time simulation) which can reduce the need for this function of a test facility at the Østerild Test Centre.

Testing of a power plant including the communication and auxiliary equipment can otherwise be verified by use of the test facility so long as this can be programmed to emulate the grid at an individual turbine's terminals.

2.3.5 Emulation of varying grid strengths

Although not a specified test in itself, the ability of the Test Facility to emulate various grid strengths has much value as this is usually only a simulation exercise and the true performance of the turbine/wind farm cannot be measured until it is installed at the wind farm site.

2.4 Functional description summary

Having considered each of the test requirements in detail, the next step was to distil this information down to a set of specific engineering criteria that would form the basis for the functional requirements for the test equipment. For each of the tests, each turbine manufacturer was individually invited to give their requirement for the identified parameter range, without reference to the other manufacturers. Risø DTU then took this information and, together with a survey of grid code requirements, put together a table that represented the boundaries of all the requirements.

This table was then discussed with each of the equipment suppliers in the project to assess the implications of the extreme ends of the parameter ranges on the costs of the equipment, following which the table was moderated. The final table is shown in Table 1 below.

Table 1. Summary of requirements to test facility from individual tests

Section	Test	Grid condition / Test designation	Parameter	Unit	Range
2.2.1	Active and reactive power control	Normal	Active power reactive power range	MW cosφ	16 MW 0,9
2.2.2	Voltage control	Normal	Voltage range, response time	%U_n s	U_n ±15% < 0.05
2.2.3	Voltage amplitude changes	Normal	Voltage, response time	%U_n, s	U_n ±15% < 50ms
2.2.4	Voltage unbalance	Normal	Voltage	%	0 – 4
2.2.5	Operation at alternative system frequencies f_n	Normal	System nominal frequency	Hz	50 Hz, 60 Hz
2.2.6	Harmonic emission assessment	Normal	Harmonic bandwidth	Hz	≤ 7f_n
2.2.7	Grid resonances	Normal	Harmonic bandwidth	Hz	≤ 7f_n
2.2.8	Voltage fluctuations caused by the turbine	Normal	Voltage, response time	%U_n, s	U_n ±15% < 50ms
2.2.9	PQ capabilities at different voltages and frequencies	Normal	Active power, Reactive power freq & voltage	MW cosφ Hz %U_n	16 MW 0.9 ±5 Hz U_n ±15%
2.2.10	Frequency control	Disturbed	Frequency & response time	Hz s	f_n ±5 Hz < 50ms
2.2.11	Low Voltage Ride Through: LVRT (incl. Double dip)	Disturbed	Voltage & duration	%U_n, s	U_n – 100% < 50ms
2.2.12	High Voltage Ride Through: HVRT	Disturbed	Voltage & duration	%U_n, s	U_n + 30% < 50ms
2.2.13	Operation during frequency variations	Disturbed	Frequency & df/dt	Hz, % f_n / s	f_n ±5 Hz 0.1% / 100ms
2.2.14	Voltage phase angle jumps	Disturbed	Angle & response time	deg, s	30º < 50ms
2.2.15	Protection strategies	Disturbed	Voltage level, freq level response time	%U_n, Hz, s	U_n ±15% f_n ±5 Hz < 50ms
2.2.16	Start and stop scenarios	Disturbed	-	-	
2.3.1	Virtual wind farm emulation	Power plant	-	-	
2.3.2	Operational tests on SCADA and SCADA-interface systems	Power plant	-	-	
2.3.3	Simulation model verifications	Power plant	-	-	
2.3.4	Tests of Power Plant Controllers	Power plant	-	-	
2.3.5	Emulation of varying grid strengths	Power plant	No load voltage (U), freq Grid impedance R + jX	%U_n Hz, Ω	U_n ±15% f_n ±5 Hz 0 ≤ R ≤ 100 Ω[1] 0 ≤ X ≤ 100 Ω

1 Calculated to cover the range from an infinitely strong grid (Z=0) to a grid with short circuit ratio 2 for a 8 MW turbine (Z=68 Ω for 33 kV grid)

3 Technical concepts for the Test Facility

3.1 Introduction

This chapter describes, in overall terms, a number of different technical concepts for the Test Facility and, for each concept, its ability to meet the individual test requirements previously outlined in the function description (Chapter 2). A summary table is then presented whereby the individual concepts can be compared with reference to their functionality. From this, a conclusion on the recommended Test Facility equipment is made.

The following technical options are described:

- Direct connection at 36kV (no test facility)
- Short circuit-based equipment (either a mobile container or located centrally)
- Centrally located solution based on power electronics
- Centrally located hybrid solution based on power electronics and a generator set
- Centrally located facility based on discrete reactive components

The concepts are based on the premise that Test Centre is established with a total of seven test stands with the possibility of connecting wind turbines of an installed capacity of up to 16 MW each.

The Test Centre will be connected to the 150kV grid by a dedicated 150/60/36 kV transformer. This transformer will be installed at the existing Frøstrup 150/60 kV sub-station and connected to a 36 kV switchboard at the Test Centre via a number of 36 kV cables of approximately 3km in length. This is outlined in Figure 5. It is understood that the transformer will have one on-load tap changer and will generally be used for supplying the Test Centre 36 kV system but, in cases where there is a local need for the 60 kV supply, the voltage regulation will be made with reference to the 60 kV system.

This technical arrangement achieves a direct connection to the 150kV grid, whereby optimal grid connection conditions are obtained in the form of a large thermal transfer capacity in the underlying 150kV grid, together with a high short circuit current at the PCC. This provides a grid connection point with a stable voltage. (Energinet.dk has advised that the minimum and maximum short circuit powers at the 150kV level are expected to be 1500MVA and 3000MVA respectively. These levels can be expected to reduce in the future due to the decommissioning and disconnection of centralised generation. In 2030, for example, the minimum level is predicted to be around 1100MVA.

The wind turbines will be individually connected through a 36 kV cable connection between the switchboard and each wind turbine connection point.

Furthermore, Figure 5 shows that there are the possibilities of connecting a centrally-located Test Facility via the Test Centre switchboard and/or a mobile test facility that can be connected locally to the individual turbines through their turbine connection points.

The foreseen electrical concepts for wind turbines in the test centre are:

- fully-rated converter interfaces between turbine generator and grid, permanent magnet or field windings synchronous generators.
- doubly-fed asynchronous generators with part-rated converter

- traditional directly connected induction generators may still be developed, although they seem to be driven out of the market.

Other future concepts, e.g. HVDC turbine will be treated as an upgrade issue.

It should be noted that the Test Centre and Facility will be designed to operate at a nominal voltage of 33kV, which means that the cabling and equipment is rated at 36kV.

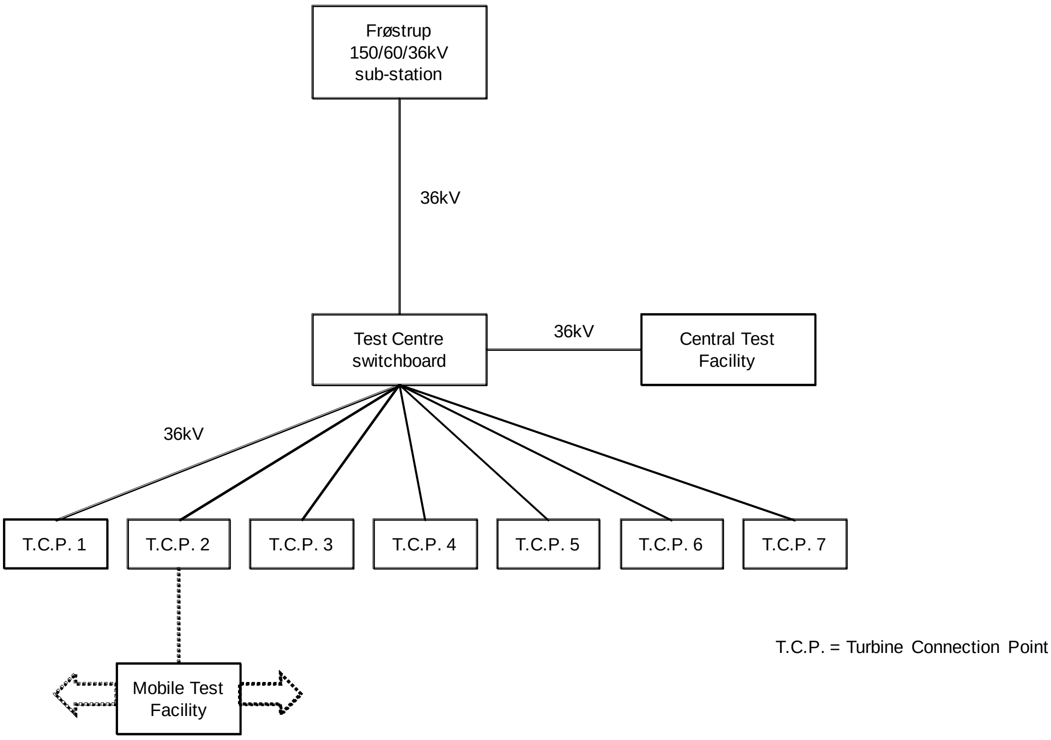


Figure 5 Block diagram of electrical connections for the Test Centre and Test Facility

3.2 Concepts for the test equipment

3.2.1 Direct 36kV connection: no test facility

With this concept the connection of the individual wind turbines is done by a direct 36 kV cable connection (radial connection) and no test facility is built, as indicated in Figure 6.

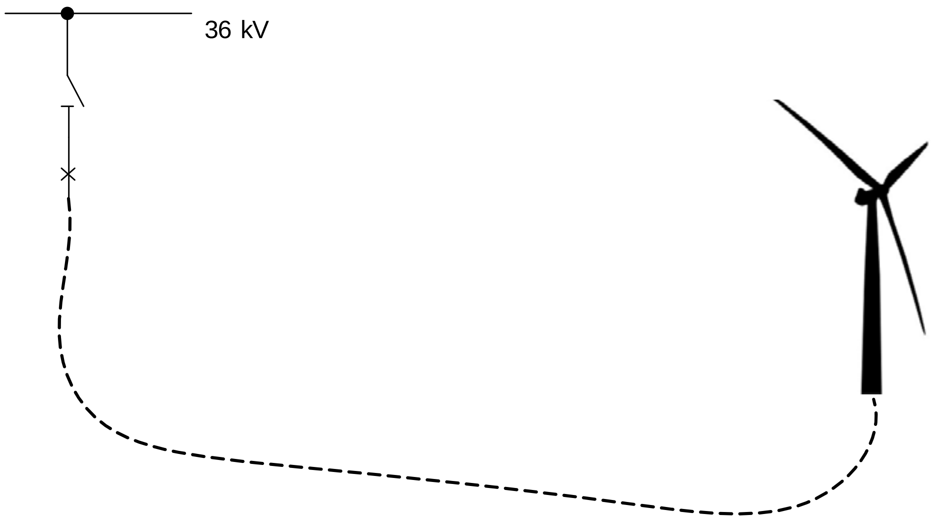


Figure 6 Direct 36kV connection: no test facility

As no test equipment is connected, this concept has a large number of limitations with respect to the verification of a wind turbine's dynamic response to external influences, including faults in the neighbouring power system.

It would, however, be possible to carry out tests of a wind turbine's steady state regulating characteristics (active power, reactive power, voltage control and frequency control, etc.) including ordinary measurement campaigns for electrical power, mechanical loading influences, verification of power curves, etc. Some of the tests may be relatively restricted as the voltage regulation will be done with the on-load tap changer on the 150/60/36 kV transformer in Frøstrup. It is unlikely that all seven turbines will be able to accept extreme voltage conditions at the same time.

ADVANTAGES: Low cost.

DISADVANTAGES: No further tests possible compared to a standard grid connection.

3.2.2 Short circuit test equipment

This is a widely used piece of test equipment. Based on a combination of various impedance units, it is housed in a standard transport container so that it can be moved between wind turbine locations with relative ease. During a test campaign, it is positioned alongside the base of the turbine tower and requires that each test stand be constructed and equipped to allow cable connections to/from the container.

For the Test Facility the arrangement could be mobile or fixed. The connection diagram in Figure 7 shows the mobile configuration where the container can be moved between the various test turbines as required. If this equipment were to be fixed then it would be centrally placed, housed alongside the Test Centre switchboard. The switchboard would need to be modified so that the fixed equipment could be coupled up to the turbine under test whilst the other turbines remained connected to the normal grid (see Section 3.3 for a description of this).

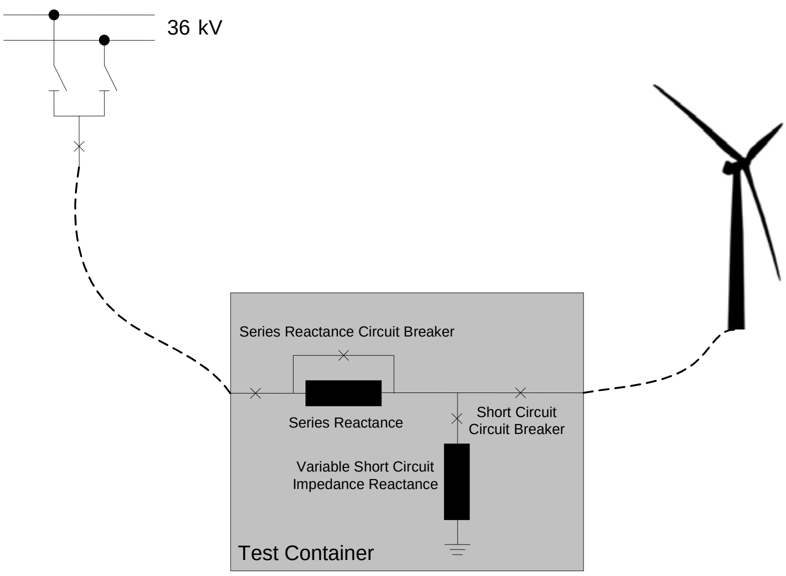


Figure 7 Mobile short circuit equipment

Whether fixed or mobile, this concept is dedicated to doing short circuit trials, i.e. the testing of a wind turbine's LVRT characteristics. It will only be possible to subject a test turbine to a defined voltage dip as set by the controllable reactances, where a stepwise adjustment of this determines with what resolution voltage dips can be generated. In principle, with the suitable design of control equipment, reactances and switchgear, symmetrical as well as asymmetrical voltage dips can be created.

The concept is well known and relatively simple and has gained popularity partly because it lends itself to relatively straightforward simulation setups.

Currently, various certification standards specify the test setup that must be used, and that it is located in the immediate vicinity of the wind turbine. The principle described here with controllable series and shunt reactances is up until now considered to be the most widely used concept and the obligation for its use can therefore be dictated by the above certification requirements, etc.

It is questionable if the fixed, centrally-located, option would fulfil these requirements and, in comparison to the mobile solution, it does not provide any further test functions. However, the central location will certainly be able to give a more ”permanent” solution with regard to the physical design of the test equipment, including the possibility to install more permanent measurement and data recording equipment, etc.

ADVANTAGES: Well proven, well understood, meets the present requirements for LVRT tests, relatively inexpensive.

DISADVANTAGES: Limited to one type of test only, may quickly be outdated.

3.2.3 Centrally located test equipment based on power electronics (“converter-based”)

This concept is based on power electronics and features a standard HVDC back-to-back converter concept that is already well known from a wide range of energy and industrial applications. With such a solution it would be possible to emulate a local grid where the voltage and frequency can be controlled independently from the surrounding power supply network. The principle is that this central unit shall be used to test the turbines one at a time. The concept is shown in Figure 8, whereby the test turbine is connected to the converter via the lower busbar and the converter is connected to the grid (along with the other six turbines) via the upper busbar.

This concept gives a wide range of possibilities in being able to emulate special grid conditions, including unusual relationships between voltage and frequency, phase angle jumps during switching of grid components, etc.

Furthermore, it is possible to subject a particular test turbine to a nearly random voltage variation – both symmetric and asymmetric in order to test the wind turbine's control and protection functions. Finally, it will be possible to carry out tests of a wind turbine's frequency control characteristics, inertial response, etc., by subjecting the whole wind turbine to a real frequency variation whilst it is generating, thus providing direct input to its measurement equipment's primary windings.

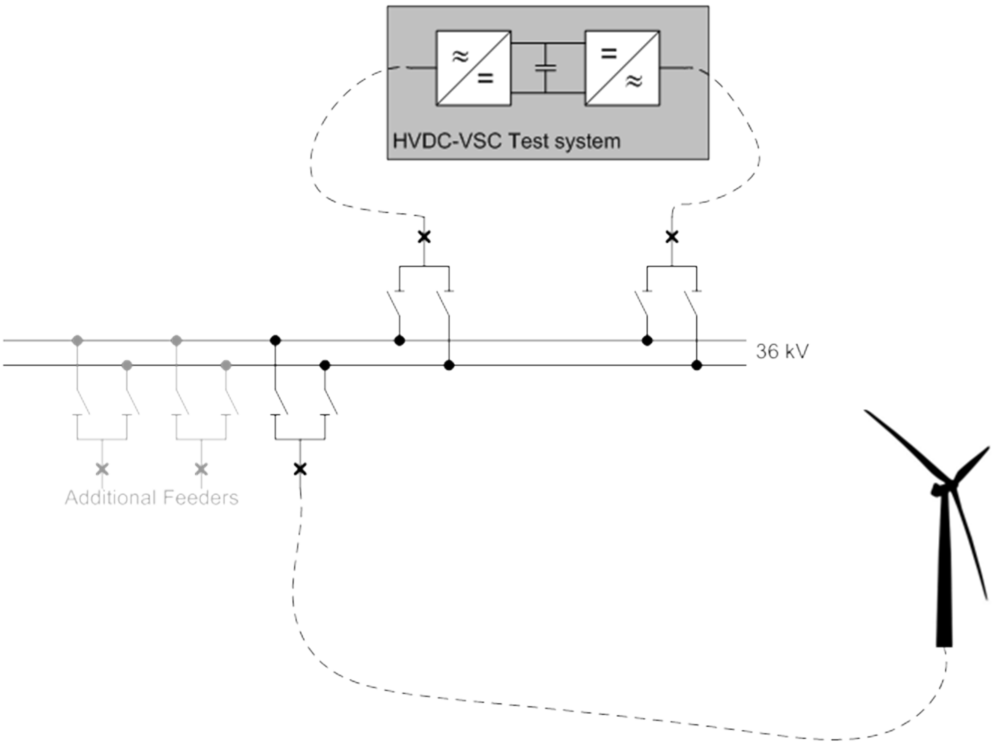


Figure 8 Converter-based solution

Thus, this concept provides the Test Facility with the most comprehensive ability to carry out a wide range of tests, but this power electronics solution is also considerably more expensive than the other concepts described.

Moreover, it is important to point out that a solution based on power electronics should be sized with a certain over capacity to be able to withstand the current and voltage variations that will arise during the testing of a wind turbine's LVRT capabilities, for example. This challenge is particularly applicable for wind turbines with direct-on-line induction generators. For converter-connected wind turbines this challenge will be limited because the transient response for this concept is much better controlled. By combining this converter-based concept with a short circuit equipment container solution for LVRT tests (refer to Section 3.2.2) the need for additional capacity can possibly be reduced.

An further option for the test facility with power electronics is a regulating transformer capable of providing voltage variations for turbine that is coupled up to the test facility. The solution envisaged was an autotransformer with a power rating covering the largest turbine. This relieves the converter from having to cover the full voltage change range.

ADVANTAGES: Full range of tests possible (most notably frequency tests), protection and control tests can be done at full scale during power generation.

DISADVANTAGES: Investment cost, sensitive to transient overloading.

3.2.4 Centrally located test equipment based on power electronics and a generator set (“hybrid solution”)

A concept that attempts to address the necessary over-rating of the converter in Section 3.2.3, is a ”hybrid solution” based on power electronics that is complemented with a generator set as shown in Figure 9. Additionally, it is shown how the individual components can be bypassed with a suitable arrangement of an associated switchboard.

In this solution a synchronous machine feeds the mechanical power though to the electrical supply net through an asynchronous generator connected to a power converter. This plainly involves two electrical machines over and above the converter but on the other hand the synchronous machine can handle the current and voltage transients, for example in connection with LVRT tests which is why the converter only needs to be sized for the wind turbine’s rated capacity. It is also thus assumed that there is a mobile short circuit equipment container between the generator unit and the test turbine.

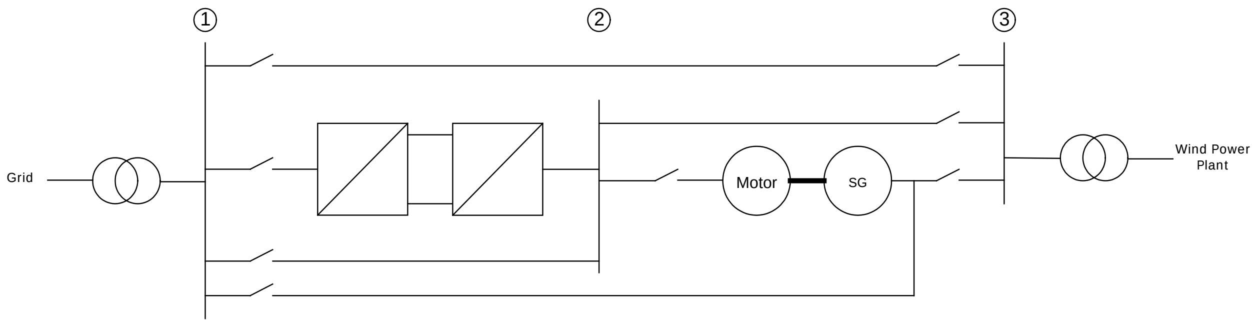


Figure 9 Hybrid solution including switchgear for bypassing various components

With a suitable design of the generator unit a certain system inertia can be achieved that can make it possible to have realistic frequency variations in connection with the testing of a wind turbine’s frequency control properties.

The advantage of a hybrid solution is that the transient characteristics of the synchronous machine will be reproduced. The converter capacity gives certain possibilities to emulate these characteristics but the possibilities are in part limited by the necessary protection of the converter against overcurrent and in part by the bandwidth of the real time simulations that will be behind such an emulation.

In conclusion, the hybrid solution will naturally emulate a system with a certain inertia but the natural inertia is relatively low so it will probably still be necessary to include inertia in a real time simulation if it is required to emulate a real system.

Besides the characteristics already described no further test functions can be achieved.

ADVANTAGES: Realistic transients, inherent natural inertia (although relatively low)

DISADVANTAGES: Additional costs on top of the converter.

3.2.5 Centrally located facility based on discrete reactive components

Equipment that can be coupled in and out for testing individual turbines for specific tests. For example,

- capacitor and inductor banks for reactive power
- regulating transformer for voltage changes

This concept could be combined with the converter-based concept, so that for example a regulating transformer could provide the Test Facility with the ability to have two turbines under test simultaneously, e.g. one connected directly to the regulating transformer undergoing alternative voltage tests and the other connected via the converter undergoing any of the wide range of tests possible. This double test arrangement has implications for the Test Centre switchboard which are discussed in Section 3.3.2.3.

ADVANTAGES: Typically able to survive temporary overloading

DISADVANTAGES:.Limited application since the hardware will be dedicated to very specific tests

3.3 Test Centre switchboard concepts

3.3.1 Test Centre connection possibilities

Currently, the 36 kV switchgear for the Frøstrup 150/60/36 kV substation has not yet been ordered. Thus the single line diagram (SLD) for Frøstrup 36 kV cannot be expected to be known. However, the connection of the Test Centre to Frøstrup must be in underground cables. As the 150/60/36 kV transformer in Frøstrup has a rated power of 125 MVA, this corresponds to 2,2 kA, which must be the rating of the connection. Even with a large cable conductor cross section of 2000 mm^2, the rating of one cable system will be less than 2200 A. Thus two cable systems are to be expected.

With two cables the substation can either be equipped with two (or in the case of three cables, with three) parallel circuit breakers each for connection of one cable (Figure 10) or with one circuit breaker connecting all the parallel cables (as shown on in Figure 11), where the possible 3rd cable is shown with a dashed line.

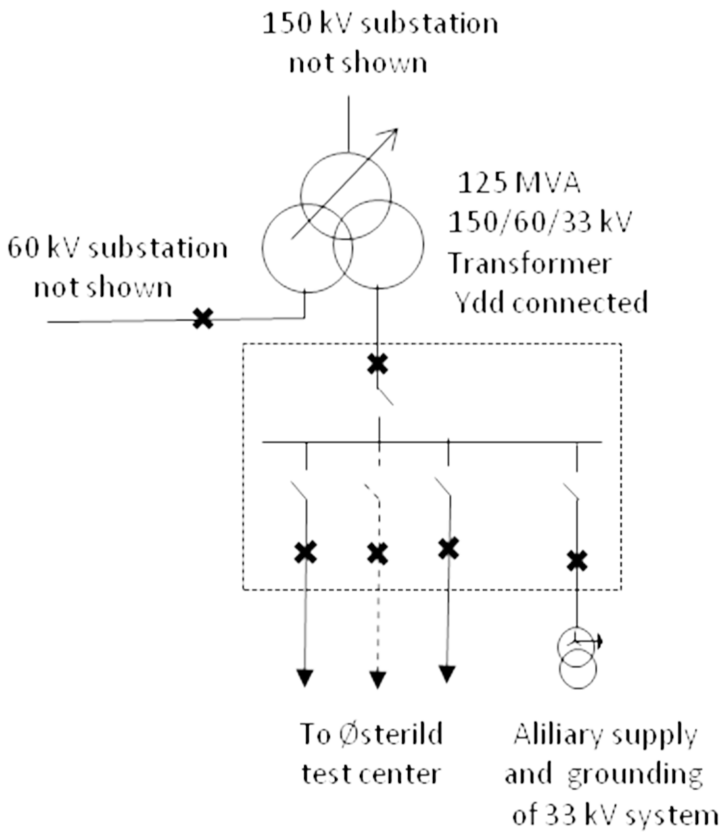


Figure 10 Multi-breaker configuration for the grid connection of the Test Centre

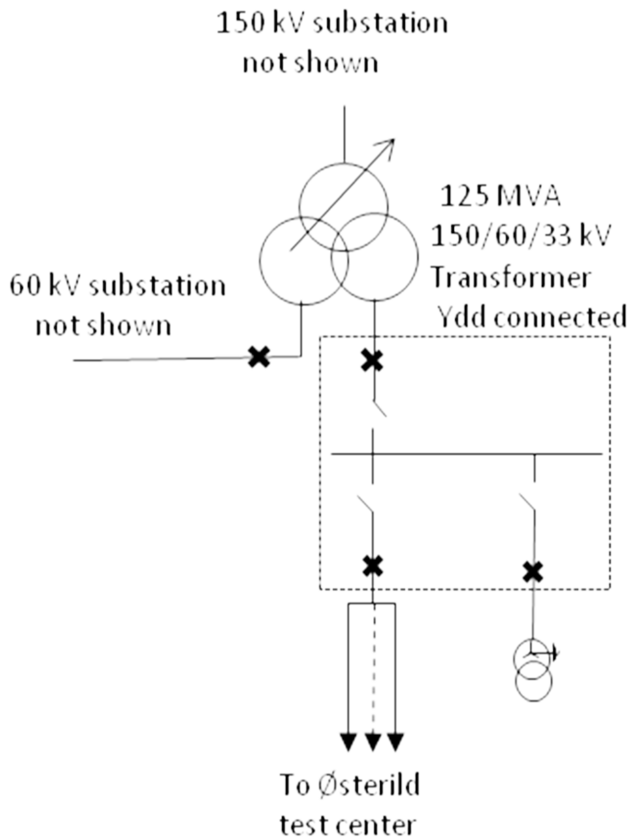


Figure 11 Single circuit breaker arrangement

As the 150/60/36 kV transformer has delta connected 36 kV windings, there is a need for access to a neutral point for system earthing. This is proposed to be made in the local auxiliary supply transformer with a primary winding, allowing system earthing of the 36 kV grid.

From a reliability point of view the two breaker solution is preferable, but the cost for an additional breaker (even with two (three) breakers with a lower current rating than for one breaker with full 2200 A power rating) is substantial, so the most likely alternative is the single breaker solution. It is worth noting that even for offshore installations the risk of cable damage, which would result in a long outage, has seldom led to the purchase of redundancy.

It is assumed that the basic switchgear in the Test Centre will have one or two incoming feeders similar to the switchgear in Frøstrup. (The basic switchgear is the switchgear necessary for the test centre without the test facility). As switchgear with one busbar is selected in Frøstrup, the same solution is assumed for Østerild. This is shown with one (Figure 12) or two (Figure 13) incoming circuit breakers similar to the possibilities in Frøstrup.

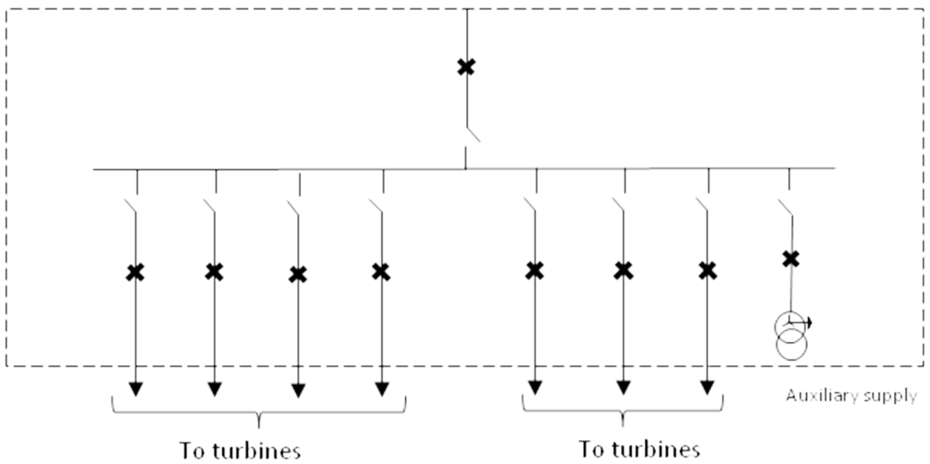


Figure 12 Single feeder into the Test Centre

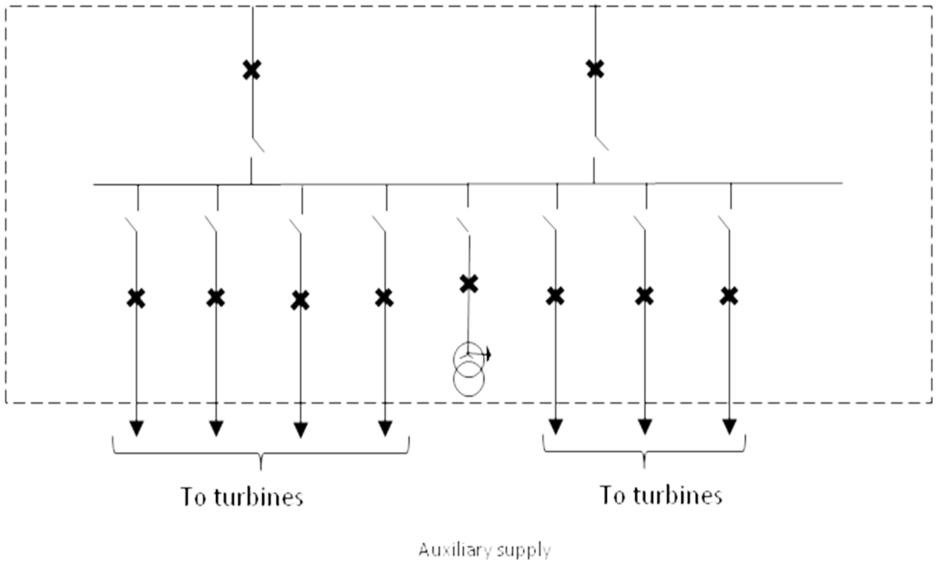


Figure 13 Double feeder into the Test Centre

With the two incoming feeders the circuit breakers are located a little from each other to allow for a possible cost reduction by use of lower current rating of the busbar

3.3.2 Test Facility requirements for the Test Centre switchgear

3.3.2.1 No test facility or mobile test facility

If there is no test equipment or if there is only a mobile equipment solution then there are no additional requirements for the Test Centre switchboard over and above that for the direct connection of the seven test stands.

3.3.2.2 Centrally located fixed test facility

With a central located test facility it is necessary to add circuit breakers for connecting the test facility and a second busbar to allow flexibility in the connection of the test facility to any turbine. By way of example, the arrangement with the converter based concept (Section 3.2.3) is shown in Figure 14.

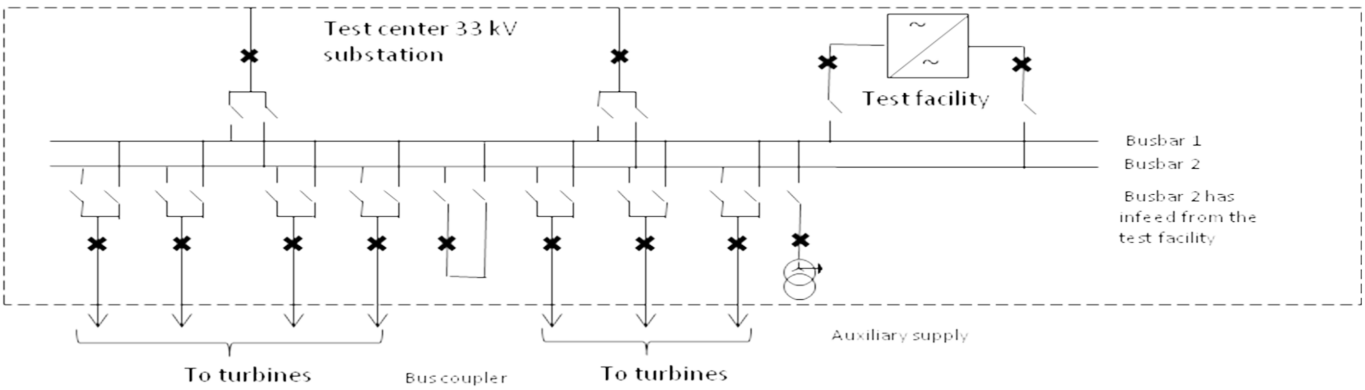


Figure 14 Double busbar arrangement and bus coupler for Test Facility connection

This figure shows only the solution with two circuit breakers. It is assumed that the 33 kV winding of the transformer of the test facility connected to Busbar 2 will have a neutral point allowing system grounding of that circuit.

With reference to the earlier point on system earthing it should be noted that there needs be access to the system neutral on the wind turbine side of the converter system. As there will be transformers in the converter system, the cost-effective way to achieve this is to specify a transformer allowing the neutral earthing system.

The additional operational flexibility afforded by the bus coupler should be balanced by the additional cost.

A requirement for all of the switchgear should be minimising the spill of the insulating gas as SF_6 is a very active greenhouse gas. (See Electra 252, October 2010: SF_6 Tightness guide [7])

3.3.2.3 Two centrally located test facilities each with a turbine connection

It has been proposed to have an additional simple and cheap test function just for voltage regulation. Such a facility can be provided by a regulating transformer and is shown in Figure 15 as an autotransformer (with the autotransformer the system earthing from the grid will do in the wind turbine side of such a device). However, an additional test facility calls for an increased flexibility of the test centre switchgear. The ideal is that both the two independent test facilities can be connected to any of the 7 turbines. That is possible with a 3-busbar switchgear, but such a solution is expensive. Thus a compromise proposal can be made based on two busbar switchgear with a longitudinal sectionalising of one busbar. The cheapest sectionalisation is “always open” as shown in Figure 15 but can also be implemented with a switch (not shown because it is assumed that the advantages cannot be justified taking the cost into consideration). Further flexibility is achieved using the solution that is shown in gray in Figure 15. The gray switches are not seen as integrated in the Test Centre switchgear but as parts of the Test Facility. Importantly, these parts of the switchgear may have a lower short circuit rating than the main switchgear.

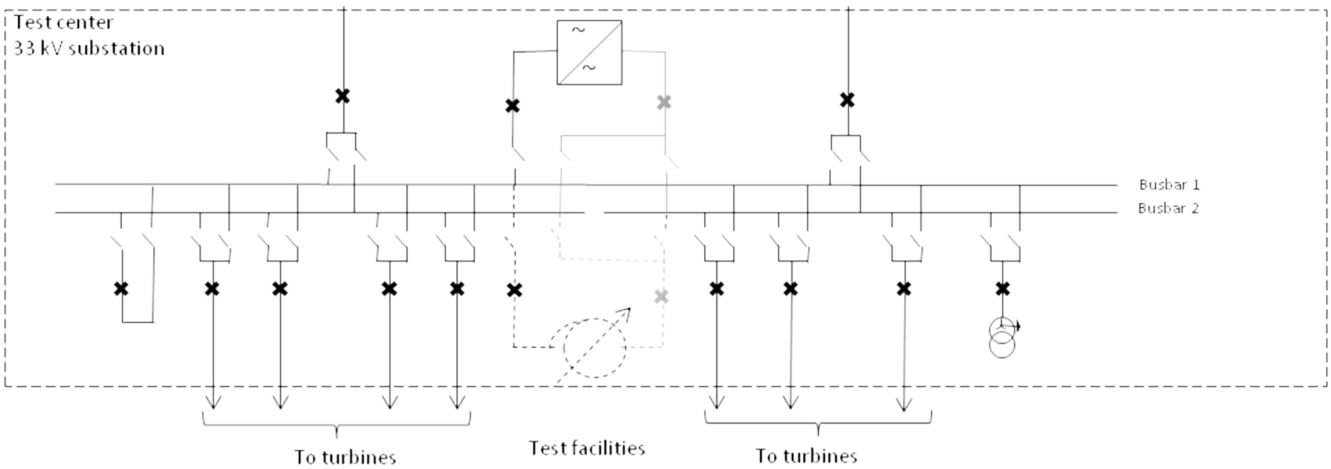


Figure 15 Double busbar configuration with a section break and additional regulating transformer facility

3.4 Assessment of technical concepts

The concepts described above for a test facility are presented together in Table 2 below in relation to the tests, functions and facilities that can be implemented with the various concepts. The chosen concept is presented in the implementation plan (section 6.1).

Table 2. The ability of the described test facility concepts 3.2.1-5 to perform the tests 2.2.1-15 and 2.3.1-5.

✓	Test can be carried out fully
(✓)[1]	Limitations on the test – see footnote for details
(×)[1]	Test cannot be done but a lesser test possible – see footnote for details
×	Test cannot be done

Section	Test	Grid condition / Test designation	3.2.1 No test facility	3.2.2 Short circuit test equipment	3.2.3 Converter-based	3.2.4 Hybrid solution	3.2.5 Discrete reactive components
2.2.1	Active and reactive power control	Normal	(✓)[1]	(✓)[1]	✓	✓	(✓)[1]
2.2.2	Voltage control	Normal	(✓)[2]	(✓)[2]	✓	✓	✓
2.2.3	Voltage amplitude changes	Normal	(✓)[3]	(✓)[3]	✓	✓	✓
2.2.4	Voltage unbalance	Normal	×	(✓)[4]	✓	✓	(✓)[4]
2.2.5	Operation at alternative system frequencies	Normal	×	×	✓	✓[5]	×
2.2.6	Grid resonances	Normal	×	×	✓	✓	×
2.2.7	Harmonic emission assessment	Normal	(×)	(×)	(✓)[6]	(✓)[6]	(×)
2.2.8	Voltage fluctuations caused by the turbine	Normal	×	×	✓	✓	×
2.2.9	PQ capabilities at different voltages and frequencies	Normal	(×)[7]	(×)[7]	✓	✓	(×)[7]
2.2.10	Frequency control & inertia response	Disturbed	(×)[8]	(×)[8]	✓	✓	(×)[8]
2.2.11	Low Voltage Ride Through: LVRT	Disturbed	×	✓[9]	✓[10]	✓	×
2.2.12	High Voltage Ride Through: HVRT	Disturbed	×	✓[9]	✓[10]	✓	×
2.2.13	Operation during frequency variations	Disturbed	(×)[8]	(×)[8]	✓	✓	(×)[8]
2.2.14	Voltage phase angle jumps	Disturbed	×	×	✓	✓	×
2.2.15	Protection strategies	Disturbed	(×)[11]	(×)[11]	✓	✓	(×)[11]
2.2.16	Start and stop scenarios	Disturbed	✓	✓	✓	✓	✓
2.3.1	Virtual wind farm emulation	Power plant	×	×	✓	✓	×
2.3.2	Operational tests on SCADA and SCADA-interface systems	Power plant	(×)	(×)	✓	✓	(×)
2.3.3	Simulation model verifications	Power plant	×	(✓)[12]	✓	✓	(✓)[12]
2.3.4	Tests of Power Plant Controllers	Power plant	(✓)	(✓)	✓	✓	(✓)
2.3.5	Emulation of varying grid strengths	Power plant	×	×	✓	✓	×

Footnotes:

1 Reactive power capabilities are limited by the range voltage limits allowed for the standard grid connection.

2 Testing of the voltage control (for example in relation to a set point) is typically done by coupling with a tap changer in the vicinity of the wind turbine. This functionality (response time, ramp rates, etc.) can be verified through measurement of the voltage at a reference point, and this can be done without access to a special test facility. The use of tap changers requires, however, that larger, more frequent and longer-lasting voltage variations are acceptable with consideration to the consumption and/or production units that are connected in the area e.g. the other turbines at the Test Centre. Furthermore, it should also be possible to block other voltage regulating equipment so that the individual turbine's regulation capacity can be verified. The converter and hybrid concepts do not have these limitations.

3 The required voltage dips can be generated by, for example, use of the tap changer on the envisaged 150/60/36 kV transformer at the Frøstrup sub-station, although this requires the agreement of all the other users which may be operationally problematic.

4 Limited ability to generate voltage unbalances.

5 Special generator and / or transformer design may be required for the hybrid solution constraints for alternative frequency operation.

6 Lower order harmonics can be controlled with a converter.

7 Compared to those with converters the other alternatives have a very limited ability to operate at the extreme range of the PQ envelope, and no ability to change frequency.

8 Ideally, the electrical frequency variations for this test are best emulated by a converter whereby a wind turbine's terminals are subjected directly to a frequency variation. However, a simulated frequency test can be undertaken, where voltages and currents are induced in the wind turbine's measurement secondary windings [having been isolated from the actual power flow on the terminals] and thus the response to emulated electrical frequency variations can be tested.

9 The short circuit concept is currently the standard means of carrying out this test and is also suited to straightforward simulation modelling, however, it does not replicate the actual grid strength seen by the turbine.

10 Converter based solution is not able to emulate single phase to ground faults on the 33 kV level, but a single phase to ground error on higher transmission voltage levels will appear as two phase errors on the 33 kV side of the transformer so this should not be an important limitation. Another limitation is that the voltage cannot drop to zero on the converter test facility terminals if the wind turbine is feeding reactive power into the converter transformer.

11 The testing of protection strategies is limited to checking the operation of the measurement (by secondary injection) and relay equipment.

12 Verification of simulation models is limited to those parameters that these equipment concepts can vary. A converter-based solution could vary the largest range of parameters and could include the emulation of compensation equipment, such as a STATCOM.

4 Organisation

4.1 Introduction

The objective of this chapter is to outline the organisational tasks needed and to recommend an organisation structure that can carry out the tasks. This serves two purposes:

- To clarify the roles and responsibilities foreseen and allow planning and resource allocation.
- To enable pricing of the organisation that can feed into the Business Case. To make the business case for the test facility it is important that only the additional organisation required for the test facility alone (over and above that required for the basic test centre) be considered.

4.2 Organisations required

There are organisations needed to cover the four phases of the Test Facility project:

Phase 1: Preliminary project (this present phase)
Functional description
Assessment of technical solutions
Organisations
Business case

Phase 2: Establishment (1) – pre-construction
Securing of finance
Prequalification
Production of tender documents (technical specifications, contracts, etc)
Contract tendering and awarding

Phase 3: Establishment (2) – construction
Construction
Installation
Testing and commissioning

Phase 4: Operation
Operation of the test facility
Maintenance

4.3 Current status of the organisations

Phase 1: Preliminary project organisation is in place. This is the present EUDP project “Test facility for grid connection characteristics of wind power plants”, lead by Risø DTU.

Phase 2 and Phase 3: Establishment. A project group has been formed for the establishment of the Test Centre Østerild (refer to “Projektfølgegruppe i forbindelse med etablering af Testcenter Østerild”, Appendix B), lead by Risø DTU. A similar group is proposed for the establishment of the Test Facility.

Phase 4: Operation and maintenance. There is currently a proposal for a steering committee for the operation and maintenance of the Test Centre, which comprises a member from each test stand owner plus Risø DTU. (See "Vedtægter for Styregruppe til drift og vedligeholdelse af Testcenter Østerild", Appendix C, for the Terms of Reference. Note that, at present, this is only a draft.) It is proposed that the organisation for the Test Facility will function as an integral part of this but for the purposes of this document it will be dealt with as a separate entity so that only that part of the organisation necessary for the running of the Test Facility is priced up for the business case.

4.4 Tasks for the operation and maintenance of the Test Facility

The overall objective for the Test Facility organisation is to operate and maintain the equipment to serve the needs of the customer using the facility. This equipment is outlined below in Figure 16.

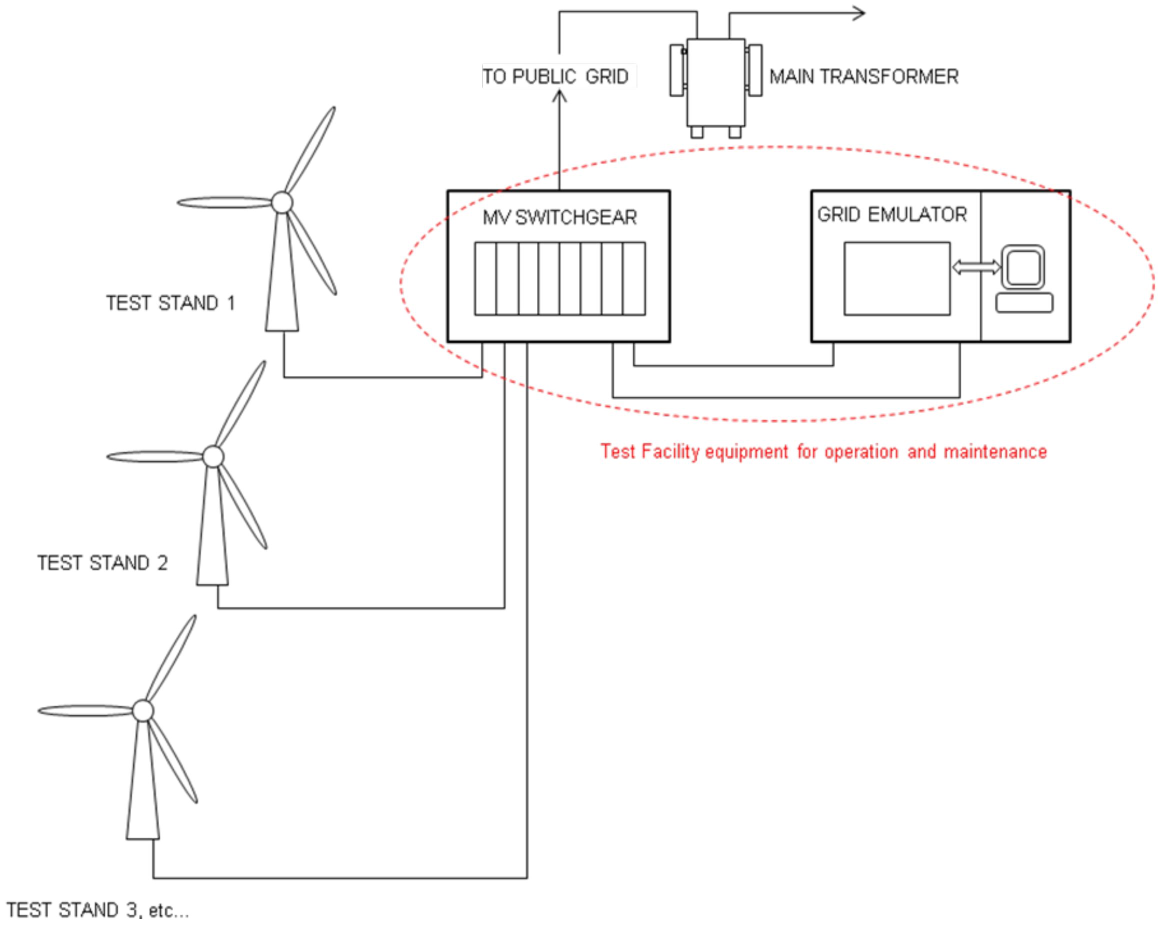


Figure 16 Outline of equipment to be operated and maintained

The tasks for the operation of the Test Facility include:

4.4.1 Operation management

The management of the facility will oversee major activities concerning the MV switchgear and grid emulation equipment. It will also establish, implement and update the maintenance plan for the facility.

4.4.2 MV equipment technical operation

Safe configuration of the equipment to meet the testing customer's needs

Converter based grid emulator

Container-based short circuit equipment (if belonging to the test centre)

Test centre switchboard switching operation

Protection settings

Responsibility to see MV health and safety requirements are met

4.4.3 Maintenance (planned) and repair (unplanned)

Facility equipment to be maintained annually (or periodically) according to maintenance plan (manufacturers' recommendations)

On-site repairs of faulty equipment where possible, or replace item and return faulty equipment to manufacturer for repair/inspection

4.4.4 Customer service functions

Day-to-day technical matters

- Setting up and safe operation of the equipment to meet the testing customer's needs
- Measurement equipment
- Data recording equipment
- Simulation computers
- Maintaining appropriate stock of spare parts
- Technical liaison with electricity utility (e.g. for MV switching operations)
- Technical liaison with test facility/centre users
- Daily maintenance activities
- Co-ordinate and supervise maintenance activities according to the maintenance plan
- Supervise call-out of certified repair company(s)
- Responsibility to see (below MV) health and safety requirements are met

Administration/accounts

- Point of contact for test facility customers
- Maintain booking system for test facility equipment and personnel
- Marketing and promotion of facility
- Handle contracts with customers
- Handle contracts for equipment maintenance
- Issue/pay invoices
- Ordering of spare/replacement parts
- Insurance contracts (personal liability, accident, equipment and building)

Centre maintenance

- Cleaning
- Building maintenance
- Domestic supplies (water, electricity, etc)

4.5 Organisation model for the Test Facility operation and maintenance

Risø DTU is responsible for the daily operational management of both the Test Centre and the Test Facility. It is proposed that the management of the Test Facility reports to the steering committee as shown in the organisation chart below:

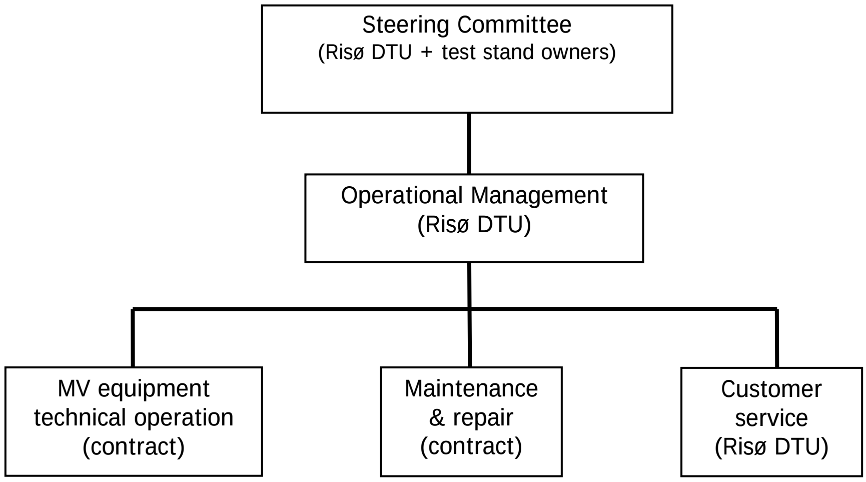


Figure 17 Organisation chart for the Test Facility

The tasks identified in section 4.4 above can be divided between those that require:

A) MV certified personnel (e.g. switchboard operation) or very specialist knowledge (e.g. maintenance of power electronics)

and

B) Broader competences for day-to-day running of the facility.

The proposal is for tasks under A to be contracted out, whilst those under B will be carried out by the Test Facility's (Risø DTU) personnel or sub-contracted out by them.

More specifically, this is divided into "A" Tasks and "B" Tasks:

<u>"A" Tasks: certified/specialised personnel</u>

- MV equipment technical operation
- Coupling of the turbine to/from the Test Facility and preparation of the grid emulation equipment as agreed with the users and Test Facility personnel will be contracted out. Estimated at 25 hours per year per test stand.
- Maintenance & repair
- MV switchboard: carry out the periodic maintenance and provide a call-out service for unplanned repairs. This will be contracted out – guideline cost is 2% of capital cost of equipment.
- Test facility grid emulator: similar contract conditions to the MV switchboard - guideline cost is 2% of capital cost of equipment.
- Test facility container-based test equipment: similar contract conditions to the MV switchboard - guideline cost is 2% of capital cost of equipment.

<u>“B” Tasks: day-to-day running</u>

- Operation management: one manager to fulfil management tasks, estimated at 150 hours per year.
- Day-to-day technical matters: two technicians, estimated together at 300 hours per year
- Maintenance of some equipment also to be by manufacturers/hired-in companies: estimate 75.000 Dkk per year.
- Building maintenance: estimated at 75 hours a year
- Administration: estimated at 375 hours per year

4.6 Organisation summary

The organisation that runs the Test Facility will be a part of the Test Centre organisation and will share personnel. These staff will carry out the day-to-day running of the facility, including assistance to the test users in arranging the appropriate tests. Operations requiring MV certified qualifications will be contracted out, as will the maintenance and repair of the equipment.

5 Business case

5.1 Introduction

The business case for the Test Facility needs to cover the funding of the establishment and the economic running of the facility for its design lifetime, including any necessary repayment of capital investments and the maintenance of a contingency fund. It is not the intention that the facility generates a profit but neither should it be required to build up a fund for future capital investments. Any investments in additional new equipment will be a matter for those users who require it and any replacement or upgrade of existing equipment will be a matter for the steering committee and borne equally among the test stand owners.

5.2 Proposals for funding possibilities

It is proposed the Test Facility organisations are funded as follows:

<u>Phase 1: Preliminary project</u>

Already EUDP co-funded.

<u>Phase 2 and Phase 3: Establishment</u>

Funding sources:

- 50% Green Labs DK, Energinet.dk, Fornyelsesfonden
- 50% test stand owners (DTU, Siemens Wind Power and Vestas)

<u>Phase 4: Operation and maintenance</u>

Fully funded by users of the facility and users of the DTU-owned stands also pay an additional fee to payback DTU’s capital investment..

5.3 Estimates of costs

The business case requires that there is an estimate of the capital investment costs required to establish the Test Facility, together with an estimate of the running costs. These will be dealt with in this section.

When providing cost figures for the business case, it should be remembered that only the costs attributable to the test facility should be included. For instance, only the additional cost of a double busbar MV switchboard over and above that needed for operation of the Test Centre without the Test Facility should be included. Likewise only the additional costs of maintaining such a more complex switchboard should be considered.

The costs of Phases 2 and 3, “Establishment”, need also to be estimated to apply for suitable funding.

The major costs are the converter equipment and short circuit test equipment, and these have been estimated through detailed discussions with the two suppliers involved in the project. Risø DTU met with the suppliers individually to discuss the options and solutions. Of particular interest was to identify any parameter that would generally prove overly expensive in relation to the importance/value of the test associated with it. In this way Risø DTU was able to explore the general cost/benefits of various aspects of requirements to the equipment.

5.3.1 Pre-construction task estimates

Application for funding

Acquisition of land necessary for building and operating the Test Facility. (Note: it is expected that this is provided without cost by the Ministry of Environment.)

Obtaining permissions necessary (e.g. for new buildings)

Choice of contract type (turn-key, individual sub-contracts, etc)

Writing of tender documentation

Inviting tenders and assessment of tender returns

Awarding of contract(s) to most suitable bidder(s).

5.3.2 Construction estimates

Buildings for switchgear, grid emulator and measurement/comms/control/computer equipment, including building services and any particular earthing requirements.

Buildings and equipment for personnel.

MV switchgear

Grid emulator

Container-based test equipment

Measurement equipment

Communications & control equipment

Computer equipment

External cabling for the above equipment

Testing and commissioning of above equipment

5.3.3 Operations and maintenance costs

Components of O&M costs:

Contract for MV switching and grid emulator operations

Contract for maintenance and repair of MV switchgear

Contract for maintenance and repair of grid emulator

Contract for maintenance and repair of container-based test equipment

Maintenance and repair costs of remaining equipment (contract/in-house)

Management personnel costs

Day-to-day technical operation personnel costs

Building maintenance equipment and personnel costs

Administration/accounts personnel costs

Insurance: personal liability, accident, building and equipment

Utility costs: electricity, water, etc.

Payback of capital investments for the establishment

Contribution to contingency fund

5.4 Funding the establishment of the Test Facility

The funding of the establishment will be met approximately 50% by the users divided proportionately between the ownerships of the test stands. The remaining 50% will be covered by grant funding (e.g. Green Labs DK).

<table>
<tr><td>~14% Vestas</td><td rowspan="3">~50% grant funding</td></tr>
<tr><td>~14% Siemens WP</td></tr>
<tr><td>~22 % RisøDTU</td></tr>
</table>

Figure 18 Capital investment share for establishment

The purpose of the Test Facility matches precisely with the aims of the Green Labs DK as stated in the Call for Applications (June 2010):

"Green Labs DK calls for applications for setting up new large-scale test facilities for tests and demonstration of new climate technologies...where enterprises can demonstrate and test new green technologies under realistic conditions. Test Facilities must be of international class and eb able to attract both Danish and foreign development and demonstration activity"

An application for GreenLabs funding is therefore planned for late 2011, Although currently the date and conditions for applications are not known for certain.

Other funding possibilities are:

- Energinet.dk finds the test facility very relevant, and has the opportunity to support it as an R&D facility, but not as a pure test facility. Especially the converter based test facility provides excellent opportunities for R&D projects based on full scale wind turbine experiments.
- "Fornyelsesfonden" can provide limited funding, which should be considered for the preparatory stages.

5.5 The distribution and funding of running costs

5.5.1 Running cost

As the funding of the running costs is carried fully by the test stand owners, the principle of the allocation of the costs needs to be laid out as part of the business case. It can be seen that operations and maintenance costs have two parts:

a) Fixed costs: those that can be predicted: e.g. contracts for periodic maintenance, insurance, and some personnel costs.

b) Variable: those that cannot be predicted (although average estimates can be used for budgeting purposes) e.g. repair costs, switching costs, utility costs and some personnel costs.

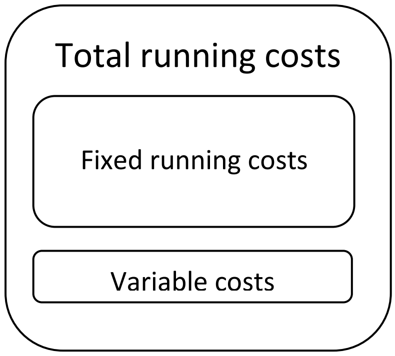


Figure 19 Components of O&M costs

It should be noted that the Test Centre also has (fixed) O&M costs to which the fixed costs of the Test Facility will be added when considering the test stand owners' total obligations.

5.5.2 Allocation of use of the test facility and consequent running costs

Each stand owner will receive seven weeks per stand per year in which they can use the Test Facility. That is, Vestas: 14 weeks, Siemens WP: 14 weeks and Risø DTU: 21 weeks. These weeks will be spread evenly throughout the year so that each test stand user has the same statistical probability of the same wind conditions during the year (Figure 20). There are three weeks allocated to O&M or other contingency.

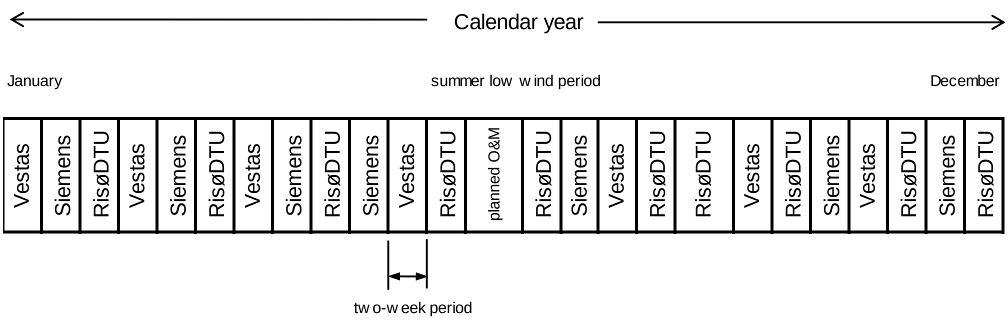


Figure 20 Allocation of two-week slots for use of the Test Facility (example only)

Each owner has, accordingly, the obligation to pay one seventh per test stand of the annual O&M costs (the sum of fixed and variable costs).

Time allocated to each owner can be bought and sold, that is, if an owner decides that they do not want to use all of their allocation they may sell them to another user but if no buyer is found then the owner remains under obligation to pay their share of the O&M costs.

Allocation of test facility time will be planned ahead on a three-year rolling programme basis.

6 Implementation plan

This chapter summarises the plan for implementation of the test facility. This plan is the technical and economic basis for the application for co-funding of the test facility, and for the final tender documents. Thus, the plan will identify which of the solutions that will be chosen, summarise the corresponding budget and detail the time line.

6.1 Chosen solutions and test equipment capacity

From the assessment of the technical concepts summarised in Table 2, it is clear that although the central converter-based solution is the most costly, it is also very flexible, and therefore enables a very extensive range of tests to be carried out. In addition, though, it is essential that the Test Facility also includes the standard impedance-based equipment for LVRT tests, which is required in many grid codes. Further centrally-located facilities were assessed as not sufficiently useful to merit inclusion.

Thus the recommended equipment for implementation is:

- Converted-based, centrally located test equipment
- A mobile unit containing short circuit impedance-based equipment for placement adjacent to a turbine.

The test equipment units will be designed to support testing of wind turbines up to 16MW, which is the size that the Østerild grid has also been laid out for. Smaller units have been considered, but the present prototype wind turbine sizes are already up to 7 MW, and the test facility should have sufficient capacity for a number of years after it is commissioned in 2014, where the size of large wind turbines may well have increased to 10 MW. Besides, the chosen size of the test equipment will enable the testing of two wind turbines simultaneously, as long as the total capacity does not exceed 16 MW.

6.2 Implementation steps and time schedule

The time schedule for the implementation is carried out in three phases, following the first phase which is the present project:

- Phase 2: Establishment preliminary work (pre-construction)
- Phase 3: Establishment construction and installation.
- Phase 4: Operation of the facility

The detailed time schedule is shown in Appendix J and contains the major tasks necessary as explained below. The two critical activities identified are the assembling of the necessary financing commitments and the lead time for the converter equipment.

The successful implementation relies heavily on gaining Green Labs DK funding and this is where the main initial follow-on effort will be in Phase 2. There will, however, also need to be a continuing co-ordination exercise with the Østerild Test Centre through the advisory committee ("Projektfølgegruppe") to ensure that the two projects have the correct alignment. Once this stage has been reached it is envisaged that the Test Facility will be very much a part of the Test Centre, using the existing legal framework as much as possible and ensuring the commitment of the current test stand owners to the Test Facility project. The application for funding will require that this commitment is explicit.

The next part of Phase 2 is the preparation for contracting the supply of the equipment. The functional specification requirements set out by the present project will make the technical aspect of this task relatively straightforward. However, Risø DTU will subcontract a technical specialist to carry out some further engineering of the solution to ensure that the tender documents are suitably comprehensive. A engineering consultancy will then be subcontracted to write the documents themselves.

Simultaneously, suppliers will be pre-qualified so as to streamline the actual tendering process and, again, Risø DTU will take the lead in this. Following the assessment of tender returns, contract negotiations will be entered into and the successful party contracted to supply the equipment. It is, however, likely that smaller ancillary contracts will be needed, for example, to pull cables, make suitable building foundations and roads.

Phase 3 starts with the placing of the order for the equipment. Activities on-site are, however, not expected straight away as there is a 12-15 month lead time for the converter equipment. However, site works will be completed in due time for the equipment to be installed following testing at the factory. Work on site will be monitored by Risø DTU (or appointed personnel) to ensure that works are co-ordinated in a timely manner. About this time in Phase 3, the operational organisation will be put in place so that, following installation, the equipment will be tested and commissioned ready for the training of personnel by the equipment supplier.

Phase 4 then starts with the operation of the Test Facility based on cycling the user's allotted time for facility access every two weeks. This cycling approach will be applied for the converter-based equipment as well as the impedance-based equipment. The time interval (two weeks) is still subject to discussion, but is a compromise between the need for continuous test periods and a reasonable number of slots to enable all manufacturers to have equivalent access to the equipment in the good wind seasons.

6.3 Contract Conditions

The contract for the supply of the Test Facility equipment will be based on a functional specification rather than a detailed design specification. This is due to the very specialised nature of the equipment and it is, therefore, much more efficient to leave the detail design to the successful supplier. A functional specification also gives the supplier more flexibility to meet the required performance as best suits the particular technical benefits of their products. An added benefit of this is the foreshortening of the pre-construction establishment period as there will be less detailed engineering work needed for the tender documents.

6.4 Interaction with the Østerild Test Centre

The particular items that require alignment between the Test Facility and the Østerild Test Centre are:

- Switch gear for connection of wind turbines and central test facility
- Interface between the test stands and the mobile test equipment

- Earthing of the 36 kV system
- Auxiliary power supply
- Planning permission and ground acquisition for the Test Facility

These issues are detailed below.

6.4.1 Switch gear for connection of wind turbines and central test facility

In order to ensure the maximum operational flexibility during normal operation and under test conditions the medium voltage equipment will be standard SF6-insulated switchgear arranged with a double busbar and circuit breakers.

The operational voltage for the 36kV collection grid is expected to be at 32-33kV which gives the possibility to test the wind turbine's grid compatibility within the normal voltage variation range of the turbines. Thus a continuous voltage variation can be achieved with a range of ±10-15%.

The switchgear has to be built in minimum two steps, because the Østerild test station is scheduled to start operating in 2012, while the test facilities will not be in operation before early 2014 as indicated in the time schedule Appendix J.

The Test Centre will request a single bus-bar system in the tender documents, but will also request the bidder to state the additional price for a double bus bar. The two busbar option is considered, because a single busbar would have to be removed again to enable the connection of the test facility 2 years later.

Moreover, the switchgear should be designed so that it will be possible to extend with a second central test facility. This second facility can either be an impedance based facility which is too large to be mobile, a second converter based facility, or other permanent or temporary test units.

Figure 21 shows a single line diagram of the planned switchgear, although some detailed engineering still needs to be done. The idea is to reduce the costs of the first phase to a minimum and still avoid that the first phase switchgear should be removed already 2 years later.

The design includes two switchboards: the first switchboard (SB1) should be built together with the Østerild Test Centre in 2012, while the second switchboard (SB2) should be built together with the test facility in 2014, in the same house as the test facility. SB2 should be built so that it can be extended to accommodate a second central test facility.

The layout makes it possible to utilise the test facility capacity to test more than one wind turbine simultaneously, provided that the total capacity of the tested turbines is below 16 MW. If only one central test facility is built, then any combination of turbines can be tested simultaneously, but if a second test facility is built, then this design allows for simultaneous test of turbines which are connected by the same stand owner: Siemens Wind Power (S), Vestas (V), or DTU (D). Finally, the layout makes it possible for another stand owner than the one who is using the first central test facility to use the second test facility.

As mentioned above, SB1 will be constructed as part of the Østerild Test Centre. Since the connection of the test facility depends on the layout of SB1, it is important to underline which restrictions another layout of SB1 will have. From Figure 21, two conclusions are made regarding SB1:

- In order to accommodate later grid connection of a test facility (TF1), SB1 should be a double busbar switchboard with room for an additional outgoing feeder to the test facility and a incoming feeder from the test facility

- In order to furthermore accommodate later grid connection of a second test facility (TF2), and allow to use the two test facilities in parallel, SB1 should have the possibility for lengthwise sectionalising of the busbars, preferably in the 3 sections shown in Figure 21.

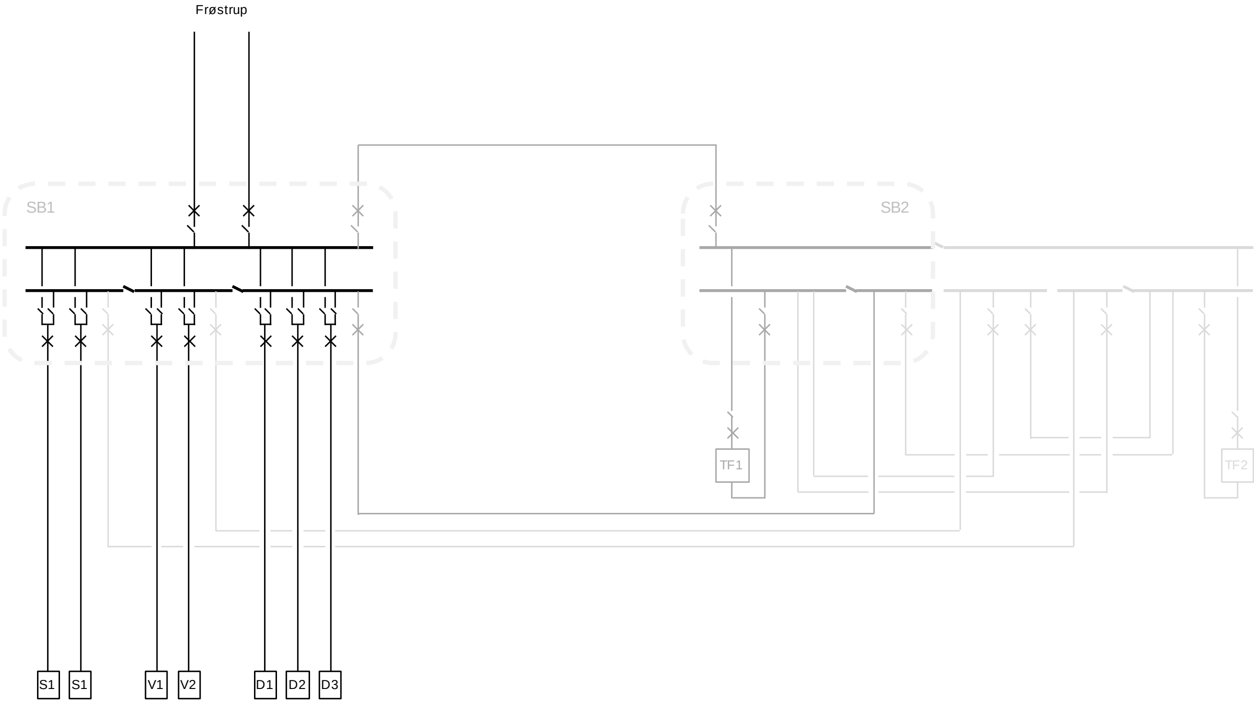


Figure 21. Planned switchgear scheduled for 2 phases:1. Østerild with no central Test Facility (2012), 2. Østerild with one central test Facility (grey, 2014). This design allows a third phase with two central test facilities (light grey, >2014)

6.4.2 Interface between the test stands and the mobile test equipment

The mobile short circuit equipment should be easy to move from one stand to another. This requires that the mobile equipment is built in container(s), but also that the necessary facilities are available at each of the 7 test stands. This includes facilities to support an easy electrical connection of the equipment and suitable hard standings for the placement of the mobile short circuit equipment.

6.4.3 Earthing of the 33kV system

Several studies have shown that the best compromise for reducing earth fault currents and transient over voltages is obtained by low-resistance grounding of the internal medium voltage cable grid. Therefore low-resistance system grounding is recommended to be applied in wind farms with an internal medium voltage cable grid.

Even though resonance grounding seems attractive this method has other disadvantages (risk of Ferro-resonance, more complex, and more expensive) which usually makes it not recommendable for wind farm collection grids.

Isolated system grounding is not recommendable due to risk of very high transient over voltages in case of single-phase earth faults followed by single-phase earth fault re-ignition.

This matter is considered further in Appendix H. The final decision on the grounding is not taken by the Test Facility group.

6.4.4 Auxiliary power supply

It may be feasible to provide the auxiliary power supply to the test facility from the planned auxiliary power supply to the test centre. This depends on the consumption of the test facility, and the possible free capacity of the Østerild auxiliary power supply.

6.4.5 Planning permission and ground acquisition for the Test Facility

This task has not been detailed yet, but will be settled at the meetings with the Østerild advisory committee.

6.5 Scope of works

This scope of works follows on from the conclusion of the solution (see section 6.1) and the interaction with Østerild Test Centre (section 6.4). The following scopes of work are defined:

- Test facility converter equipment
- Mobile short circuit equipment
- Maintenance contract
- Central switch board (SB1)

6.5.1 Test Facility converter equipment

This shall include everything necessary to provide the required test functionality, from the relevant outgoing breaker of the Test Centre switchboard, the test equipment, and back to the relevant incoming breaker on the Test Centre switchboard. This includes the grey parts framed as SOW in Figure 22, i.e. only the parts of the switchboard which are needed to connect a single test facility (TF1).

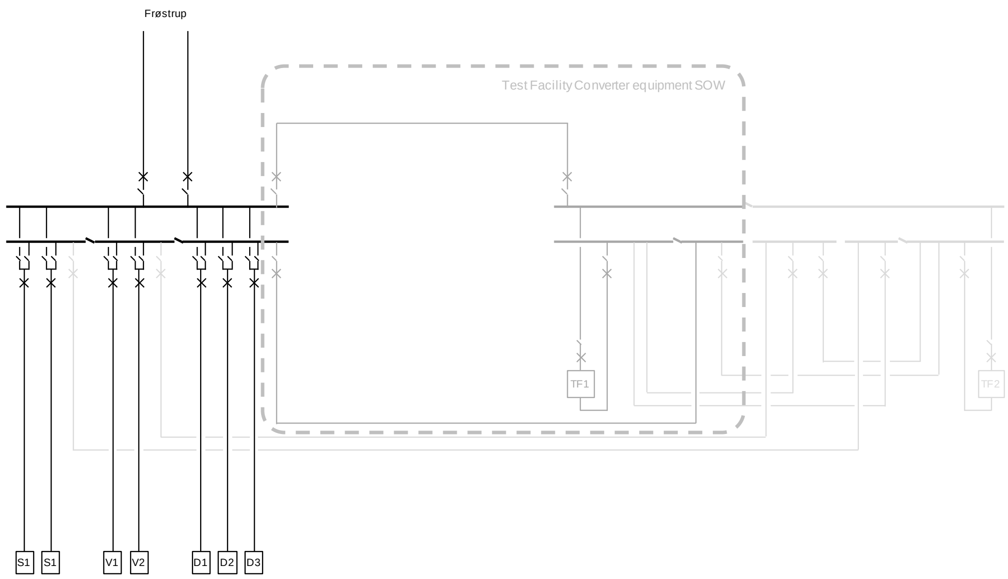


Figure 22 Extent of scope of works for the Test Facility converter equipment

This includes but is not limited to:

- Converter including internal control systems
- The transformer connecting the converter to grid side
- The transformer connecting the converter to turbine side (including offline tap changers if needed to meet specifications).
- Switchgear and protection devices for the safe operation of the equipment.
- System for interface with test facility operator
- System for interface to supplier's maintenance personnel.
- All cabling and earthing equipment necessary for connection to switchboard
- Building or container for proper protection from external environment, with associated works and building services inside and out.
- All design, engineering and manufacturing work.
- Factory tests.
- Delivery to site, installation, testing and commissioning.
- Customer on-site training for operation and maintenance.
- Two year warrantee.
- Recommended spare parts to be stored by customer.

6.5.2 Mobile short circuit equipment

This shall comprise a mobile short circuit impedance-based test unit with a capacity to test turbines up to 16 MW. The unit will be housed in containers and suitable for deployment adjacent to any of the test stands at the Test Centre. The containers shall be straightforward to move from one test stand to another.

6.5.3 Maintenance contract

The maintenance contract shall include for remote diagnostics and technical telephone service for the customer's personnel. An annual (or as recommended) maintenance visit shall ensure the correct and proper working of the equipment. Software shall also be regularly maintained and updated as necessary. A response to breakdowns/faults that cannot be handled by the customer's personnel should ensure the equipment is operational again promptly.

6.5.4 Central test facility switchboard

The switchboard should be suitable for connecting seven turbines of maximum capacity 16 MW to the 36kV grid. Individual turbines can be switched so that a single turbine can use the test facility whilst the remaining turbines operate undisturbed on the grid.

A possible solution could include, but it not limited to:

- A double bus bar switchboard.
- A suitable foundation and building to house the switchboard, together with associated works and building services inside and out.
- All design, engineering and manufacturing work.
- Factory tests.
- Delivery to site, installation, testing and commissioning.

- Customer on-site training.
- Two year warrantee.
- Recommended spare parts to be stored by customer.

6.6 Functional specifications for equipment

Chapter 2 including Table 1 specifies functional requirements to the test facility given by the individual tests which were identified. This section 6.6 will condense these requirements to specific requirements to the centrally located converter based unit and the short circuit mobile unit respectively.

6.6.1 Centrally located unit

6.6.1.1 Operator interface

It is envisaged that there will be an operator interface which will be able to receive direct instructions via a touch screen and/or computer terminal. These instructions for how the unit is to behave should include the following possibilities to specify the test facility output (local grid side to be connected to the turbine):

- Specification to emulate a simple Thévenin equivalent circuit representing a grid, i.e. as a constant voltage in series with a resistance and a reactance. This will include the following parameters to be set by the user:
  - The amplitude of the (positive sequence) no-load voltage (V)
  - The frequency of the (positive sequence) no-load voltage (Hz)
  - The reactance (Ω)
  - The resistance (Ω)
- Specification to behave according to a pre-determined time series of values (e.g. for the voltage dip for a LVRT test and phase shifts). This involves specification of a system frequency (50 Hz or 60 Hz) and time series for the following parameters:
  - The amplitude of the individual phase voltages (V)
  - The phase angle of the individual phase voltages (deg)
- Unit properties should adjust themselves according to a real-time signal (e.g. the output of an external real time simulation running concurrently with the test turbine). This involves specification of a system frequency (50 Hz or 60 Hz) and real time signals for the following parameters:
  - The amplitude of the individual phase voltages (V)
  - The phase angle of the individual phase voltages (deg)
- Specification to enable a voltage step performed by an online tap change:
  - The amplitude of the *converter* voltage (i.e. not the test facility voltage) (V)
  - Tap changer initial setting
  - Tap changer new setting

Furthermore the unit should give a range of useful status/fault/alarm outputs so that the test personnel can operate the unit safely and with sufficient knowledge of the unit's condition.

6.6.1.2 Maintenance interface

A local maintenance interface should be provided to allow local staff to assess the nature of faults and possible recommendations for actions. The unit should be also able to be interrogated remotely by the supplier in order to aid fault diagnostics.

6.6.1.3 Parameter ranges

Table 3 shows the parameters specifications for the converter based test unit. It is assumed that the unit is equipped with onload tap changers, which significantly reduces the requirement to the voltage and current ranges of the converter as shown in Appendix K.

Table 3. Parameters for converter based test unit

Parameter	**Range**
Active power	16 MW
Power factor	0,9
Nominal voltage	33 kV
Voltage range	U_n ± 15 %
Nominal (system) frequencies	f_n = 50 Hz or 60 Hz
Fundamental frequency range	f_n ± 5 Hz
Phase angle shifts	± 30 deg
Response time (95% rise time)	< 50 ms
Onload tap changer step size	5 %
Onload tap changer range	± 30 %
Harmonic filter bandwidth	$f \leq 7f_n$
Thevenin grid resistance	0 ≤ R ≤ 100 Ω
Thevenin grid reactance	0 ≤ X ≤ 100 Ω

6.6.2 Short circuit mobile unit

The short circuit unit is dedicated a single test: the low voltage ride through described in section 2.2.11. It must be designed to meet the requirements to accuracy of the voltage drops specified in IEC 61400-21 and the requirements to power quality in the point of common coupling of the test centre on the 150 kV grid in Frøstrup.

The unit must be capable of performing three phase short circuits and 2 phase short circuits.

Table 4 shows the main technical parameters.

Table 4. Parameters for short circuit unit

Parameter	Range
Active power	16 MW
Nominal voltage	33 kV
Response time according to IEC 61400-21	20 msec
Minimum voltage and duration	0 V for 1,3 sec[2]
Maximum voltage change in 150 kV PCC	3% for S_k = 1000 MVA

6.7 Budget estimate and business case

The cost of establishing the Test Facility have been estimated based on the various budgets obtained during the course of the project. The overall figures for the budget estimates are given below in Table 5 and the detailed breakdowns of the estimates for the establishment and operational phases are given in Appendix I.

The business case for the Test Facility centres around the costs and consequent funding of a) the establishment of the facility and b) its operation. These will now be considered individually.

[2] The final specification may be less demanding than 0 V for 1,3 sec, which will hardly appear in any grid

ESTABLISHMENT BUDGET COSTS IN DKK	
Phase 2: Pre-construction	**budget cost**
Applications, preparatory work, pre-qualifying, tender documents, etc	6,009,763
Phase 3: Construction	
Buildings	4,200,000
MV switchgear (double busbar), cabling and auxiliary equipment	4,040,000
Converter-based grid emulator, associated trafos and equipment	50,000,000
Short circuit (container-based) test equipment	18,750,000
Project management & design work	3,826,400
Project contingency	4,041,000
Sub total	84,857,400
Total for Phases 2 and 3 (rounded to nearest 1000)	**90,867,000**
ANNUAL OPERATION AND MAINTENANCE COSTS	
Phase 4: Operation	
Test facility personnel, maintenance contracts and administration	**2,544,000**

Table 5 Summary of budget costs for the establishment and running of the Test Facility

Establishment cost: The budget estimate for the establishment of the Test Facility with a testing capacity of 16MW is 91M Dkk, of which approximately 87% is for equipment, buildings, their installation and construction. The remaining 13% covers the project costs such as funding applications, further engineering design, tender documents, project management and construction supervision. This compares well with an typical figure of around 15% for this type of specialised project.

Establishment funding: For the implementation of the establishment an application will be made to Green Labs DK for a 50% grant, amounting to 45,5M Dkk.

The remaining 50% of the funding is proposed to be sourced from the owners of the Østerild Test Centre test stands in proportion to the number of test stands owned. DTU will, effectively, take out a loan to cover their share and the approximate proportions are as follows:

DTU	19,5M Dkk	(22%)
Vestas	13M Dkk	(14%)
Siemens WP	13M Dkk	(14%)

At present the deadline and conditions for the second Green Labs call is unclear, but the passing-on of the grant to users of the test facility has been demonstrated (see below) but will, of course, be refined when the final conditions are known.

Operational cost: The budget estimate for the annual O&M of the Test Facility is approximately 2,5M Dkk, which equates to 363k Dkk per test stand per year.

Operational funding: The operation of the Test Facility will be entirely financed by the users of the test stands as they will be obligated to cover the operation and maintenance costs in proportion to the number of test stands used. In this way the income necessary for the Test Facility will be secure. As is required under the current Green Labs rules, The Test Facility will not make a profit but the users of the DTU stands will pay an additional fee to repay the DTU loan, estimated at approximately 1,2M Dkk per test stand annually. (For the purposed of these calculations the loan is assumed to have an annual interest rate of 7% and a payback period of seven years.) Vestas and Siemens who own their test stands and who contribute to the capital cost of the Test Facility will have a consequently lower annual charge, estimated at 364k Dkk.

Business case: Table 6 & Table 7 give the project economics with and without grant funding. The purpose of this is to illustrate how the grant gets passed on to the industry by means of a reduction in annual charges for use of the Test Facility. Without the grant, DTU would take out a correspondingly larger loan resulting in larger rentals for both the owners and the subsequent renters. It can therefore be seen that a grant corresponding to 50% of the capital costs leads to a reduction in the annual rent per test stand of approximately 1,175M Dkk. Over seven years this represents the passing on of the total grant to the users and the write-down of the value of the grant.

To give an example of the potential effect, the wind turbine industry partners in this project (Vestas and Siemens Wind Power) supplied 7031 MW wind turbine capacity in 2009, which corresponds to 19 % of the total wind power world market in 2009 according to BTM Consult's "World Market Update 2009". Assuming conservatively 10 DKK/W of wind turbine capacity, this market share corresponds to more than 70000 MDKK. The present budget investment cost of the test equipment of approximately 91 MDKK thus corresponds to approximately 0.13 % of the partners' turnover in 2009, and this percentage is expected to be much smaller taking into account 2-3 more expected manufacturers on Østerild and the expected growth in the world market for wind power.

6.8 Organisation

Establishment: Following the end of Phase 1, the project group will continue – lead by RisøDTU – with the primary aims of securing funding and supporting the Østerild Test Centre project with the information necessary to ensure provisions for the Test Facility are made in a timely and economic manner. The project group will, therefore, liaise with and report to the Test Centre Advisory Board (Projektføglegruppe). It is expected that the involvement of Siemens A/S and ABB will be minimal as it is likely that they will be potential bidders for supplying equipment for the Test Facility.

Operation: The Test Facility will be run as a part of the Østerild Test Centre and will, indeed, share personnel where appropriate. Staff will be trained on the Test Facility equipment by the suppliers prior to the commencement of operation. Specialist activities such as MV switching and equipment maintenance will be contracted in.

The establishment and operation of the Test Facility will be implemented within the same legal framework as the Test Centre, albeit as a separate economic entity.

A) Calculation with 50% grant funding

	Project	Capital investments				Operational budget per test stand						
	Total	**Grant**	**DTU**	**Vestas**	**Siemens**	**DTU 1**	**Vestas 1**	**Vestas 2**	**DTU 2**	**DTU 3**	**Siemens 1**	**Siemens 2**
Establishment budget costs						1	2	3	4	5	6	7
Phase 2 establishment pre-construction	6,009,763											
Phase 3 establishment construction	84,857,400											
Establishment total	90,867,163											
Share of establishment costs		45,433,581	19,471,535	12,981,023	12,981,023							
Annual repayment on loan 7%,7yrs			3,526,532									
Operational budget costs												
Phase 4 O&M costs per year	2,544,000											
Share of O&M costs per year per owner			1,090,286	726,857	726,857							
O&M costs per year per test stand						363,429	363,429	363,429	363,429	363,429	363,429	363,429
Repayment of loan per test stand						1,175,511	0	0	1,175,511	1,175,511	0	0
Annual total cost of a test stand to user						1,538,939	363,429	363,429	1,538,939	1,538,939	363,429	363,429

Table 6 Financing of the Test Facility establishment and funding of the operation

Table 7 Comparative financing calculation without grant funding

B) Calculation with no grant funding

	Project	Capital investments				Operational budget per test stand						
	Total	**Grant**	**DTU**	**Vestas**	**Siemens**	**DTU 1**	**Vestas 1**	**Vestas 2**	**DTU 2**	**DTU 3**	**Siemens 1**	**Siemens 2**
Establishment budget costs						1	2	3	4	5	6	7
Phase 2 establishment pre-construction	6,009,763											
Phase 3 establishment construction	84,857,400											
Establishment total	90,867,163											
Share of establishment costs		0	64,905,116	12,981,023	12,981,023							
Annual repayment on loan 7%,7yrs			11,755,106									
Operational budget costs												
Phase 4 O&M costs per year	2,544,000											
Share of O&M costs per year per owner			1,090,286	726,857	726,857							
O&M costs per year per test stand						363,429	363,429	363,429	363,429	363,429	363,429	363,429
Repayment of loan per test stand						2,351,021	1,175,511	1,175,511	2,351,021	2,351,021	1,175,511	1,175,511
Annual total cost of a test stand to user						2,714,450	1,538,939	1,538,939	2,714,450	2,714,450	1,538,939	1,538,939

Reduction in annual payment per test stand due to grant, i.e. B - A	1,175,511	1,175,511	1,175,511	1,175,511	1,175,511	1,175,511	1,175,511

Summation of total reduction over 7 years	57,600,018
Value of 45,433,581 (the grant) in 7 years at 7%	57,600,018

7 Project summary and conclusion

This Phase 1 project, "Test Facility for Grid Connection Characteristics of Wind Power Plants", has concluded on the preferred technical, economic and organisational solution for providing such a test facility. This culminates in an Implementation Plan suitable for taking the project through to establishment and operation. All this has been achieved through a series of working sessions, group and individual meetings where the participation of the industry has been essential. Their input has guided discussions and is hereby gratefully acknowledged. The interest shown by the group has furthermore demonstrated that a Test Facility such as is recommended will provide manufacturers and turbine owners with a unparalleled facility for the research and development of the turbines of the future by being able to emulate grid conditions beyond what is done in standard tests today.

At the end of this Phase 1, it is clear that the resulting project group is the right one to carry the project on further and that Phase 1 has set the process in the right direction. This report will generate discussion amongst the stakeholders and interested parties which will, for the first time, be based on a thorough study of the options available and a clear budget for the costs of the implementation and operation. These discussions must be channelled usefully into realising the Test Facility and this is the next challenge for the project group.

Acknowledgements

Risø DTU would like to acknowledge the substantial contributions made by the project partners in providing input to this report. Notably:

Section 2: Wind turbine tests: Lars Højbjerg Nielsen / Claus Larsen (Vestas) and John Bech (Siemens Wind Power). Wind farm operation: Peter Nielsen (Vattenfall).

Section 3: Test equipment concepts: Lars Højbjerg Nielsen (Vestas). Switchboard concepts: Erik Koldby (ABB) and Peter Weinreich-Jensen (Siemens).

Appendix H: Earthing requirements: Peter Weinreich-Jensen (Siemens) and Erik Koldby (ABB)

References

[1] GL,http://www.gl-group.com/en/certification/renewables/GridCodeCompliance.php

[2] FGW, TR8 (Rev. 4), TR4 (Rev. 5), TR3 (Rev. 21) with IEC 61400-21 (edition 2), http://www.wind-fgw.de

[3] Spain: PVVC (Rev. 8) (http://www.aeeolica.es/contenidos.php?c_pub=27)

[4] IEC 61400-21 Wind Turbines Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines. Edition 2.0 2008-08.

[5] EN 50160: Voltage Characteristics in Public Distribution Systems (edition 2009)

[6] IEC 61000-3-6. EMC Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems. Technical Report.

[7] Electra 252, October 2010: SF_6 Tightness guide.

Appendices: Documents

A. DTU: Presentation of Østerild

B. Projektfølgegruppe i forbindelse med etablering af Testcenter Østerild

C. Udkast: Vedtægter for Styregruppe til drift og vedligeholdelse af Testcenter Østerild

D. Siemens: Proposed MV solution (SIPLINK)

E. ABB: Proposal for 33 kV switchgear with extension for grid connection of test facility

F. Vattenfall: Developer's view on proposed functional description and Grid-code compliance

G. Vestas: Introduction to possible technical concepts for layout of the test facility

H. The importance of system earthing and earthing design for Østerild
a) Siemens
b) ABB

I. Budget estimate for establishment and operation

J. Time schedule for implementation

K. Use of transformer tap changers to reduce required capacity of test converter (Risø DTU)

L. Literature survey summary (AAU)

APPENDIX A

DTU: Presentation of Østerild

Testcenter Østerild

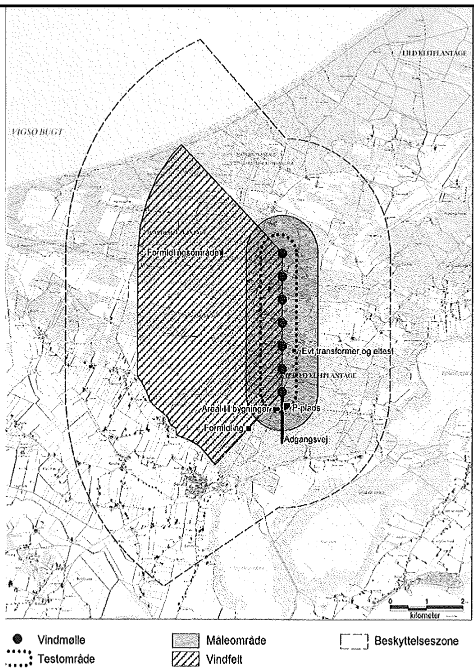
Orientering af gruppen for EUDP programmet for en testfacilitet
14.10.2010

Østerild

- Aftalegrundlaget
  - Anlægsloven
  - Købsaftaler
  - Lejeaftaler
- Testcenterets udformning
  - Testcenteret
  - Naturområdet omkring testcenteret

Østerild

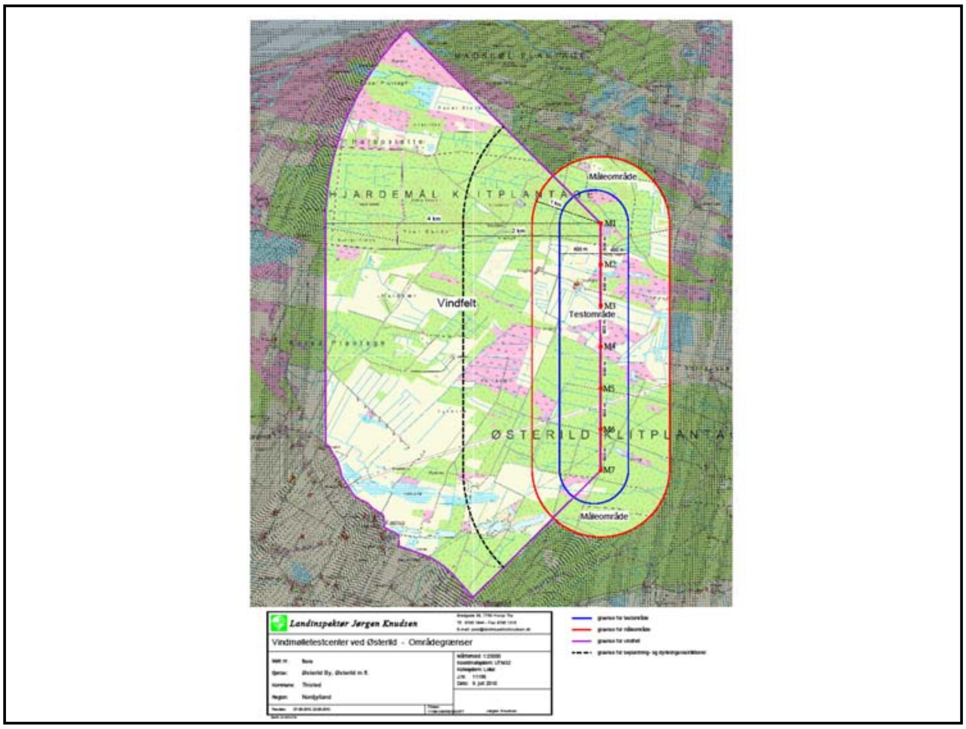
- Ejerforhold
  - Skov- og Naturstyrelsen (SNS)
  - Private lodsejere
  - Simens og Vestas
  - Risø DTU
- Anlægsfasen
  - Projektfølgegruppen
- Tidsplan
- Driften
  - Styregruppen

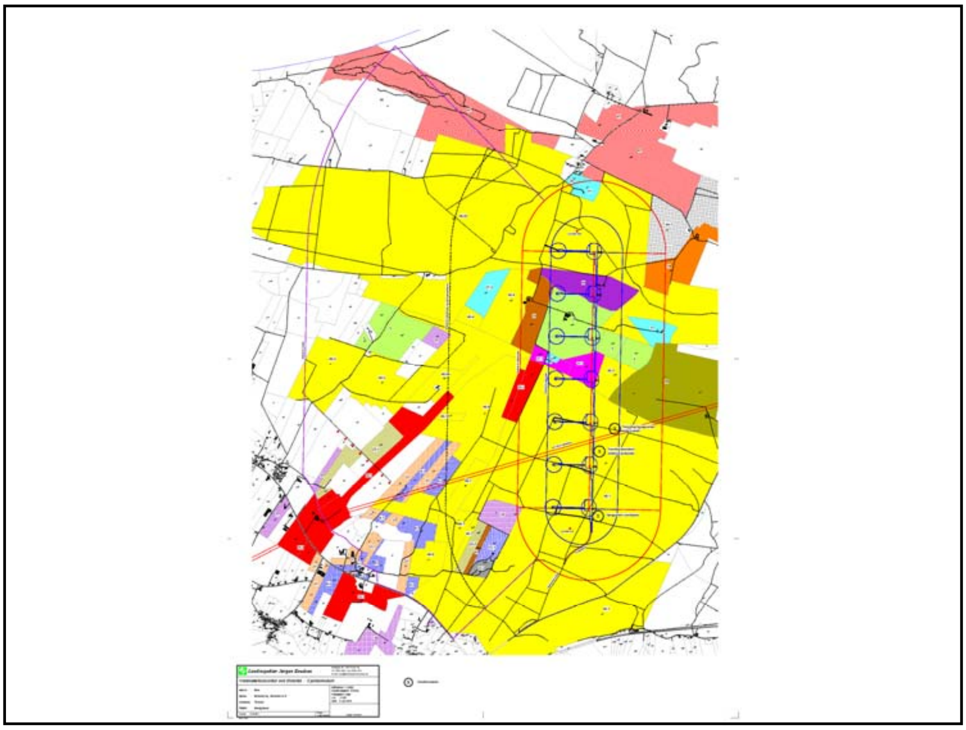


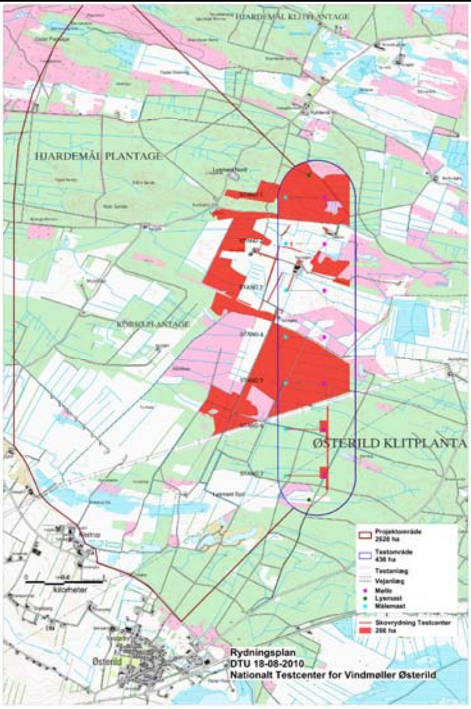
• Test af tilslutning af vindmølleparker til el-nettet

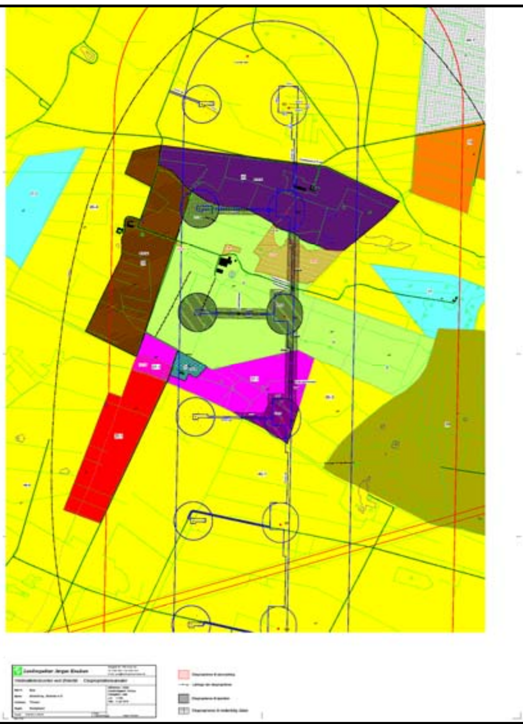
På samme måde som etablering af et nationalt testcenter skaber rammerne for industriens og forskernes muligheder for at teste fremtidens møller, er det en væsentlig forudsætning for partierne, at der samtidig skabes rammerne for, at der kan etableres de nødvendige faciliteter til at teste vindmølleparkernes tilslutning til el-nettet.
I forbindelse med planlægning og godkendelse af testcentret er der skabt mulighed for, at der nu eller senere kan etableres en avanceret nettilslutningsfacilitet, som gør det muligt at afprøve møllerne under varierende netforhold, uden at dette påvirker det overordnede elnet. Det er forventningen, at behovet herfor vil stige i takt med, at en større del af elproduktionen kommer fra vindkraft, og vindmøllerne derfor i højere grad skal kunne medvirke til at opretholde et driftssikkert elnet.
Med Risø DTU som lead partner er der samlet et konsortium bestående af - udover Risø DTU - bl.a. Vestas, Siemens (vind), Suzlon, Gamesa, DONG Energy, Vattenfall, ABB og Siemens, som i fællesskab har indgivet en ansøgning om et forprojekt til EUDP-programmet. EUDP-bestyrelsen har valgt at give penge til forprojektet, der nu er igangsat og forventes afsluttet i begyndelsen af 2011. Disse selskaber har udtrykt interesse i at bruge testfaciliteten. EUDP-forprojektet har til formål at komme nærmere en teknisk/økonomisk vurdering af forskellige specifikke løsninger af en avanceret nettilslutningsfacilitet. Forprojektet skal afklare, hvad der er af muligheder, samt hvordan evt. brugerinteresser orienterer sig i forhold til stationære eller flytbare løsninger. Som udløber af forprojektet og drøftelserne af tekniske, økonomiske og organisatoriske muligheder, må det vurderes, hvordan et projekt kan realiseres, samt hvordan mulige finansieringsmodeller kan se ud.
Risø DTU har samtidig gennemført en serie interviews med de enkelte interessenter, som har bekræftet den kommercielle interesse i at kunne få adgang til en testfacilitet. Efter gennemførelsen af forprojektet forventes det, at netfaciliteten vil kunne etableres på 2 år og således stå klar i begyndelsen af 2013. Testcenteret er designet til 7 møller á 20 MW eller i alt 140 MW. Der planlægges derfor en nettilslutning til 150 kV-nettet.

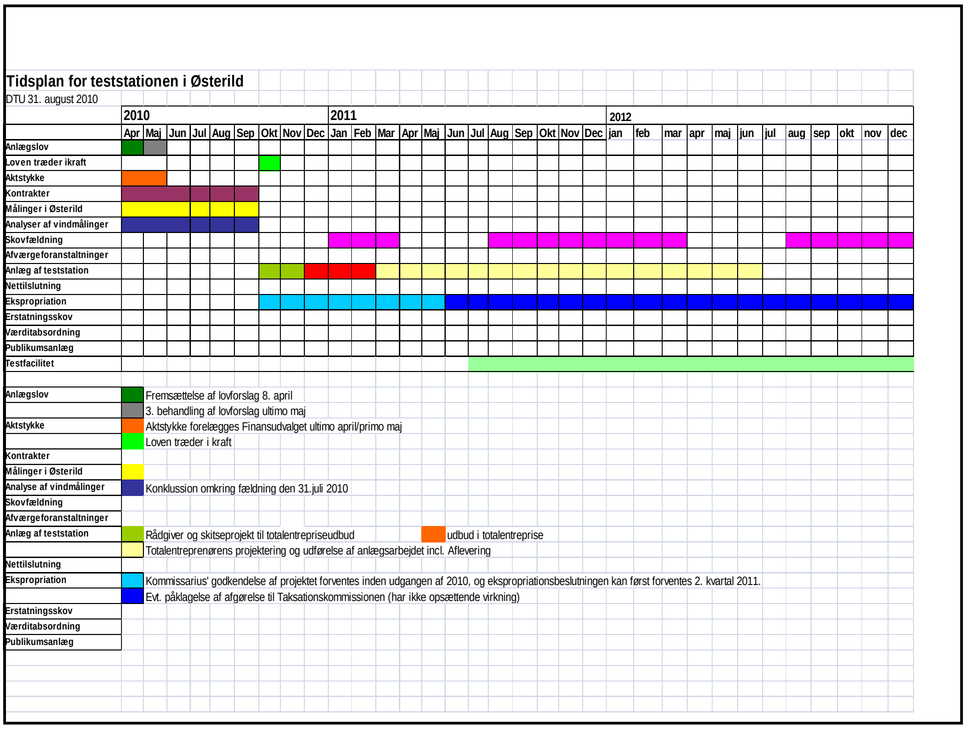
• Tilbud til borgere udenfor 44 dB-støjzonen til sikring mod økonomisk tab ved ejendomssalg og mulighed for naboer for at sælge deres ejendom til staten


Måleområde
M1
M2
M3
Testområde
M4
M5
M6
M7
Måleområde
Vindfelt
4 km
2 km
Landinspektør Jørgen Knudsen
Vindmølletestcenter ved Østerild - Områdegrænser
Østerild By, Østerild m.fl.
Thisted
Nordjylland




HJARDEMÅL KLITPLANTAGE
HJARDEMÅL PLANTAGE
ØSTERILD KLITPLANTA
Projektområde
2628 ha
Testområde
436 ha
Testanlæg
Vejanlæg
Mølle
Lysmast
Målemast
Skovrydning Testcenter
266 ha
kilometer
Østerild
Rydningsplan
DTU 18-08-2010
Nationalt Testcenter for Vindmøller Østerild




Tidsplan for teststationen i Østerild
DTU 31. august 2010
2010
2011
2012
Apr Maj Jun Jul Aug Sep Okt Nov Dec Jan Feb Mar Apr Maj Jun Jul Aug Sep Okt Nov Dec jan feb mar apr maj jun jul aug sep okt nov dec
Anlægslov
Loven træder ikraft
Aktstykke
Kontrakter
Målinger i Østerild
Analyser af vindmålinger
Skovfældning
Afværgeforanstaltninger
Anlæg af teststation
Nettilslutning
Ekspropriation
Erstatningsskov
Værditabsordning
Publikumsanlæg
Testfacilitet
Anlægslov
Fremsættelse af lovforslag 8. april
3. behandling af lovforslag ultimo maj
Aktstykke
Aktstykke forelægges Finansudvalget ultimo april/primo maj
Loven træder i kraft
Kontrakter
Målinger i Østerild
Analyse af vindmålinger
Konklussion omkring fældning den 31.juli 2010
Skovfældning
Afværgeforanstaltninger
Anlæg af teststation
Rådgiver og skitseprojekt til totalentrepriseudbud
udbud i totalentreprise
Totalentreprenørens projektering og udførelse af anlægsarbejdet incl. Aflevering
Nettilslutning
Ekspropriation
Kommissarius' godkendelse af projektet forventes inden udgangen af 2010, og ekspropriationsbeslutningen kan først forventes 2. kvartal 2011.
Evt. påklagelse af afgørelse til Taksationskommissionen (har ikke opsættende virkning)
Erstatningsskov
Værditabsordning
Publikumsanlæg

APPENDIX B

Projektfølgegruppe i forbindelse med etablering af Testcenter Østerild

Kammeradvokaten

Vester Farimagsgade 23
DK-1606 København V

Telefon: 33 15 20 10
Telefax: 33 15 61 15

mail@kammeradvokaten.dk
www.kammeradvokaten.dk

Dato: 23. september 2010

J.nr.: 50-2659 KB/JAV

BILAG 2

Projektfølgegruppe i forbindelse med etablering af Testcenter Østerild

1. Baggrund og formål

1.1 I henhold til anlægsloven for etablering af testcenteret for store vindmøller i Østerild og Hjardemål Klitplantager (herefter "Testcenteret") er DTU driftsansvarlig for anlæggelse af Testcenter Østerild. DTU etablerer efter aftale med Miljøministeriet, Skov- og Naturstyrelsen (herefter "SNS") en projektfølgegruppe i projekt- og anlægsfasen for Testcenteret. Projektfølgegruppen skal sikre, at ejerne af standpladser på Testcenteret, og SNS løbende inddrages i anlægsprojektets forløb og økonomiske status. Standpladsejerne inddrages endvidere altid og forud for beslutninger, som kan have indflydelse på testcenteranlæggets samlede økonomi og tekniske funktioner af betydning for standpladsejerne.

2. Medlemmer af projektfølgegruppen

2.1 Medlemmerne af projektfølgegruppen omfatter DTU som driftsansvarlig og som bygherre, en repræsentant fra hver af de vindmølleproducenter, som er ejere af standpladser på Testcenteret og repræsentanter fra SNS, der udlejer de statsejede arealer til DTU, hvor Testcenteret anlægges.

3. Projektfølgegruppens opgaver og kompetence

3.1 DTU inddrager projektfølgegruppen i Testcenterets udformning og inddrager standpladsejernes ønsker til den tekniske udformning af Testcenteret i forbindelse med anlægsprojektets udformning, projektering og tidsplan.

3.2 Parterne er enige om et foreløbigt budget og tidsplan for anlæg af Testcenteret. På baggrund af en foreløbig skitse af anlægsprojektet er der budgetteret med udgifter på DKK 73,1 mio. excl. moms med tillæg af rådgivningsydelser på DKK 7,1 mio. excl. moms, i alt et samlet anlægsbudget på DKK 80,2 mio. excl. moms.

3.3 DTU inddrager projektfølgegruppen i hvert fald i beslutningen af følgende:

(1) Tidsplan for gennemførelse af anlægsarbejderne for Testcenteret.
(2) Specifikation af anlægsprojektet.
(3) Anlægsbudget for det samlede Testcenter.
(4) Resultatet af gennemført udbud af rådgiveropgaver og hvem DTU indgår rådgiverkontrakt med.
(5) Udformningen af oplæg til anlægsprojekt for Testcenteret, som DTU har til hensigt at sende i udbud.
(6) Kravspecifikation af følgende enkeltområder:
    (a) Veje og pladser
    (b) El-anlæg
    (c) Master
    (d) Målesystemer
    (e) Bygninger
    (f) Ekspropriationsgrundlag
    (g) Lysafmærkning
    (h) Datakommunikation
(7) Resultatet af gennemført udbud af bygge- og anlægsopgaverne m.v. og hvem DTU har til hensigt at indgå bygge- og anlægskontrakter med.
(8) Dispositioner, som har indflydelse på den samlede projektøkonomi

Der tilstræbes enighed om beslutningerne, hvorfor DTU er forpligtet til i vidt omfang at tage hensyn til standpladsejernes ønsker.

3.4 Projektændringer og ændringer ud over det samlede anlægsbudget kræver standpladsejernes godkendelse, medmindre forhøjelsen af anlægsbudgettet skyldes eller er en konsekvens af uforudsete forhold på testområdet, herunder jordbundsforhold m.v. for hvilke DTU ikke er ansvarlig. I sidstnævnte tilfælde forelægger DTU standpladsmedlemmerne det konstaterede forhold for kommentering. Parterne søger i fællesskab at finde en for DTU og projektfølgegruppen økonomisk og teknisk tilfredsstillende løsning set i forhold til det samlede anlægsprojekt og anlægsbudget m.v. og afdækker muligheden for at finde besparelser andre steder i anlægsbudgettet, dog med respekt af anlægslovens bestemmelser for testcenteranlæggets funktionalitet, udformning m.v.

3.5 Projektfølgegruppen fastsætter overtagelsesdag for de enkelte standpladsejere. På overtagelsesdagen overtager de enkelte ejere ejendomsretten til standpladserne, får adgang til deres areal og kan påbegynde opstillingen af mølle m.v. Overtagelsesdagen fastsættes som det tidligst mulige tidspunkt, hvor den enkelte standplads er befæstet, planeret og gruset, og standpladsejerne kan få adgang til standpladsen uden at skabe hindringer for færdiggørelsen af Testcenteret.

3.6 DTU indkalder skriftligt og med mindst 3 måneders varsel de øvrige medlemmer af projektfølgegruppen til en overtagelsesforretning. Ved overtagelsesforretningen udfærdiger DTU en skriftlig rapport (overtagelsesrapport), hvori det anføres, om Testcenteret er klar til ibrugtagning, eller om der er væsentlige mangler ved Testcenteret og i givet fald hvilke. Overtagelsesrapporten underskrives af såvel standpladsejerne som DTU. I dokumentet skal den præcise ibrugtagningsdato for Testcenteret fremgå. Ibrugtagningsdatoen er defineret som den dag, centeret er færdigetableret og funktionsdygtigt, dvs. at centeret er tilsluttet elnettet og der er mulighed for at gennemføre målinger på Testcenteret. Samtlige medlemmer af projektfølgegruppen modtager kopi af overtagelsesrapporten.

4. Orientering og møder

4.1 DTU indkalder skriftligt medlemmerne til møde minimum én gang hvert kvartal, eller når der er behov herfor, eller når et medlem af projektfølgegruppen fremsætter begæring herom overfor DTU med angivelse af, hvilket emne som ønskes behandlet på mødet. Møder kan eventuelt afholdes som video- eller telefonmøder.

4.2 DTU orienterer løbende og som minimum hver måned medlemmerne om status, fremdrift og eventuelle ændringer for så vidt angår projektering og anlæg af testcenteret samt tidsplan og økonomi. Såfremt der indtræffer uforudsete forhold, herunder misligholdelse af de af DTU indgåede aftaler vedrørende Testcentret, der har væsentlig betydning for anlægsprojektets tekniske funktion, økonomi eller tidsplan, orienterer DTU uden ugrundet ophold medlemmerne af projektfølgegruppen herom.

5. Start og ophør af projektfølgegruppen

5.1 Projektfølgegruppen etableres, når salget af standpladser er gennemført i forbindelse med underskrivelse af betingede købsaftaler, dog tidligst 1. oktober 2010.

5.2 Projektfølgegruppen ophører på ibrugtagningsdatoen, hvor Testcenteret er færdigetableret og funktionsdygtigt, dvs. at Testcenteret er tilsluttet elnettet, og der er mulighed for at gennemføre målinger på Testcenteret. Projektfølgegruppen afløses af "Styregruppen til drift og vedligeholdelse af Testcenter Østerild" med deltagelse af DTU, standpladsejerne og lejerne i henhold til de i vedtægterne for Styregruppen fastsatte bestemmelser. Projektfølgegruppen kan i forbindelse med overtagelsesforretningen i henhold til pkt. 3.6 beslutte at overdrage eventuelle mindre udeståender vedrørende etablering af Testcenteret til "Styregruppen til drift og vedligeholdelse af Testcenter Østerild".

København 2010

APPENDIX C

Udkast: Vedtægter for Styregruppe til drift og vedligeholdelse af Testcenter Østerild

Kammeradvokaten

Vester Farimagsgade 23
DK-1606 København V

Telefon: 33 15 20 10
Telefax: 33 15 61 15

mail@kammeradvokaten.dk
www.kammeradvokaten.dk

Dato: 10. september 2010

J.nr.: 50-2659 JAV/dch

V E D T Æ G T E R

for

Styregruppe til drift og vedligeholdelse af

Testcenter Østerild

1. Baggrund og formål

1.1 I henhold til lov nr. 647 af 15. juni 2010 om etablering af et nationalt testcenter for store vindmøller ved Østerild og Hjardemål Klitplantager i Thisted Kommune (herefter anlægsloven) er Danmarks Tekniske Universitet DTU ansvarlig for anlæg og drift af testcenteret. DTU etablerer en "Styregruppe til drift og vedligeholdelse af Testcenter Østerild" (herefter "styregruppen").

Testcenteranlægget omfatter veje, bygninger, standpladser, pladser til måle- og meteorologimaster mv. En skitse for testcenteret ved denne vedtægts godkendelse samt geografisk afgrænsning af testcenteret fremgår af Bilag A. Det er i anlægsloven forudsat, at brugerne af møllepladserne afholder alle omkostninger til anlæg og drift af testcenteret. De forventede drifts– og vedligeholdelsesomkostninger på baggrund af det forventede centeranlægsprojekt ved godkendelse af denne vedtægt fremgår af Bilag B.

1.2 Styregruppens formål er:

(a) At sikre en lovlig, forsvarlig og effektiv drift og vedligeholdelse af testcenterets anlæg (herefter under ét "testcenteranlægget") og at bidrage økonomisk hertil, således at dette til enhver tid fremstår velvedligeholdt og opfylder gældende krav for testcenteret, herunder krav fastsat i anlægsloven for testcenteret, plan- og miljømæssige krav samt arbejdsmiljø- og sikkerhedskrav m.v. Testcenteranlægget skal drives og vedligeholdes således, at der til enhver tid kan foretages forskning, udvikling og afprøvning af vindmøller og ny vindmølleteknologi på alle testcenterets standpladser, dog med behørig hensyntagen til de dermed forbundne omkostninger. Drift og vedligeholdelse af testcenteranlægget sker i overensstemmelse med de til enhver tid vedtagne vedligeholdelses- og driftsplaner. Standplads-ejerne forestår selv drift og vedligeholdelse af egne standpladser.

(b) At sikre og bidrage økonomisk til, at DTU som overordnet ansvarlig for testcenteret kan efterleve de forpligtelser overfor Den Danske Stat repræsenteret ved Miljøministeriet, Skov- og Naturstyrelsen ("Staten"), som følger af den til enhver tid gældende lejeaftale mellem Staten og DTU, jf. Bilag C. Forpligtelserne i lejeaftalen omfatter bl.a. økonomisk bidrag til løbende pleje og vedligeholdelse af naturarealer og kompensation for indtægtstab fra tidligere skovdrift m.v. på testcenterets områder (herefter under ét benævnt ”Jordleje”).

(c) At sikre og bidrage økonomisk til, at der foretages ny- og reinvesteringer i testcenteranlægget og testcenteret, herunder om nødvendigt at foretage indstilling overfor Miljøministeren om yderligere skovfældning inden for de rammer og under de betingelser, der er fastsat i anlægsloven og afholde de hermed afledte omkostninger i overensstemmelse med beslutninger truffet i henhold til denne vedtægt og således at testcenteret til stadighed og for alle brugerne kan anvendes efter sit formål.

2. Juridisk status

2.1 Styregruppen kan træffe bindende beslutninger i det omfang, det er i overensstemmelse med denne vedtægts formål, jf. pkt. 1.2, og inden for rammerne af anlægsloven.

3. Medlemmer af styregruppen

3.1 Styregruppen omfatter pligtmæssigt medlemskab for samtlige ejere og lejere af standpladser på testcenteret inklusiv lejere på de to ekstra midlertidige standpladser, som DTU er berettiget til at etablere i en periode (herefter kaldet ”standplads-medlemmer”) og DTU (under ét ”styregruppemedlemmerne”). Lejeres medlemskab gælder i perioden fra deres lejekontrakt med DTU træder i kraft og indtil denne ophører.

3.2 Hvis en eller flere af DTU’s permanente standpladser ikke er lejet ud, repræsenterer DTU disse pladser i styregruppen, mens de midlertidige pladser ikke er repræsenteret, hvis de ikke er lejet ud. DTU svarer for de ikke-udlejede permanente standpladsers forpligtelser og udgifter i henhold til denne vedtægt, men ikke for de ikke-udlejede ekstra standpladser. Udgiftsfordelingen blandt styregruppemedlemmerne tager udgangspunkt heri.

3.3 I tilfælde af at et standplads-medlem ophører med at være ejer eller lejer af en standplads på testcenteret ophører medlemskabet af styregruppen samtidig hermed for så vidt angår den pågældende standplads. Ved ophør af medlemskabet skal medlemmet betale eventuelle udeståender senest på det tidspunkt, hvor medlemskabet ophører.

3.4 Måtte DTU´s medlemskab af styregruppen ophøre uanset årsagen hertil, træffer en statslig myndighed afgørelse om, hvorledes der skal forholdes i den konkrete situation, herunder om der eventuelt skal udpeges en anden organisation eller lign., der varetager de opgaver, som i henhold til disse vedtægter varetages af DTU. Eventuelle ændringer i denne vedtægt og grundlaget for drift og vedligeholdelse m.v. af testcenteret samt samarbejdet omkring testcenteret i den anledning forhandles nærmere med standplads-medlemmerne.

4. Forpligtelser for styregruppens medlemmer

4.1 Styregruppemedlemmerne er forpligtet til:

(a) At efterleve de beslutninger, som vedtages af styregruppen i overensstemmelse med disse vedtægter og styregruppens formål.

(b) At overholde de for testcenteret til enhver tid gældende regler, herunder sikkerhedsforskrifter og ordensreglementer, som fastsættes i henhold til lovgivningen, af DTU, af Miljøministeriet, Skov- og Naturstyrelsen, af andre offentlige myndigheder eller af styregruppen i henhold til disse vedtægter.

(c) At overholde de til enhver tid gældende miljømæssige og planmæssige krav m.v., der er gældende for testcenteret, herunder krav som i henhold til lovgivningen forvaltes og administreres af DTU. Det gælder for eksempel støjkrav fra samtlige vindmøller på testcenteret, samlet årlig skyggetid, helikopterflyvninger i forbindelse med afprøvninger m.v.

(d) At betale til DTU de til enhver tid fastsatte økonomiske bidrag til drift og vedligeholdelse m.v. af testcenteranlægget i henhold til de vedtagne drifts- og vedligeholdelsesplaner. Styregruppemedlemmerne er forpligtet til at bidrage til finansieringen af de omkostninger, som DTU skal betale til Staten i Jordleje for testcenteret, jf. <u>Bilag C</u>, og til finansieringen af eventuel yderligere skovfældning og ny- og reinvesteringer m.v. på testcenteret samt hermed relaterede omkostninger i henhold til beslutninger truffet i overensstemmelse med denne vedtægt.

(e) At bidrage til et godt og konstruktivt samarbejdsklima blandt styregruppemedlemmerne på testcenteret. Styregruppemedlemmerne er til enhver tid forpligtet til at samarbejde med henblik på, at testcenteret drives under skyldig hensyntagen til (i) testcenterets formål, som nationalt testcenter for forskning, udvikling og afprøvning af vindmøller og vindmølleteknologi, (ii) myndighedskrav m.v. og (iii) omkostningerne til drift og vedligeholdelse af testcenteret. Ethvert styregruppemedlem kan på ethvert tidspunkt anmode et eller flere styregruppemedlemmer om en drøftelse af et hvilket som helst emne og styregruppemedlemmerne skal udøve alle rimelige bestræbelser på at finde løsninger, der respekterer de enkelte medlemmers interesser inden for rammerne af denne vedtægt.

(f) At respektere den mellem Staten og DTU indgåede lejeaftale (Bilag C).

5. DTU´s opgaver

5.1 DTU er i henhold til anlægsloven og lejeaftale med Staten ansvarlig for anlæggelse af testcenteret og for centerets drift og vedligeholdelse, jf. Bilag C. DTU er herunder ansvarlig for, at sikre, at afprøvningen af testmøller sker i overensstemmelse med anlægsloven og den øvrige plan- og miljølovgivning.

5.2 DTU indgår på grundlag af beslutninger truffet i henhold til denne vedtægt de fornødne aftaler med tredjemand om drift og vedligeholdelse af testcenteranlægget. Aftalerne indgås i henhold til de vedtagne drifts- og vedligeholdelsesplaner og med henblik på overholdelse af krav fastsat i anlægsloven for testcenteret, plan- og miljømæssige krav samt arbejdsmiljø- og sikkerhedskrav. Såfremt der i henhold til denne vedtægt træffes beslutninger om ny- eller reinvesteringer på testcenteranlægget, indgår DTU ligeledes aftaler med tredjemand om gennemførelsen heraf. Eventuel yderligere skovfældning og deraf følgende naturgenopretning m.v., jf. pkt. 6.7 gennemføres i henhold til DTU´s lejeaftale med Staten, jf. Bilag C.

5.3 DTU er ansvarlig for indhentelse af de fornødne myndighedsgodkendelser m.v. i forbindelse med drifts, anlægs- og vedligeholdelsesopgaver, herunder myndighedsgodkendelser i forbindelse med ny- og reinvesteringer i testcenteranlægget. Der kan i henhold til bestemmelserne i denne vedtægt træffes nærmere beslutning om, at DTU selv skal varetage visse opgaver omkring drift og vedligeholdelse m.v. af testcenteranlægget. DTU forelægger sine planer for aftaleindgåelser efter pkt. 5.2 og 5.3 for styregruppen, der tillige godkender tilbud fra 3. mand, såfremt der er tale om væsentlige aftaler, der repræsenterer en værdi på over DKK 100.000 årligt.

5.4 DTU forestår i henhold til lovgivningen, herunder anlægsloven, administrationen af en række myndighedskrav for testcenteret, herunder støjkrav, skyggetid, helikopteroverflyvninger m.v. DTU administrerer i forhold til styregruppe-medlemmerne disse myndighedskrav ud fra saglige og objektive fordelingskriterier, jf. pkt. 6.3 nedenfor. DTU påser, at disse krav overholdes af ejerne og lejerne af standpladserne på testcenteret og kan i tilfælde af manglende overholdelse gøre misligholdelsesbeføjelser gældende, jf. pkt. 11.

5.5 DTU har som udgangspunkt kontakten til områdets private lodsejere. Hvis ejeren af standpladser midlertidigt skal anvende jord i forbindelse med prøvning af deres vindmølle, indgår DTU uden unødigt ophold aftale med lodsejeren. Aftalen skal følge det grundlag, der er etableret ved ekspropriationen af retten til midlertidigt at anvende lodsejerens jord i forbindelse med prøvning af vindmøller. DTU skal efter anmodning lade standpladsejer indgå bilateral aftale samt varetage dialogen med lodsejeren. Standpladsejeren skal på anmodning fra DTU forevise eller på anden måde dokumentere indgået aftale med lodsejeren.

5.6 DTU fastsætter i samråd med standplads-medlemmerne ordensreglement og øvrige reglementer for anvendelse af testcenteranlægget. Reglerne fastsættes bl.a. med henblik på at sikre overholdelse af de til enhver tid fastsatte myndighedskrav og med henblik på, at der til enhver tid kan foretages forskning, udvikling og afprøvning af vindmøller og ny vindmølleteknologi på alle standpladser på testcenteret.

5.7 DTU indgår lejekontrakt med Staten om leje af statsejede arealer i testcenterets test- og måleområde, med undtagelse af solgte standpladser. Ikke-solgte standpladser kan af DTU udlejes til vindmølleproducenter på nærmere fastsatte lejevilkår. Lejerne af standpladserne har pligt til at være medlem af styregruppen, jf. pkt. 3.1.

5.8 DTU forestår administrationen af styregruppen og indkalder blandt andet til møder i styregruppen, jf. pkt. 8 og forestår udarbejdelse af årsregnskab, jf. pkt. 10.

5.9 DTU kan påtale et standplads-medlems manglende overholdelse af sine forpligtelser i henhold til denne vedtægt og kan indskærpe og påtale overfor medlemmet pligten til at overholde de for testcenteranlægget og testcenteret gældende regler.

6. Beslutninger og stemmeret m.v.

6.1 Hvert medlem har én stemme for hver standplads på testcenteret og DTU har én stemme. Såfremt en standplads ikke er udlejet eller ejet af en vindmølleproducent varetager DTU den pågældende standplads stemme. Dette gælder dog kun for de syv permanente standpladser på testcenteret, idet DTU ikke kan stemme på vegne af ikke-udlejede midlertidige ekstra møllepladser.

6.2 Beslutninger i styregruppen træffes ved simpelt stemmeflertal, medmindre andet er fastsat i denne vedtægt, herunder de i pkt. 6.3- 6.8 nævnte særregler. I tilfælde af stemmelighed er DTU´s stemme udslagsgivende.

6.3 Alle beslutninger om opfyldelse af myndighedskrav og myndighedsbeslutninger, der angår testcenteranlægget, standpladserne eller afprøvning af testmøllerne i det nationale testcenter, som DTU er tillagt ansvaret for i henhold til anlægsloven, træffes af DTU. Beslutninger træffes inden for de gældende rammer ud fra saglige og objektive kriterier. DTU indhenter en indstilling fra styregruppen. Indstillingen kan kun fraviges af DTU, hvis der foreligger tungtvejende grunde.

6.4 Opfyldelse af myndighedskrav i henhold til lovgivningen, herunder anlægsloven, påhviler det enkelte standplads-medlem for standpladsen, i de tilfælde, hvor standplads-medlemmet iht. aftale med Miljøministeriet eller DTU selv har indhentet myndighedsgodkendelse, f.eks. byggetilladelse, eller der er tale om forhold, der ikke vedrører driften af det nationale testcenter, og som DTU derfor ikke er tillagt ansvaret for i henhold til anlægsloven.

6.5 I det omfang forpligtelser hertil ikke fremgår af lovgivningen, træffes beslutninger om nyinvesteringer eller andre udvidelser af testcenteranlægget og dets faciliteter samt beslutning om reinvesteringer eller særligt vidtgående vedligeholdelsesbeslutninger, der ikke er omfattet af de vedtagne vedligeholdelsesplaner, jf. pkt. 6.6 ved enighed mellem ejerne af standpladserne og DTU. Ejerne af standpladserne og DTU kan fremsætte forslag om iværksættelse af nyinvesteringer af hensyn til anvendelsesmulighederne af en eller flere, men ikke alle standpladser og som dermed ikke er begrundet i opretholdelsen af det samlede testcenters funktionsdygtighed, hvor finansieringen af nyinvesteringen alene påhviler det eller de styregruppemedlemmer, der foreslår nyinvesteringens gennemførelse (herefter kaldet "individuelle nyinvesteringer"). Beslutning om individuelle nyinvesteringer træffes ligeledes ved enighed mellem ejerne af standpladserne og DTU, idet ikke berørte styregruppemedlemmer dog ikke kan modsætte sig beslutningen, medmindre der foreligger væsentlige og saglige grunde herfor, der kan henføres til udnyttelsen, driften eller vedligeholdelsen af testcenteranlægget eller øvrige standpladser.

6.6 Beslutninger om godkendelse af drifts- og vedligeholdelsesplaner og driftsbudget i overensstemmelse med formålsbestemmelsen i pkt. 1.2, træffes ved simpelt stemmeflertal blandt samtlige styregruppemedlemmer. Dette gælder ligeledes beslutninger til realisering af vedtagne vedligeholdelsesplaner, idet intet styregruppemedlem dog kan modsætte sig realisering af beslutninger, der er omfattet af en vedligeholdelsesplan, som er påkrævet for overholdelse af den i pkt. 1.2 nævnte formålsbestemmelse eller i henhold til den mellem Staten og DTU indgåede lejeaftale (Bilag C).

6.7 Beslutning om yderligere skovfældning indenfor anlægslovens rammer kræver alene, at enten DTU på vegne og foranledning af én af lejerne af standpladserne eller én af ejerne af standpladserne fremsætter skriftlig begæring herom overfor DTU, og at DTU indhenter godkendelse af skovfældningen hos Miljøministeren, jf. anlægslovens § 8, stk. 1. Begæringen skal være bilagt en skriftlig motiveret redegørelse om årsagen til ønsket om yderligere skovfældning. Yderligere skovfældning kan begæres af hensyn til at sikre opfyldelsen af de internationale standarder for vindmålinger. Såfremt yderligere skovfældning sagligt kan begrundes i nævnte hensyn indstiller DTU overfor Miljøministeren, at yderligere skovfældning godkendes af ministeren. DTU orienterer de øvrige styregruppemedlemmer om anmodningen til Miljøministeren om godkendelse af yderligere skovfældning, om Miljøministeriets endelige afgørelse i sagen og om gennemførelsen af yderligere skovfældning i henhold til lejeaftalen, jf. Bilag C.

6.8 Medmindre andet følger at denne vedtægt, er styregruppen beslutningsdygtigt, når mindst 5/8 af styregruppestemmerne inklusive DTU er til stede. Beslutninger om godkendelse af investeringsplaner/særligt vidtgående vedligeholdelsesplaner, jf. pkt. 6.5 kræver dog at samtlige styregruppemedlemmer er til stede, medmindre et styregruppemedlem udebliver uden lovligt forfald. I sådanne tilfælde kan nævnte beslutninger træffes blandt de tilstedeværende styregruppemedlemmer. Udebliver et styregruppemedlem for 3. gang til et lovligt indkaldt møde til behandling af et bestemt emne, kan beslutninger træffes blandt de tilstedeværende styregruppemedlemmer, uanset årsagen til at det pågældende medlem er udeblevet.

6.9 Såfremt DTU i en periode vælger at etablere midlertidige ekstra standpladser til opstilling af yderligere to vindmøller og en eller begge er lejet ud justeres kravet i pkt. 6.8 fra mindst 5/8 til at mere end halvdelen af styregruppestemmerne inklusive DTU er til stede.

7. Økonomi og udgiftsfordeling

7.1 Årlige driftsbidrag

7.1.1 Ejerne og lejerne af standpladserne finansierer gennem et årligt driftsbidrag (herefter kaldet "driftsbidraget") omkostningerne til drift og vedligeholdelse af testcenteranlægget i overensstemmelse med de til enhver tid vedtagne drifts- og vedligeholdelsesplaner. Ejerne og lejerne finansierer ligeledes gennem driftsbidraget de årlige omkostninger, som DTU har i forbindelse med betaling af Jordleje til Staten, jf. lejeaftalen med Staten (Bilag C).

7.1.2 Det årlige driftsbidrag beregnes som summen af samtlige årlige omkostninger til drift og vedligeholdelse af testcenteranlægget samt summen af samtlige beløb, som DTU er forpligtet til at betale til Staten i Jordleje, jf. lejeaftalen (Bilag C), fordelt ligeligt mellem de 7 permanente standpladser samt eventuelle midlertidige ekstra standpladser, som DTU i en periode faktisk måtte have udlejet. Såfremt der i henhold til pkt. 6.5 er truffet beslutning om individuelle nyinvesteringer fordeles drift og vedligeholdelsesomkostningerne hertil alene mellem de styregruppemedlemmer, der har ønsket nyinvesteringens gennemførelse.

7.1.3 På grundlag af det af medlemmerne af styregruppen godkendte drifts- og vedligeholdelsesbudget, opkræver DTU et a conto driftsbidrag, der reguleres på grundlag af det endelige årsregnskab. A conto driftsbidraget og et eventuelt reguleringsbeløb forfalder til betaling 30 dage efter, at DTU har fremsat skriftligt påkrav herom. Har standplads-medlemmerne betalt for meget i a conto driftsbidrag modregnes det for meget betalte i det kommende års a conto-betalinger.

7.2 Anlægsbidrag

7.2.1 Ejerne af standpladserne og DTU (til fordeling mellem lejerne af standpladserne), afholder endvidere gennem anlægsbidrag (herefter kaldet "anlægsbidraget") omkostningerne til ny- og reinvesteringer på testcenteret og omkostninger til yderligere skovfældning, såfremt der træffes beslutning om sådanne projekter i henhold til denne vedtægt. Anlægsbidraget kan af DTU opkræves som up-front betaling. DTU forestår gennem lejeopkrævninger hos de styregruppemedlemmer, der er lejere af standpladserne disse medlemmers andel af anlægsbidraget.

7.2.2 Anlægsbidraget beregnes som summen af samtlige omkostninger til ny- og reinvesteringer på testcenteret inklusive forrentning af investeringen og omkostninger til eventuel yderligere skovfældning, fordelt med 3/7 til DTU og med 1/7 for hver standplads, der ejes af øvrige medlemmer. Såfremt der i henhold til pkt. 6.5 er truffet beslutning om individuelle nyinvesteringer afholdes anlægsbidraget hertil alene af de styregruppemedlemmer, der har ønsket nyinvesteringens gennemførelse.

7.2.3 På grundlag af det af ejerne af standpladserne og DTU godkendte anlægsbudget, jf. pkt. 6.5 og pkt. 5.2, opkræver DTU et a conto anlægsbidrag, der reguleres på grundlag af de endelige anlægsudgifter. A conto anlægsbidraget og et eventuelt reguleringsbeløb forfalder til betaling 30 dage efter, at DTU har fremsat skriftligt påkrav herom. Har ejerne af standpladserne betalt for meget i a conto anlægsbidrag tilbagebetales det for meget betalte til ejerne af standpladserne eller modregnes i nævnte medlemmers a conto-betalinger til driftsbidraget for det kommende år.

7.3 Drifts- og anlægsbidragene er pligtmæssige pengeydelser, hvilket indebærer at manglende betaling statuerer væsentlig misligholdelse af medlemmets forpligtelser, jf. pkt. 11.

8. Indkaldelse og afholdelse af styregruppemøder

8.1 Indkaldelse til møder i styregruppen, herunder Årsmøde og Budgetmøde foretages skriftligt af DTU med mindst 30 dages varsel. Hvis der på mødet skal behandles særlige presserende forhold kan indkaldelse til møde ske med et kortere varsel, dog minimum 8 dages varsel.

8.2 Indkaldelsen skal angive tid, sted og dagsorden for mødet. Forslag, der agtes stillet på et møde, skal så vidt muligt fremgå af indkaldelsen. Der kan kun tages stilling til forslag, der fremgår af indkaldelsen, medmindre samtlige styregruppemedlemmer er til stede på mødet og godkender, at forslaget optages på dagsordenen. Med indkaldelsen til Årsmødet skal medfølge årsregnskab. Med indkaldelsen til Budgetmødet skal medfølge drifts- og vedligeholdelsesplaner og driftsbudget fra DTU for det kommende år.

8.3 Ethvert medlem har ret til at få et angivet emne behandlet på Årsmødet. Begæringen skal være indgivet til DTU senest 5 uger før Årsmødets afholdelse.

8.4 Øvrige styregruppemøder afholdes, når det besluttes af DTU eller når det begæres af et eller flere standplads-medlemmer, med angivelse af et bestemt emne til behandling. DTU træffer beslutning om, hvorvidt nævnte møder skal afholdes som fysiske møder eller som telefon- eller videokonferencer.

8.5 Fremkommer begæring om et styregruppemøde i henhold til pkt. 8.4 skal mødet afholdes senest fire uger efter.

8.6 Samtlige styregruppemedlemmer er berettiget til at være til stede på styregruppemøderne, uanset om det pågældende medlem ikke har stemmeret om det emne, som behandles på mødet, jf. pkt. 6. Angår emnet for mødet et standplads-medlems særlige adfærd eller handlinger, kan DTU i disse særlige ekstraordinære tilfælde konkret beslutte, at det pågældende medlem ikke kan være til stede på styregruppemødet under behandling af dette emne. Et standplads-medlem har ret til at udtale sig til styregruppemedlemmerne om det pågældende medlems særlige adfærd eller handlinger eventuelt skriftlig eller på et styregruppemøde.

9. Årsmøde og Budgetmøde

9.1 Årsmøde i styregruppen afholdes hvert år inden 1. april med følgende dagsorden:

1. Valg af dirigent
2. Aflæggelse af årsberetning fra DTU
3. Forelæggelse af årsregnskab med revisorpåtegning til godkendelse
4. Forslag fra DTU eller standplads-medlemmerne
5. Valg af revisor
6. Eventuelt

9.2 Budgetmøde afholdes i styregruppen hvert år inden den 1. december med følgende dagsorden:

1. Valg af dirigent
2. Forelæggelse af drifts- og vedligeholdelsesplaner og driftsbudget fra DTU for det kommende år til godkendelse
3. Eventuelt

9.3 Beslutninger træffes i overensstemmelse med bestemmelserne i vedtægtens pkt. 6 og med respekt af formålsbestemmelsen, jf. pkt. 1.2.

9.4 Såfremt der opstår uenighed om godkendelse af årsregnskabet eller godkendelse af de af DTU fremlagte drifts- og vedligeholdelsesplaner og driftsbudget, kan hvert medlem af styregruppen beslutte at anmode en uvildig sagkyndig tredjemand om at udtale sig om det pågældende forhold, der måtte være uenighed om. Medmindre medlemmerne aftaler andet, er den uvildige tredjemands udtalelse alene vejledende for medlemmerne. Omkostningerne til den uvildige sagkyndige tredjemand afholdes af de medlemmer, der har stemt for indhentelse af en udtalelse hos en uvildig sagkyndig tredjemand. Ethvert medlem af styregruppen er endvidere berettiget til for egen regning at indhente en udtalelse fra en uvildig sagkyndig tredjemand om forhold, der måtte være uenighed om til vejledning for vurderingen af den konkrete problemstilling. Såfremt der ikke kan opnås enighed omkring den opståede uenighed løses tvister i henhold til pkt. 12.

10. Regnskab

10.1 Regnskabet for styregruppen følger kalenderåret. Første regnskabsår løber dog fra vedtægtens ikrafttræden.

10.2 Årsregnskabet udarbejdes af DTU og revideres af en af styregruppen valgt statsautoriseret eller registreret revisor. Revisor vælges for ét år ad gangen.

10.3 Årsregnskabet skal indeholde en opgørelse over afholdte drifts- og vedligeholdelsesudgifter samt eventuelle anlægsudgifter, herunder udgifter til yderligere skovfældning eller ny- og reinvesteringer, der er truffet beslutning om at gennemføre i henhold til denne vedtægt.

10.4 Årsregnskabet med revisorpåtegning forelægges på Årsmødet til godkendelse af styregruppen.

10.5 Det reviderede og godkendte regnskab skal af DTU indsendes til Miljøministeriet, Skov- og Naturstyrelsen til orientering.

11. Misligholdelse

11.1 Såfremt et standplads-medlem, som er ejer af standpladsen væsentligt misligholder sine forpligtelser i henhold til denne vedtægt samt beslutninger truffet i henhold til vedtægten, herunder manglende betaling af pligtmæssige pengeydelser til DTU eller manglende overholdelse af miljøkrav og øvrige krav m.v., der påhviler det pågældende standplads-medlem, og såfremt standpladsmedlemmet ikke retter for sig efter at have modtaget skriftligt påkrav herom 2 gange med hver 30 dages frist, kan Miljøministeriet, Skov- og Naturstyrelsen efter indstilling fra DTU uden yderligere varsel forlange den misligholdende standpladsmedlems ejendom afstås efter bestemmelserne fastsat i "Deklaration om tilbagekøbsret og forbud mod pantsætning mv.", der indgår som en del af aftalegrundlaget i købsaftalerne for standpladserne.

11.2 Såfremt et standplads-medlem, som er lejer af standpladsen væsentligt misligholder sine forpligtelser i henhold til denne vedtægt samt beslutninger truffet i henhold til vedtægten, herunder manglende overholdelse af miljøkrav og øvrige krav, der påhviler det pågældende standplads-medlem, og såfremt standplads-medlemmet ikke retter for sig inden 30 dage efter at have modtaget skriftligt påkrav herom, er DTU forpligtet til at håndtere dette i regi af DTU's lejekontrakt med lejer.

11.3 Såfremt DTU væsentligt misligholder sine forpligtelser i henhold til denne vedtægt og ikke retter op på situationen inden 30 dage efter at have modtaget skriftligt påkrav herom, kan standplads-medlemmerne anmode Staten om en forhandling om DTUs fremtidige rolle som driftsansvarlig og administrator for testcenteret, herunder hvilke tiltag, der kan iværksættes for at rette op på den opståede situation, herunder om der eventuelt i en periode skal føres tilsyn med DTU eller om der eventuelt kan udpeges en anden organisation eller lign., som kan varetage opgaver, som i henhold til denne vedtægt varetages af DTU.

11.4 Det misligholdende styregruppemedlem er i øvrigt erstatningsansvarlig efter dansk rets almindelige regler, herunder i forhold til DTU. Tilsvarende gælder for Miljøministeriet, Skov- og Naturstyrelsen, såfremt tilbageoverdragelseskravet, jf. pkt. 11.1, overfor standpladsejere efter domstols- eller voldgiftsprøvelse, jf. pkt. 12 viser sig at være uberettiget.

12. Tvister

12.1 Vedtægterne er undergivet dansk ret. Såfremt der opstår uoverensstemmelse mellem medlemmerne i tilknytning til styregruppen og denne vedtægt og de beslutninger og afgørelser m.v., der træffes i henhold til denne vedtægt, skal de medlemmer, der er opstået uoverensstemmelser mellem indlede forhandlinger med henblik på at løse tvisten. Om nødvendigt skal forhandlingerne søges løftet op på højt plan i medlemmernes organisationer.

12.2 Såfremt der ikke ved forhandlingerne opnås nogen løsning, skal medlemmerne søge at opnå enighed om i fællesskab at udpege en uafhængig og sagkyndig mægler, der kan mægle og komme med ikke-bindende forslag til tvistens løsning.

12.3 Når ovennævnte har været forsøgt, kan uoverensstemmelser efter DTU´s valg enten indbringes for de almindelige domstole med værneting i København eller kræves afgjort endeligt ved voldgift efter "Regler for behandling af voldgiftssager ved Det Danske Voldgiftsinstitut". Forhold der angår inddrivelse af forfaldne krav, kan ske gennem de almindelige domstole.

12.4 Såfremt tvisten skal afgøres ved voldgift udpeges Voldgiftsretten af Voldgiftsinstituttet i overensstemmelse med ovennævnte regler. Klageren kan i sit klageskrift komme med forslag til sin voldgiftsdommer, mens indklagede i sit svarskrift kan komme med forslag til sin voldgiftsdommer. Den tredje voldgiftsdommer, der er voldgiftsrettens formand, bringes i forslag af Det Danske Voldgiftsinstitut, medmindre parterne inden udløbet af fristen for indklagedes svar i fællesskab foreslår en formand. Stedet for voldgift er aftalt til København.

13. Vedtægtsændringer

13.1 Vedtægtsændringer kan indstilles af DTU og/eller af ejerne af standpladserne, idet Miljøministeriet, Skov- og Naturstyrelsen træffer beslutning om vedtagelse og gennemførelse af vedtægtsændringer. Afslås et ønske fra standpladsejerne om vedtægtsændringer, der er væsentlige for det eller de pågældende medlemmer, kan medlemmet vælge at afstå standpladsen efter bestemmelserne fastsat jf. pkt. 3.1 i ”Deklaration om tilbagekøbsret og forbud mod pantsætning m.v.”, der indgår som en del af aftalegrundlaget for køb af standpladsen.

14. Ikrafttræden

14.1 Denne vedtægt træder senest i kraft på ibrugtagningsdatoen for testcenteret, det vil sige den dag, hvor testcenteret er færdigetableret og funktionsdygtigt, det vil sige, at testcenteret er tilsluttet elnettet, og der er mulighed for at gennemføre målinger på testcenteret. Senest på ibrugtagningsdagen opløses den projektfølgegruppe med deltagelse af standpladsejerne, Miljøministeriet, Skov- og Naturstyrelsen og DTU, der er nedsat af DTU i projekt- og anlægsfasen for testcenteret.

15. Opløsning

15.1 Beslutning om opløsning af styregruppen træffes af Miljøministeriet, Skov- og Naturstyrelsen. Ejerne af standpladserne og/eller DTU kan indstille overfor Miljøministeriet, Skov- og Naturstyrelsen, at styregruppen opløses, idet der henvises til bestemmelserne fastsat i pkt. 2 og pkt. 3.1. i "Deklaration om tilbagekøbsret og forbud mod pantsætning mv.", der indgår som en del af aftalegrundlaget for køb af standpladsen. Afslås et ønske fra standpladsejerne om opløsning af styregruppen, kan det eller de medlemmer, der har begæret opløsning vælge at afstå standpladsen efter bestemmelserne fastsat i pkt. 3.1. i "Deklaration om tilbagekøbsret og forbud mod pantsætning m.v.".

16. Tinglysning

16.1 Denne vedtægt vil være at tinglyse servitutstiftende på de under testcenteret hørende ejendomme, som har pligt til at være medlem af styregruppen. Påtaleberettiget er Miljøministeriet, Skov- og Naturstyrelsen og DTU.

17. Eksemplarer af vedtægten

17.1 Denne vedtægt er udfærdiget i ét originalt eksemplar, der opbevares af Miljøministeriet, Skov- og Naturstyrelsen.

***

Den / 2010

Miljøministeriet, Skov- og Naturstyrelsen.

BILAG:

Bilag A: Kortskitse over Testcenter Østerild og testcenteranlægget

Bilag B: Skønsmæssigt anlægs- og driftsbudget for Testcenter Østerild

Bilag C: Lejeaftale mellem Danmarks Tekniske Universitet, DTU og Staten, repræsenteret ved Miljøministeriet, Skov- og Naturstyrelsen vedrørende leje af statsejede arealer for testcenteranlægget og DTU´s varetagelse af opgaver som driftsansvarlig m.v.

APPENDIX D

Siemens: Proposed MV solution (SIPLINK)

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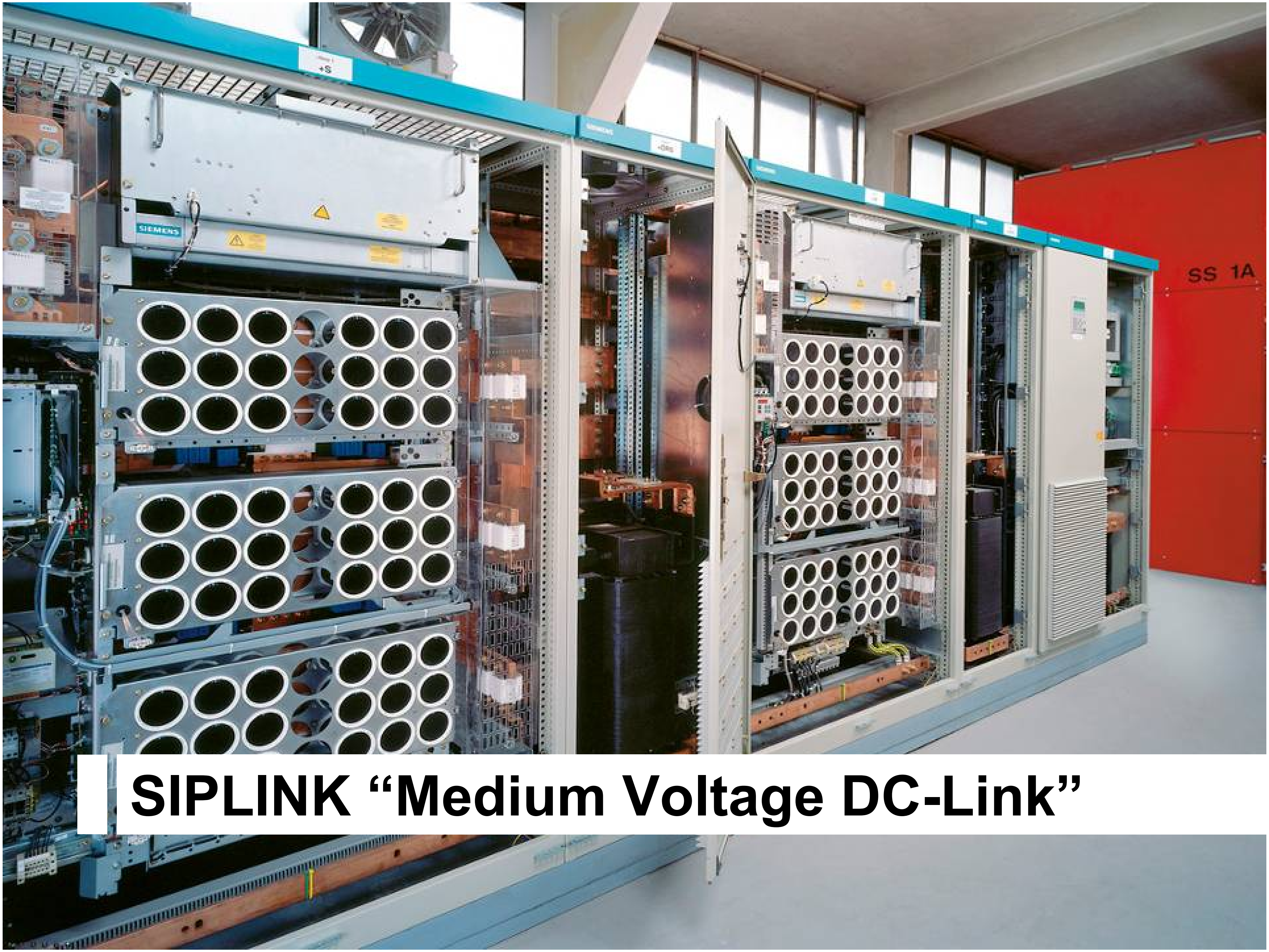
SIPLINK Solutions

Power Distribution Solutions – Branches

SIEMENS

* MEV: Main Electrical Vendor / **O&G: Oil & Gas

	Utilities	**Primary Distribution**	Electrical packages & turn-key solutions
	Utilities	**Secondary Distribution**	Secondary distribution up to private consumers, cable networks, over head lines and diesel power
	Utilities	**Generator Switchgear**	Solutions for medium size power plants and industry turbines
	Industries	**Chemical, O&G, Automotive Semiconductor**	Electrical packages and MEV* concepts for automotive & chemical industries, O&G** plants, semiconductor industry
	Industries	**SIPLINK Networks**	Power Quality & Power Flow Control Solutions with DC - Power Links (SIPLINK), energy transfer between different networks
	ECO Solutions	**SIPLINK Back to Back**	SIPLINK (SIHARBOR) Solutions for onshore power supply in ship yards or harbors for network connection
	ECO Solutions	**Energy Storage**	Solutions for distribution networks for peak load management, power quality and micro grids for utilities and Industry
	ECO Solutions	**BoP Renewable**	Balance of Plant (BoP) for windparks, concentrated solar power (CSP) and photovoltaic (PV), also in combination with Energy Storages



SIPLINK “Medium Voltage DC-Link”

General purpose of SIPLINK

- Connection of two grids which are different in:
  - Voltage
  - Frequency
  - Phase angle
  - Neutral point treatment
- Load flow control
- Additional power without short circuit power increase
- Secondary power supply
- Connection of three or more grids with (in adition to above):
  - Load balancing
  - Secure power supply

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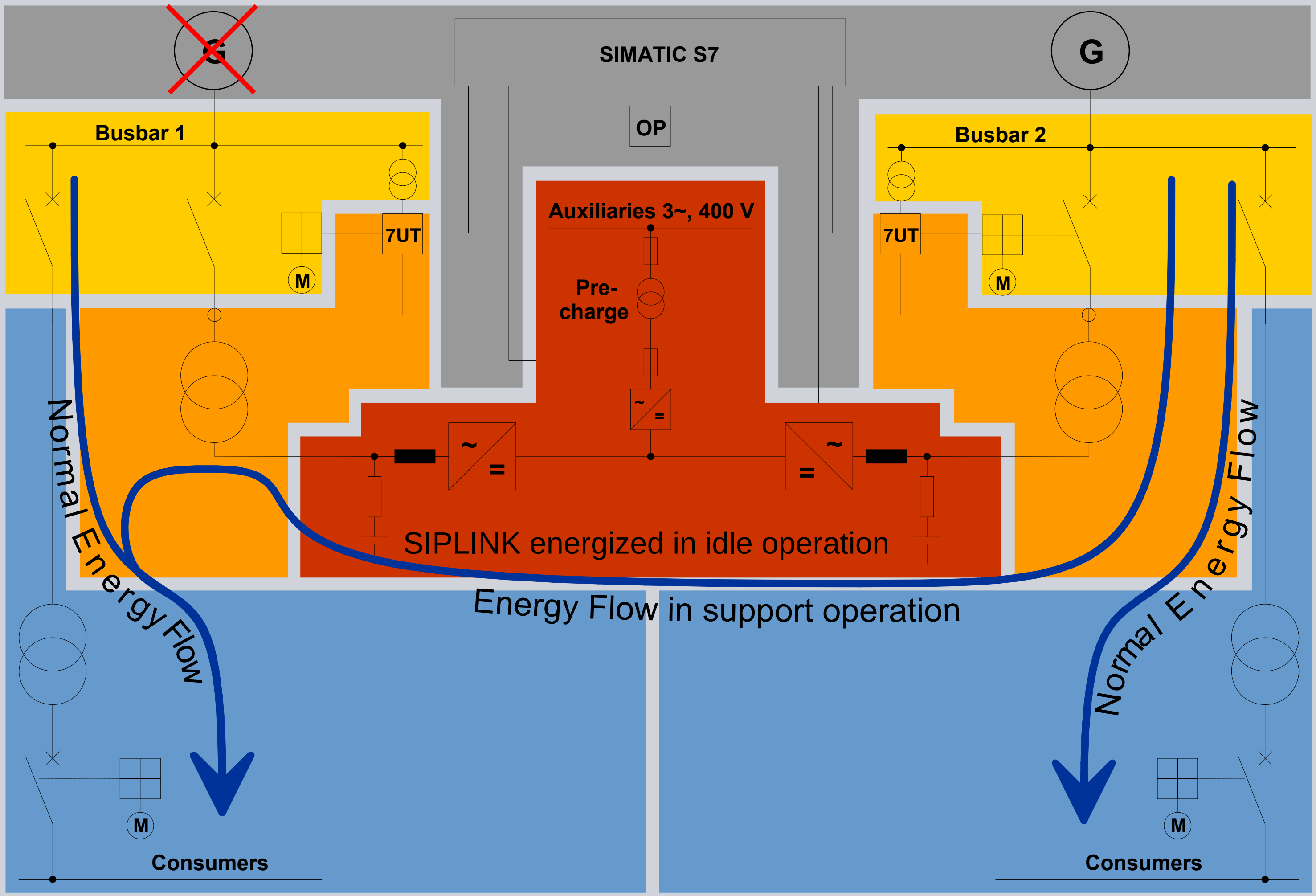
SIPLINK in back-to-back connection



SIEMENS

Reference: Flender-Werft AG ”SIPLINK for Shipyards“, Germany

Customer: Flender Werft AG
Country: Germany
Project: Flender Shipyard
Date: 2002

Scope of Supply

- 1 MVA Island-network power supply for 50/60 Hz ship networks
- Reverse power supply from the 50/60 Hz ship generators into the shipyard-network 450V; 50 Hz
- Exchange of active power between both networks in case of peak-load
- Reactive power compensation & load tests of the ship-generators

Requirements

Ship construction in Germany: Optimal energy flow between the shipyard and on-board networks.

Solution

SIPLINK showed here what highly modern energy management can do: whether 50 or 60 Hz is used, this innovative technology regulates the supply of on-board power from the shipyard network – and simultaneously ensures that the shipyard network can make any necessary compensation. In the other direction, it feeds energy freed up from on-board generator testing into the shipyard network. This enables testing on-board generators with differing power factors.

Highlights

Intelligent energy flow between the shipyard and on-board networks

SIEMENS

Reference: SIPLINK shore to ship connection FSG, Germany

Customer: Flensburger Schiffbaugesellschaft
Country: Germany
Project: SIPLINK shore to ship c. FSG
Date: 07.2007

Scope of Supply

- SIMOVERT Masterdrive converter with Active Front End
- GEAFOL static converter transformers
- Cooling unit with air-water-heat exchanger
- Medium voltage control panel 8DH10
- Low voltage control panel SENTRON 3WL
- SIMATIC S7-300 controller
- Unit container-installed

Requirements

- Ships shall be provided with different voltages (440V / 60Hz, 600V / 60 Hz, 690V / 60 Hz) from the 5KV, 50Hz network via converter.
- Converter capacity of 1.0 MVA
- Energy recovery from the on-board generators to the network
- Sound pressure level 45dB (A) in 65m
- Short project execution: 7 month

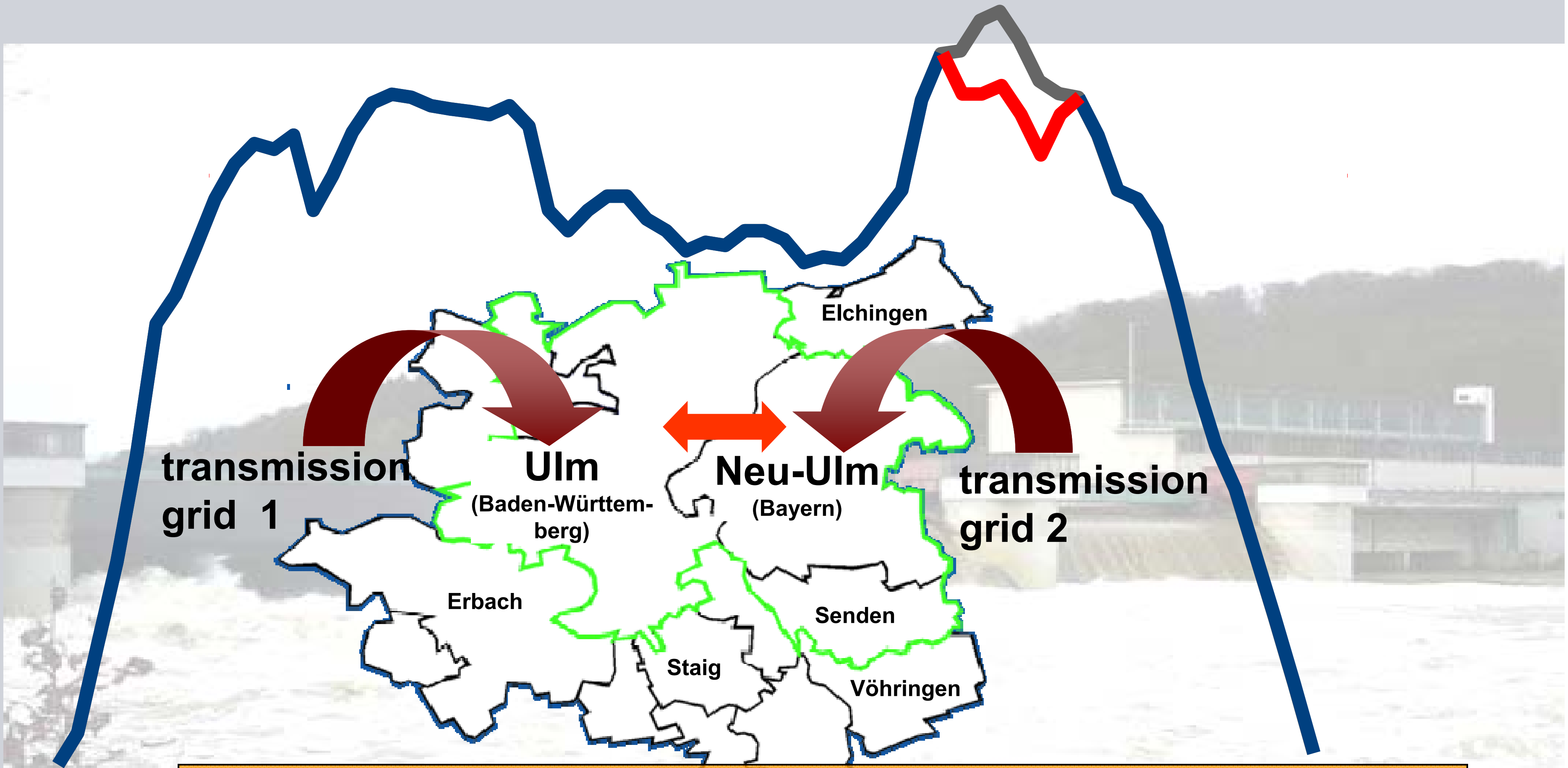
Solution

- SIPLINK system solution on the base of Flender Werft project
- Delivery of Siemens standard products
- Client services by local Siemens departure

Highlights

- Good cooperation of Siemens regions
- Installation and commissioning assistance from the customer
- Compliance of difficult delivery schedules

Reference: City Network Ulm (SIPLINK № 1 and № 2)



"The Siemens system allows us to utilize existing energy reserves at times of peak demand without having to buy in costly regulating energy"

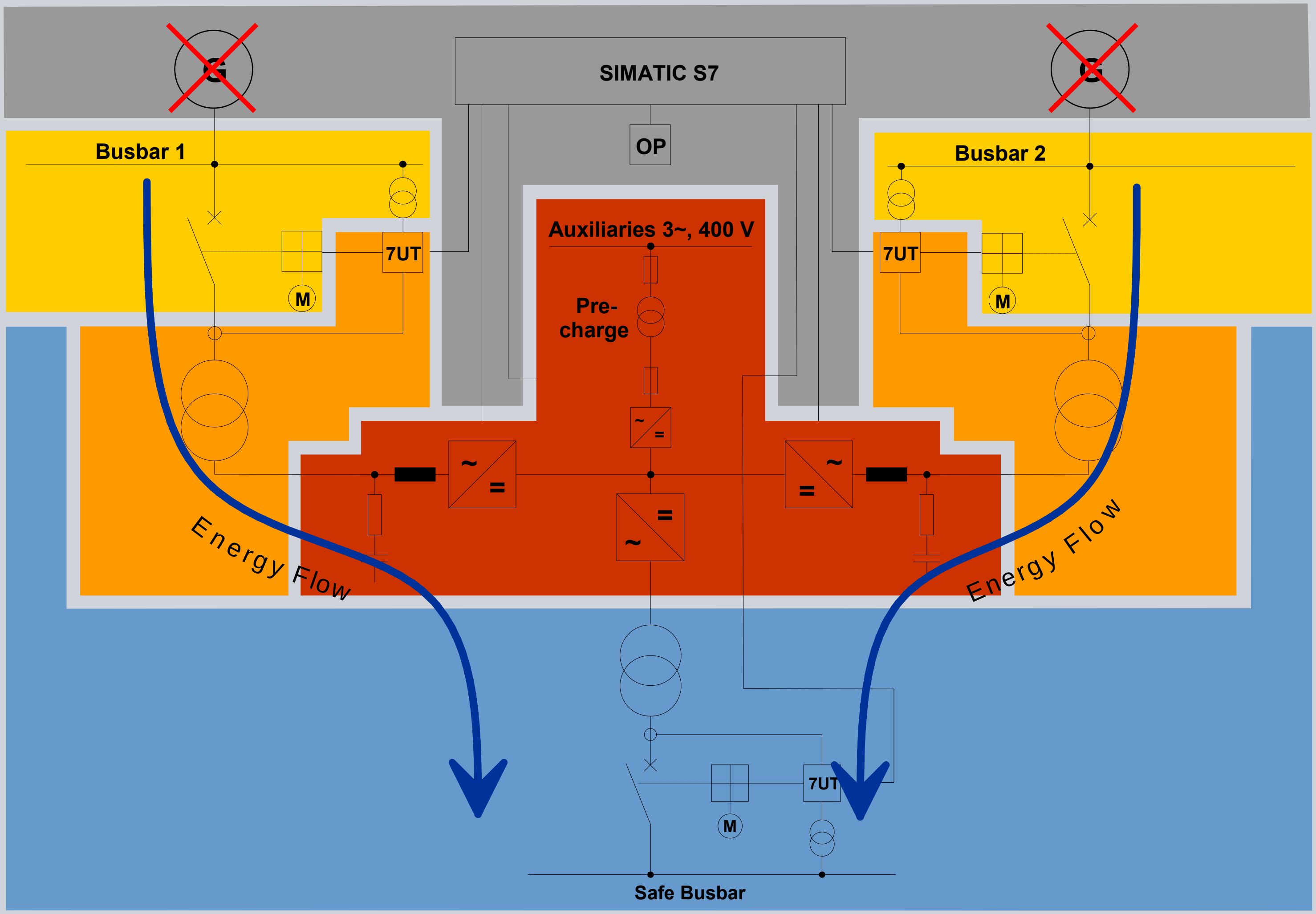
Jürgen Schäffner; Chief Technical Officer of SWU Energie GmbH

Reference: City Network Ulm (SIPLINK № 1 and № 2)

- Controlled power exchange between to different MV grids during peak demand times.
- Reduction in purchase of costly balancing power
- Supply of reactive power to both grids
- Transfer Power approx. 2 MVA each

SIEMENS

SIPLINK in Y- connection



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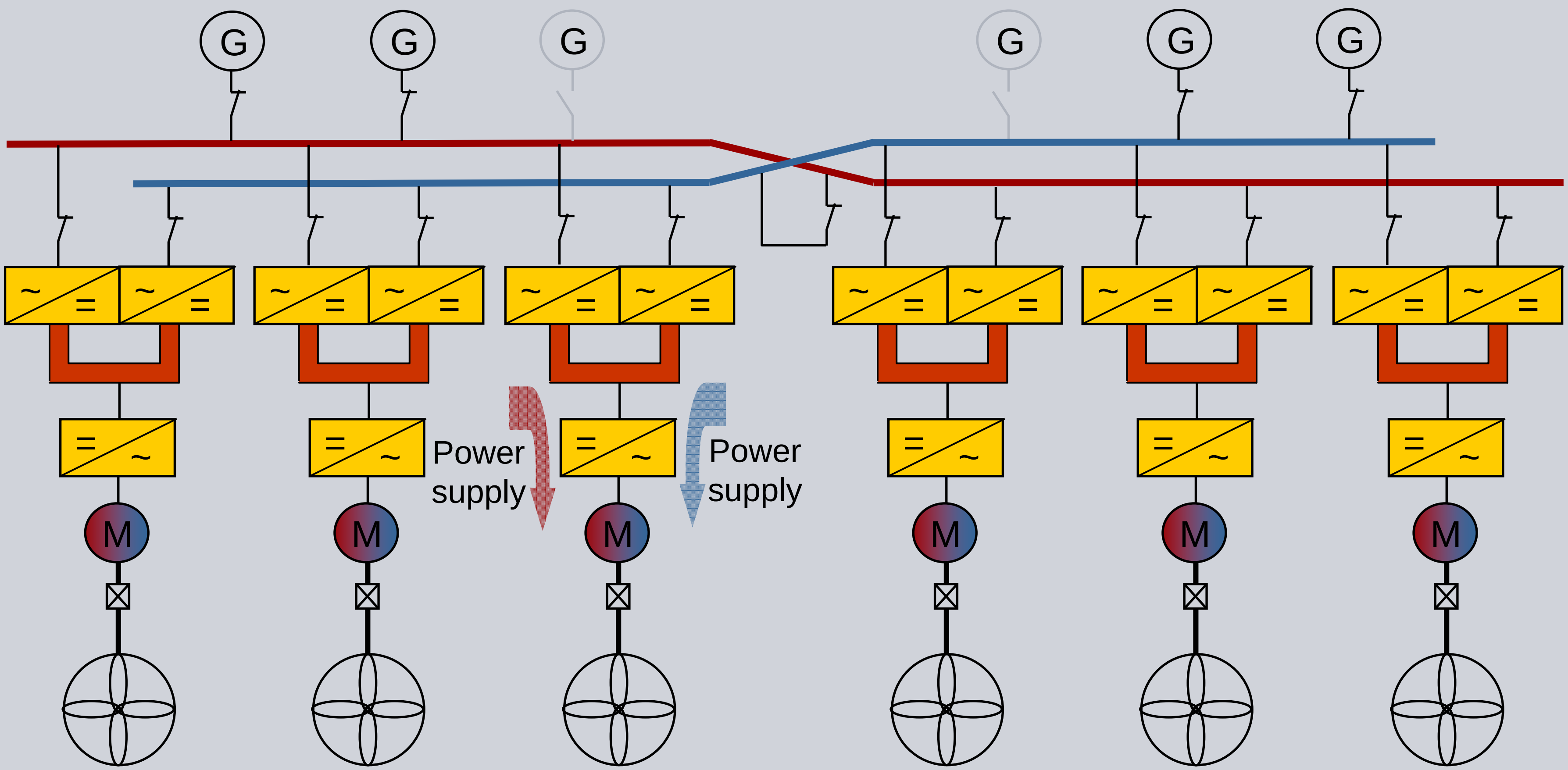
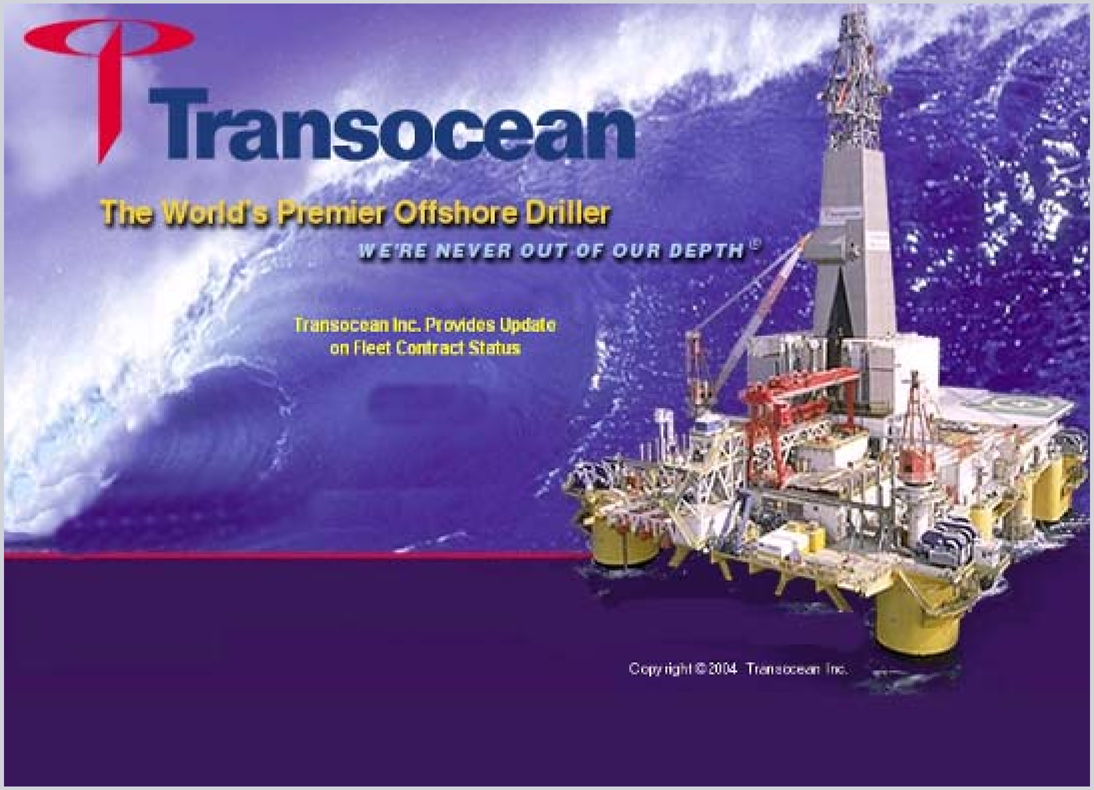
SIPLINK double feed thruster supply system with DC-Bus



SIEMENS

Reference: Transocean SEDCO 706 / 706 Drilling Rig



- Reliable power supply to thrusters. Load distribution. Black-out with no effect.
- Reduction of running gen-sets in low load situation
- Supply of reactive power to both grids
- Power approx. 4 x 5 MVA

Reference: Transocean 5 Drilling Vessels

Customer: Transocean
Country: Korea, USA
Project: New enterprise class
Date: since 2006

Scope of Supply

- SIPLINK, transformers and motors for thruster drives and auxiliary drives
- SIPLINK, transformers and inverter switchgear for draw works
- SIPLINK, transformers and inverter switchgear for mud pumps
- Generators for power generation
- 11 KV switchgear
- Distribution transformer

Requirements

- Fail-safe energy supply for the consumer
- Decrease of the number of running generators in low load mode

Solution

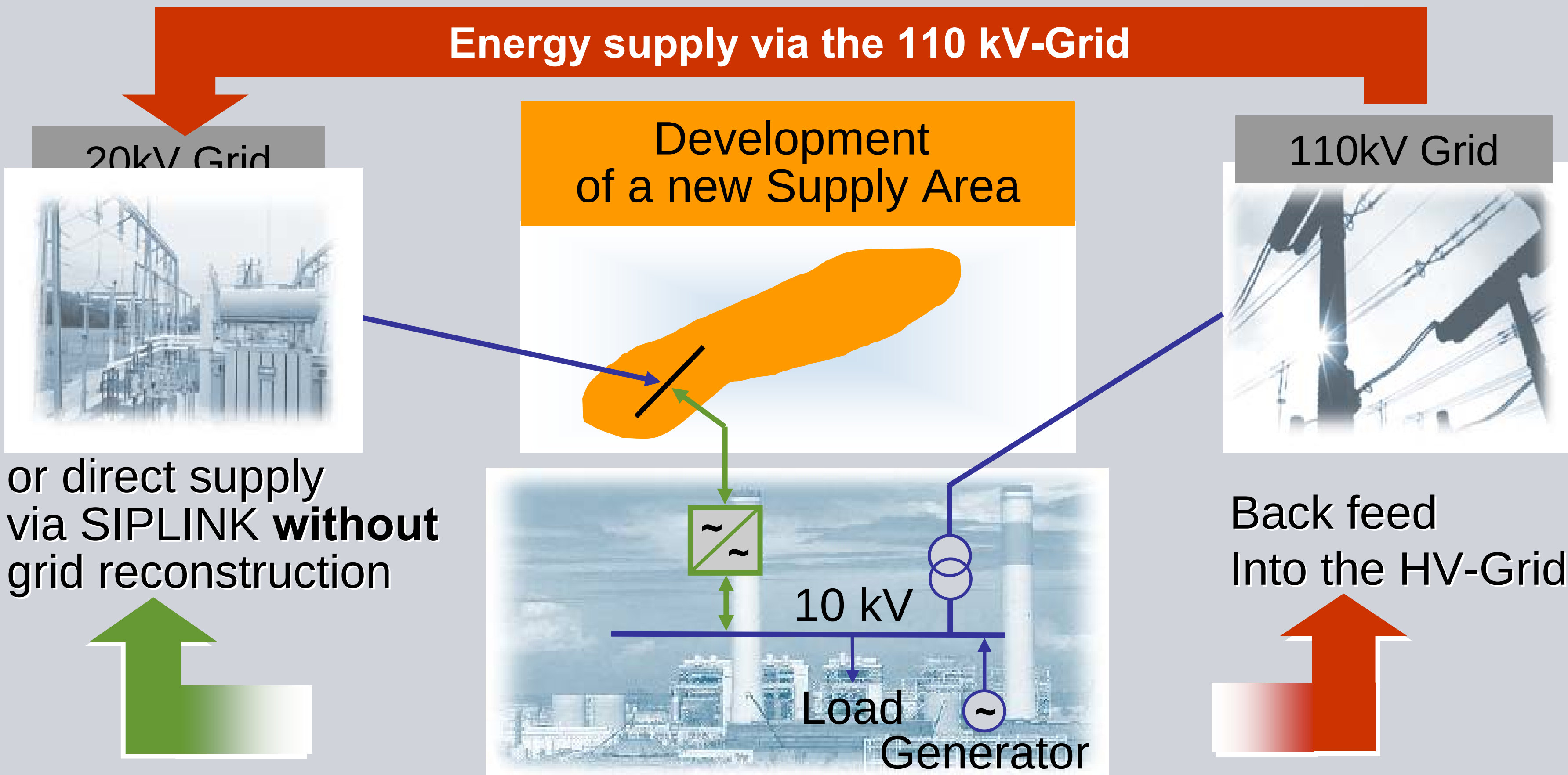
Together with the client, the subdivision Siemens E D MV 3 developed a solution with inverters, which can provide energy from two different sources without time delays when switching over.

Highlights

- Decrease of maintenance costs
- Decrease of operating costs
- No switching time when switching over
- High safety level

SIPLINK Examples of Use:
Optimization of Energy Supply for a new Supply Area

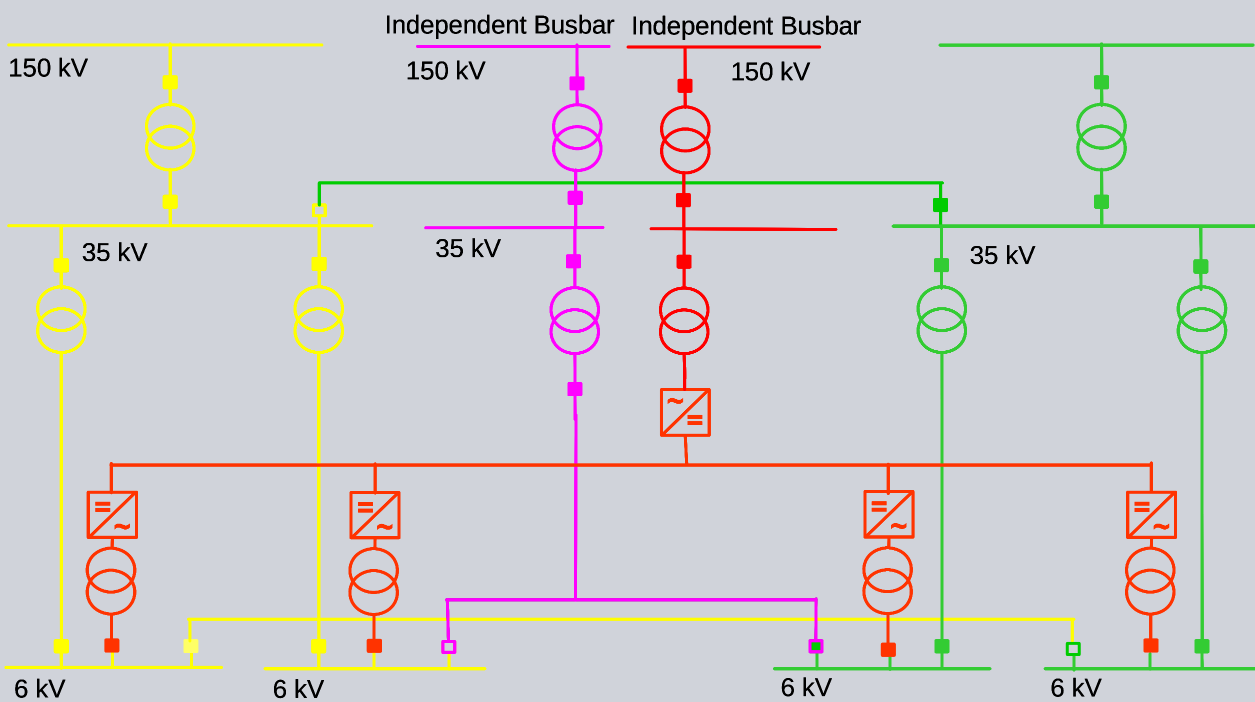
SIEMENS



Cost reduction on energy supply and Investment savings!

SIPLINK Examples of Use:
High availability for industry grids: SIPLINK Multi Feed

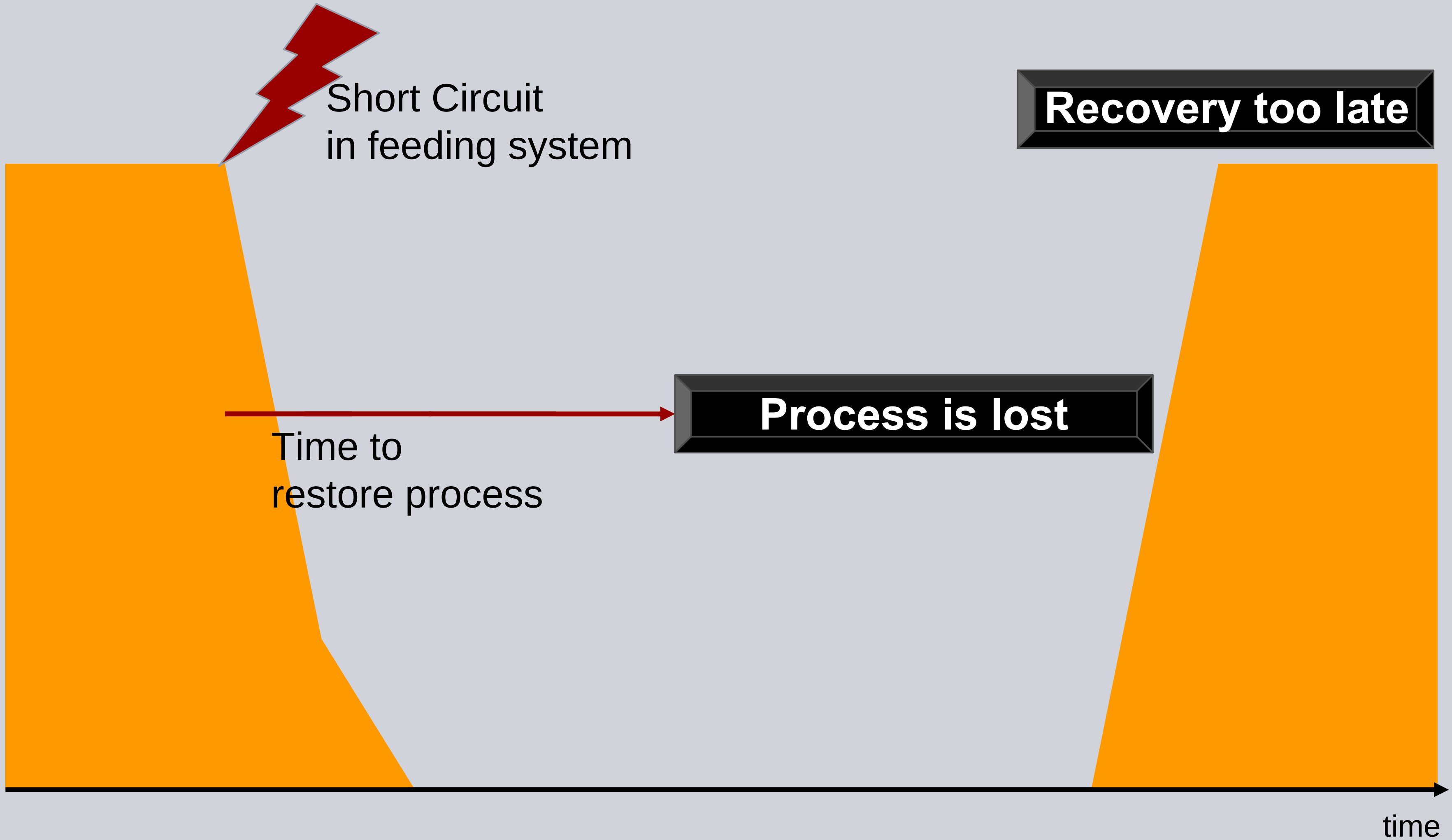
SIEMENS



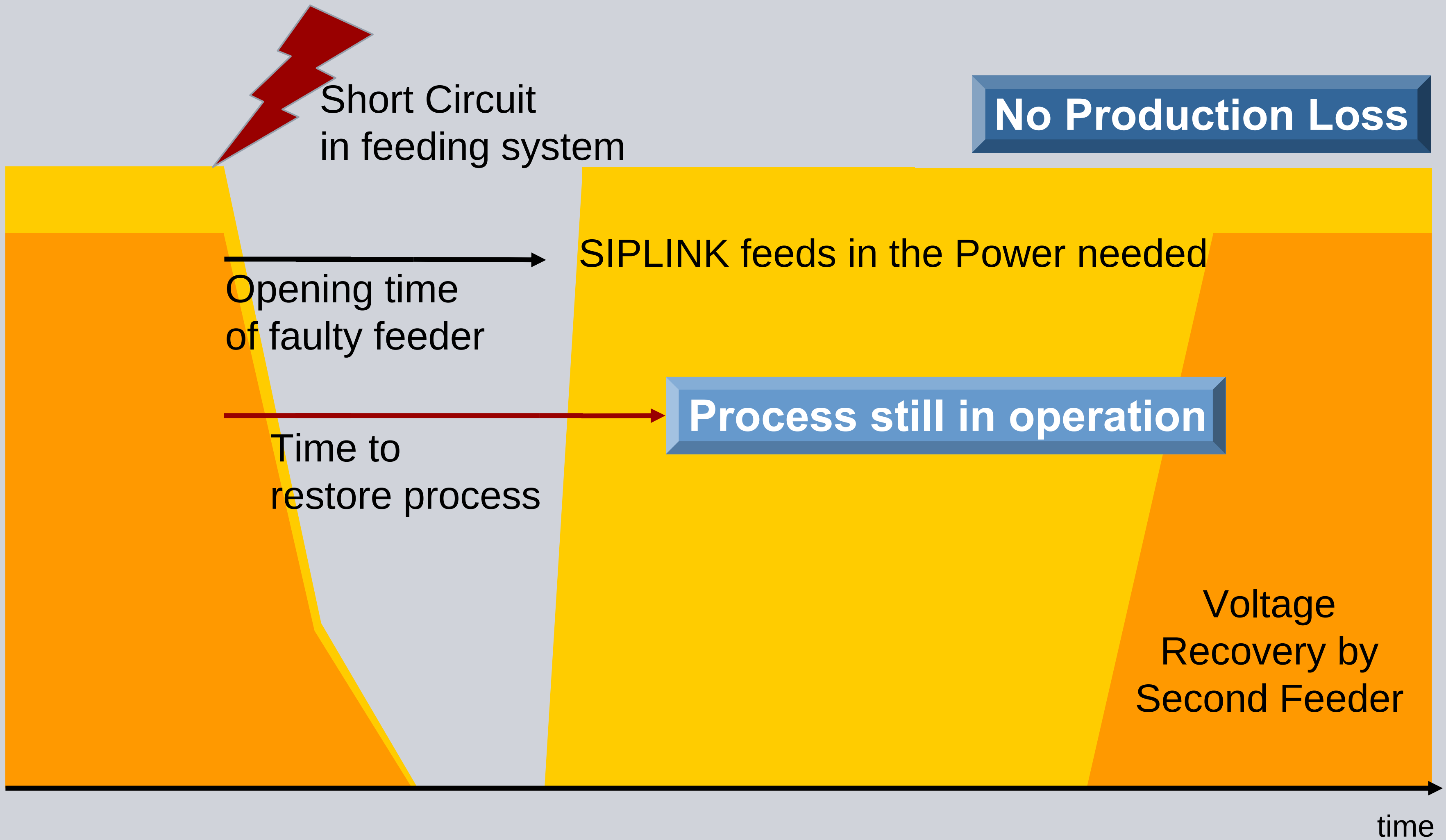
- No voltage dips > 70 ms allowed
- Each safe busbar is connected to 3 busbars and 1 independent feeder simultaneously
- SIPLINK allows immediate power transfer in case of a failure in any of the infeeds

Voltage Curve in case of Failure in Feeding Power System

SIEMENS



Voltage Curve in case of Failure in Feeding Power System with SIPLINK



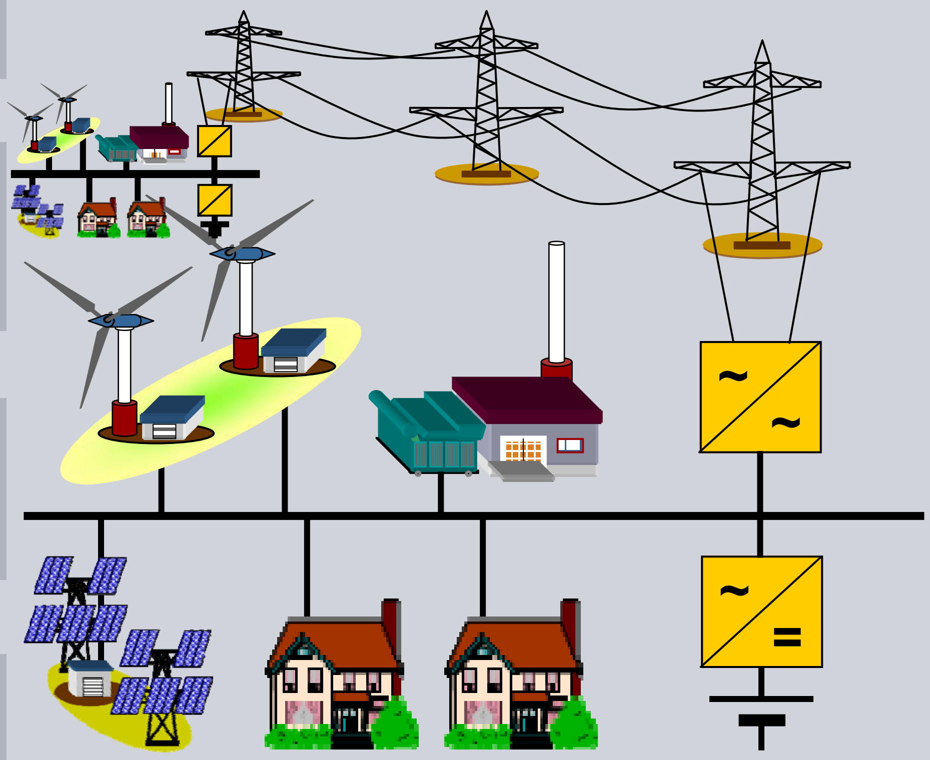
A glimpse at the future

Existing local grids will be expanded by renewable energies which are not constant energy sources

Autonomy will be gained by utilizing energy storage which is connected by power electronics

Connection to the HV grid is made utilizing power electronics to ensure the stable operation of the energy storage.

HV grids will only take care of balancing power between independent island grids or bulk power transfer via long distances.



SIEMENS

Thank you for your attention

Energy Sector

Power Distribution Solutions

P.O. Box 3240

D-91050 Erlangen

Germany

www.siemens.com/energy

Disclaimer

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APPENDIX E

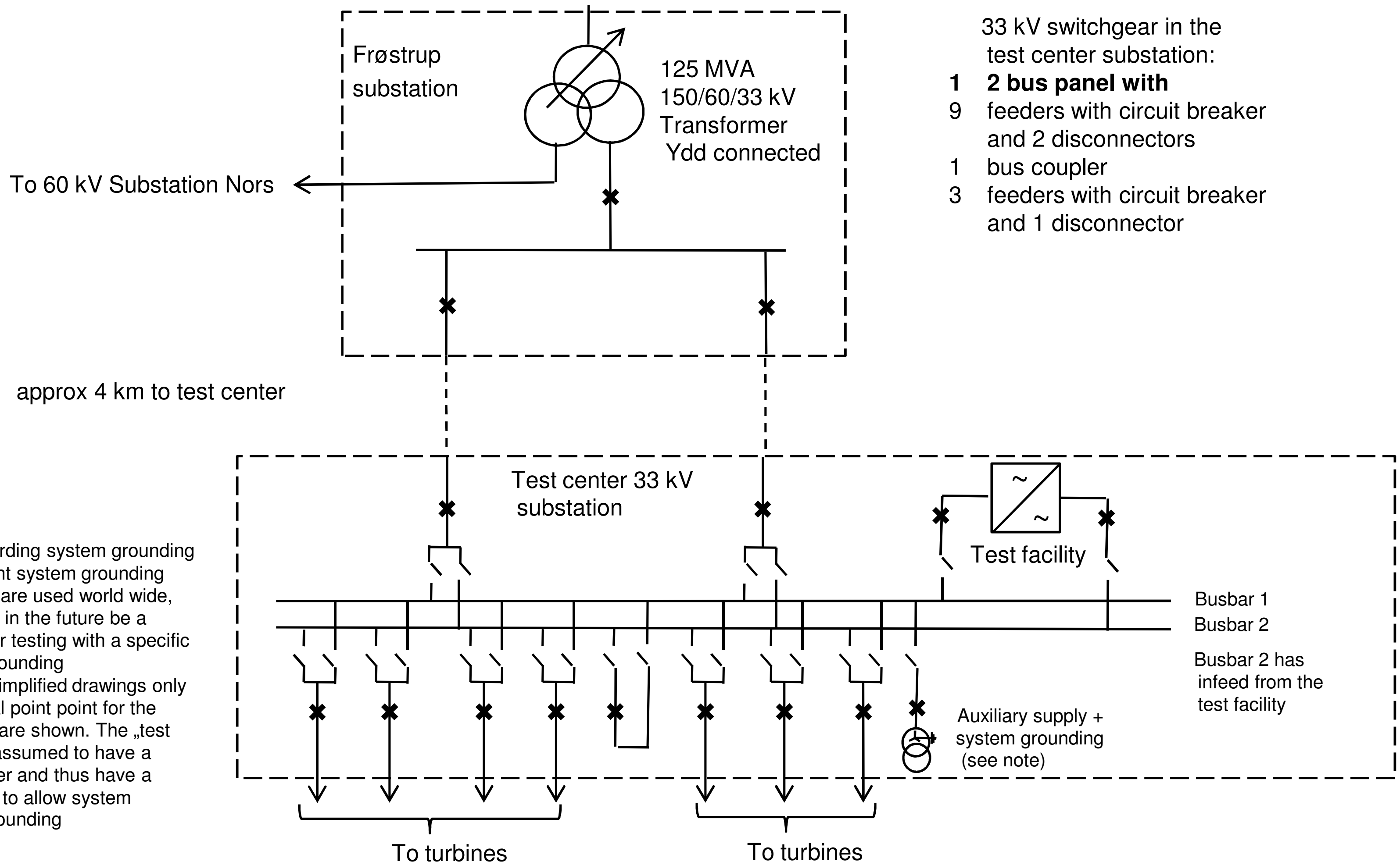
ABB: Proposal for 33 kV switchgear with extension for grid connection of test facility

Erik Koldby, DKABB/PP-FES, 2010-10-19

Østerild test center, 33 kv substation
Connection of the test facility

Power and productivity
for a better world™

Østerild Proposed test station 33 kV switchgear
with extension for grid connection test facility



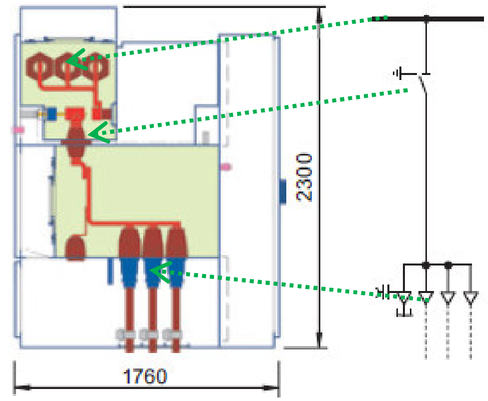
33 kV switchgear in the test center substation:

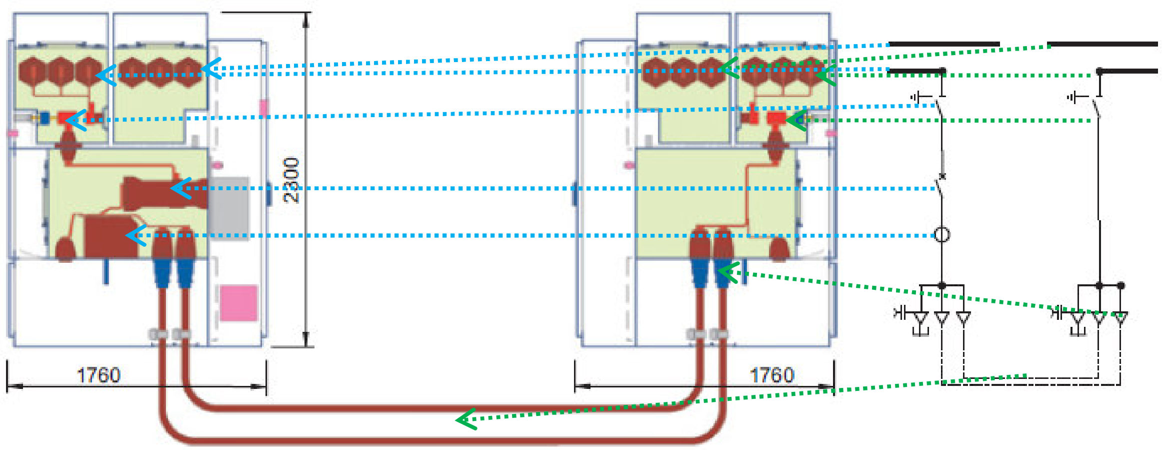
1 2 bus panel with
9 feeders with circuit breaker and 2 disconnectors
1 bus coupler
3 feeders with circuit breaker and 1 disconnector

Note regarding system grounding
As different system grounding principles are used world wide, there may in the future be a request for testing with a specific system grounding
In these simplified drawings only the neutral point point for the main grid are shown. The „test facility is assumed to have a transformer and thus have a possibility to allow system neutral grounding

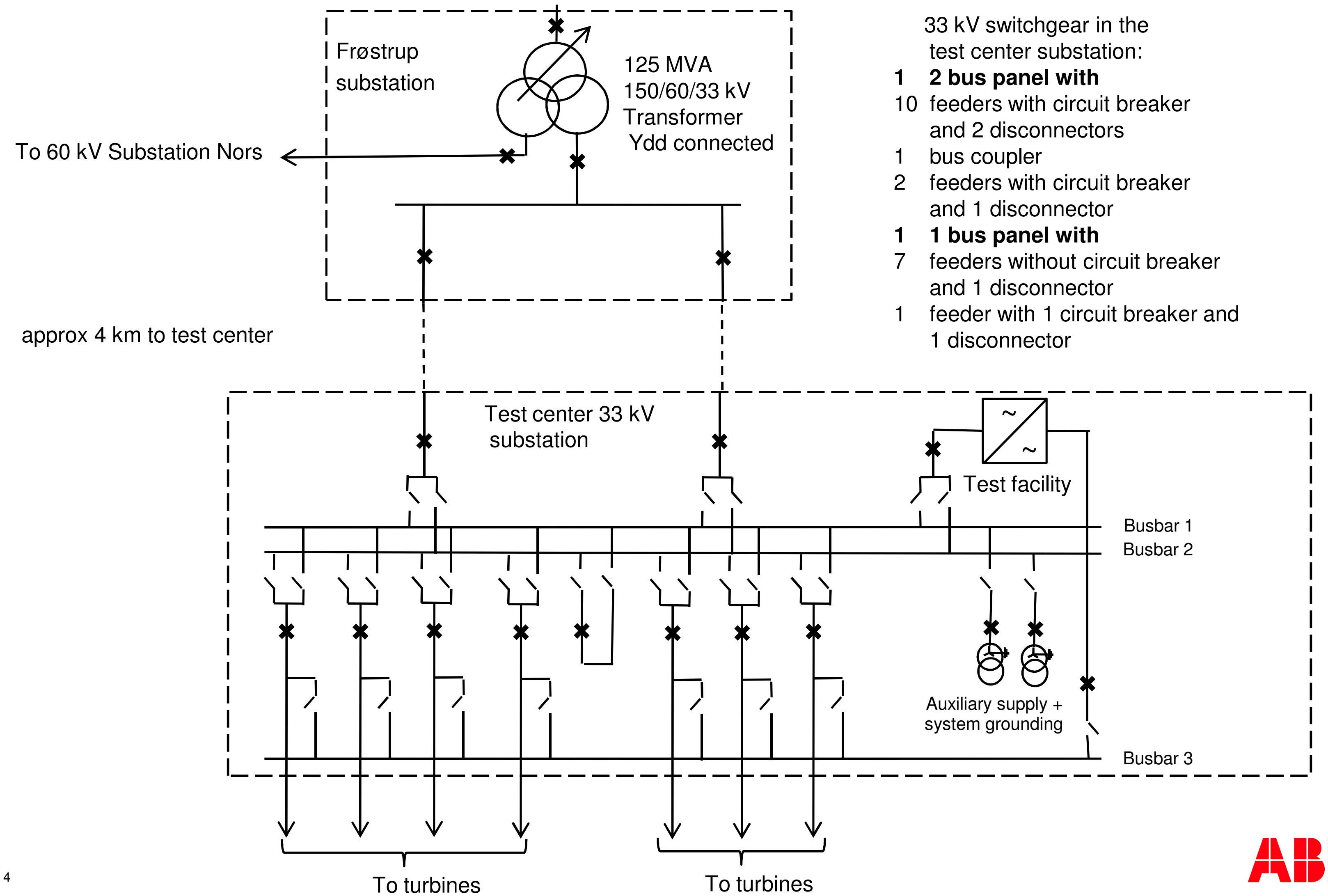
3 (and 4) bus systems
How are they made

The standard solutions allow one or two busbars. As it can be seen, the dimensions do not allow a third busbar. Thus the connection to a 3rd (or even 4th) must be made with cables as it can be seen on the figures (ABB type ZX2, 36 kV)





Østerild
Improved flexibility with 3 busbars



33 kV switchgear in the test center substation:

1 2 bus panel with
10 feeders with circuit breaker and 2 disconnectors
1 bus coupler
2 feeders with circuit breaker and 1 disconnector

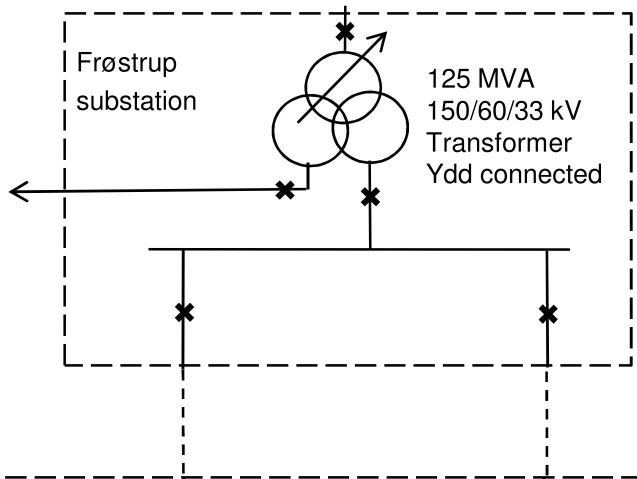
1 1 bus panel with
7 feeders without circuit breaker and 1 disconnector
1 feeder with 1 circuit breaker and 1 disconnector

Østerild

Assume two central test facilities - and a 4 bus system

Note regarding test facility 2:
Obvious possibilities besides the "HVDC" solution are:

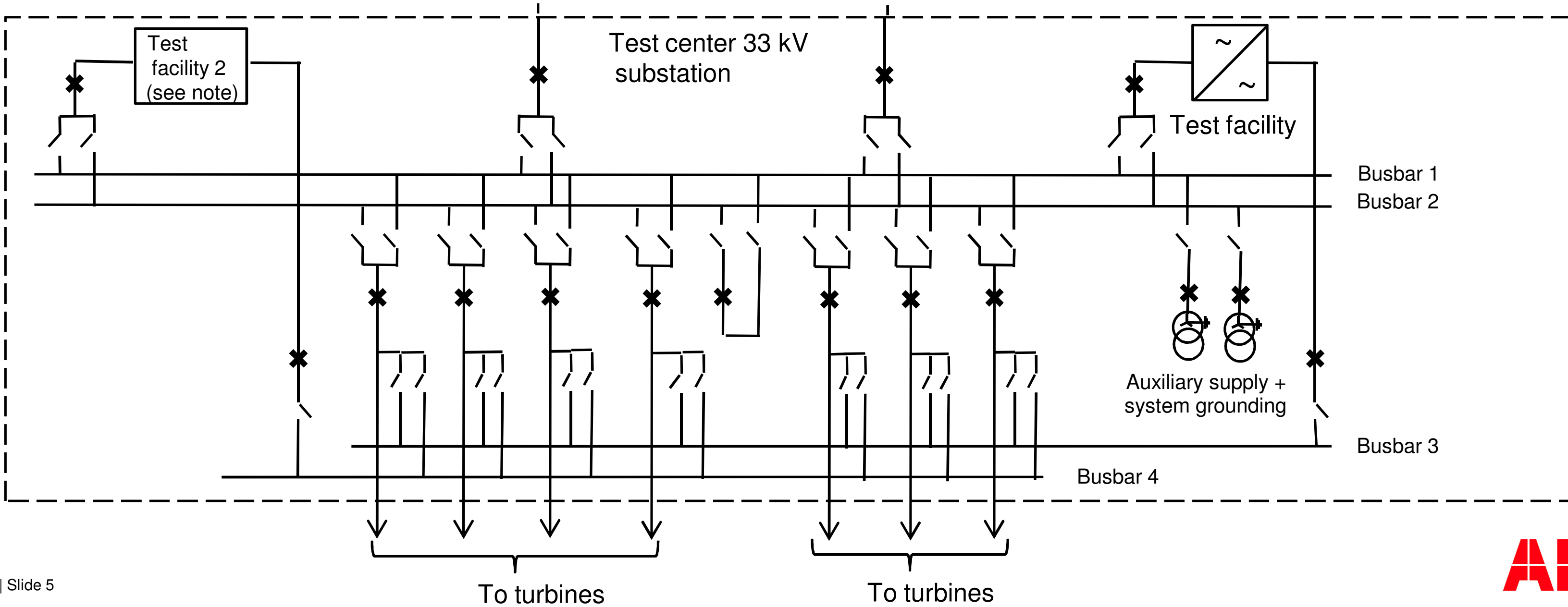
1. A test device like the traditionally used "test container", but larger.
2. A transformer for individual regulation of the 33 kV voltage to a single turbine
3. Most likely there are more possibilities, but all these are assumed to have a size so they can be located at the "test facility 2 location" or be located close to the turbine under test .



33 kV switchgear in the test center substation:

1 2 bus panel with
11 feeders with circuit breaker and 2 disconnectors
1 bus coupler
2 feeders with circuit breaker and 1 disconnector

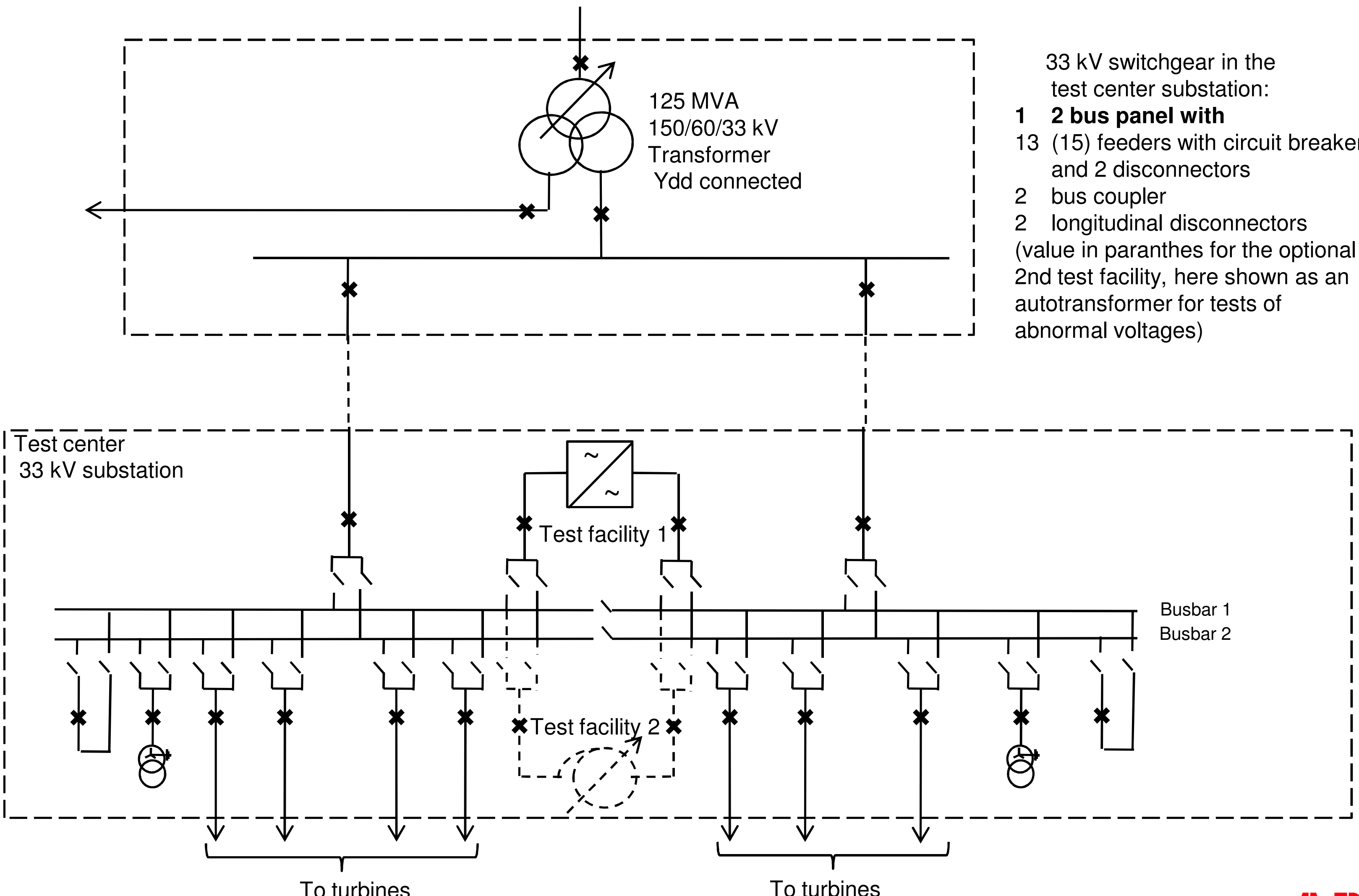
1 1 bus panel with
7 feeders without circuit breaker and 2 disconnectors
2 feeders with 1 circuit breaker and 1 disconnector



ABB

Østerild. Increased flexibility

Can it be obtained in a cheaper way than with multi-bus?



33 kV switchgear in the test center substation:

1 2 bus panel with

13 (15) feeders with circuit breaker and 2 disconnectors

2 bus coupler

2 longitudinal disconnectors

(value in paranthes for the optional 2nd test facility, here shown as an autotransformer for tests of abnormal voltages)

Power and productivity
for a better world™

APPENDIX F

Vattenfall: Developer’s view on proposed functional description and Grid-code compliance

EUDP Teststand – functional specification

Developers view on
Grid-code compliance

October 15‘th 2010

Peter Nielsen, Vattenfall Wind Power

VATTENFALL

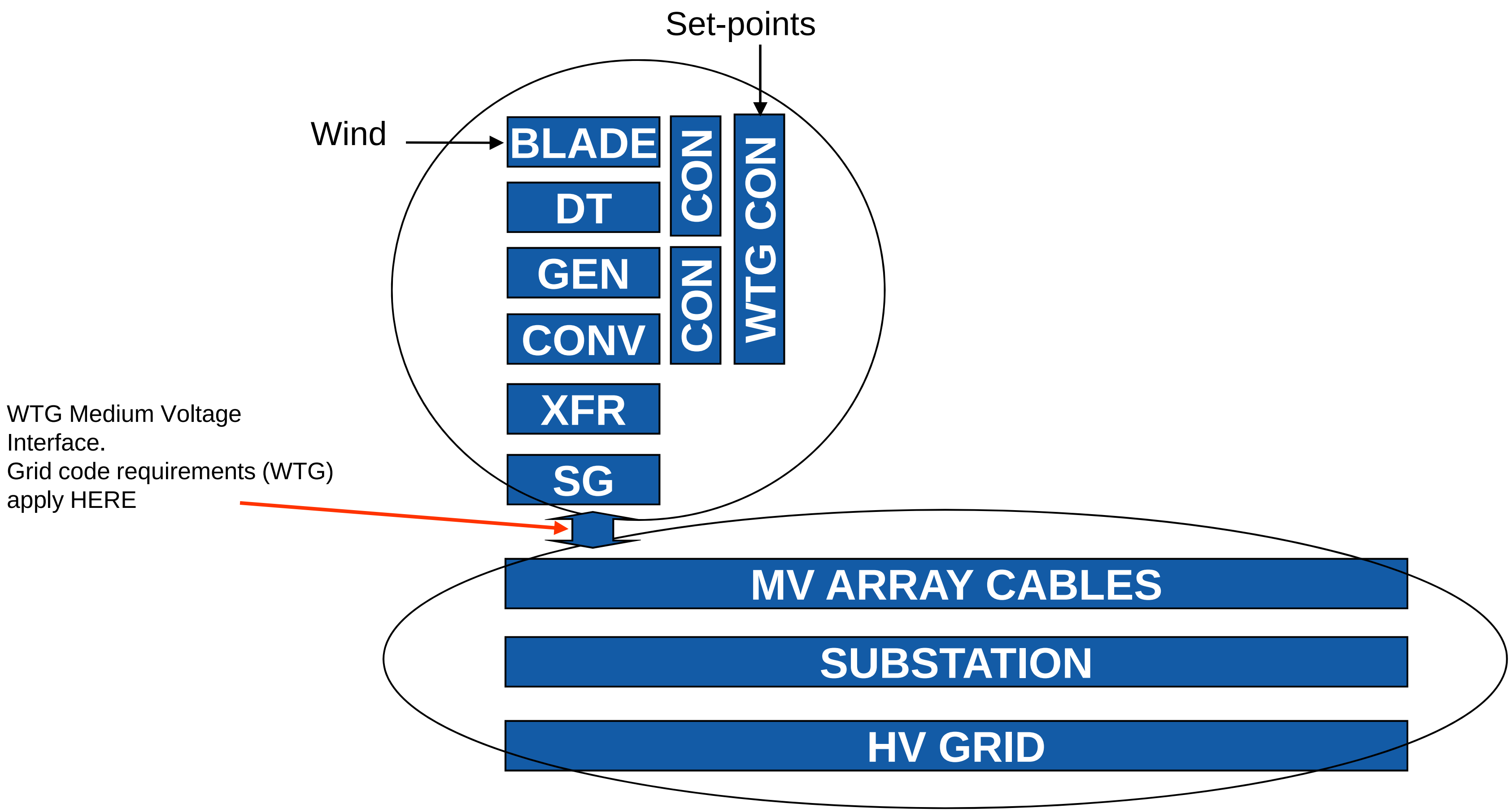
Grid Code Requirements

- Differ from country to country
  - Standardisation on its way (long term)

- Main performance requirements
  - Operating range (Voltage, frequency…)
  - Active power control
    - Curtailment
    - Fast Ramp Down
    - Frequency control
  - Reactive power control
    - Voltage control
    - PF control / Q control
    - Stationary PQ requirements
  - Grid Faults
    - LVRT
    - Grid support
  - Virtual Inertia, PSS etc.. (future)

Requirements both on turbine level and wind farm level

Wind Turbine Specific Performance Requirements

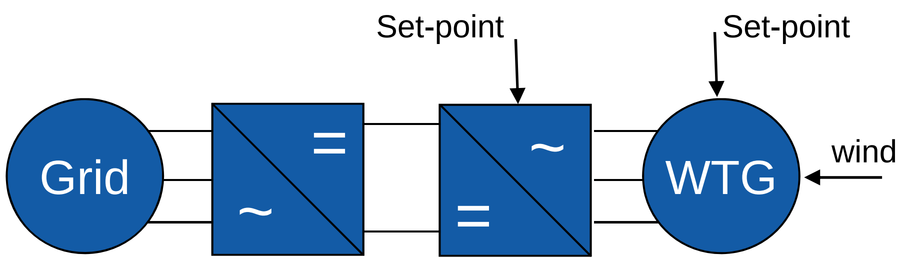


Wind Turbine Test Requirements

To reproduce MV grid interface @ rated WTG power

Measure/apply

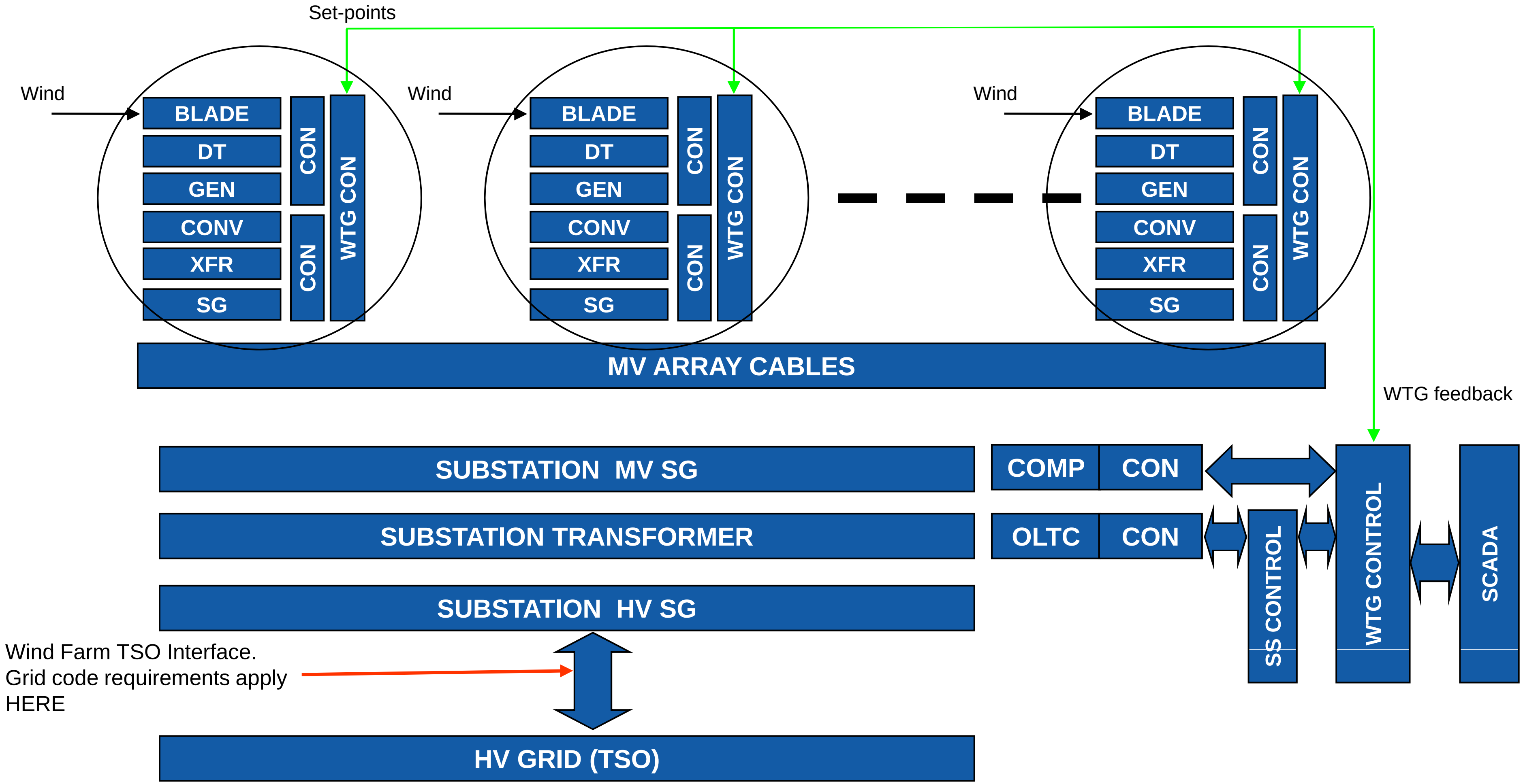
- PQ
- LVRT
- Negative sequence
- Harmonics
- Flicker
- ….



Developers gain :

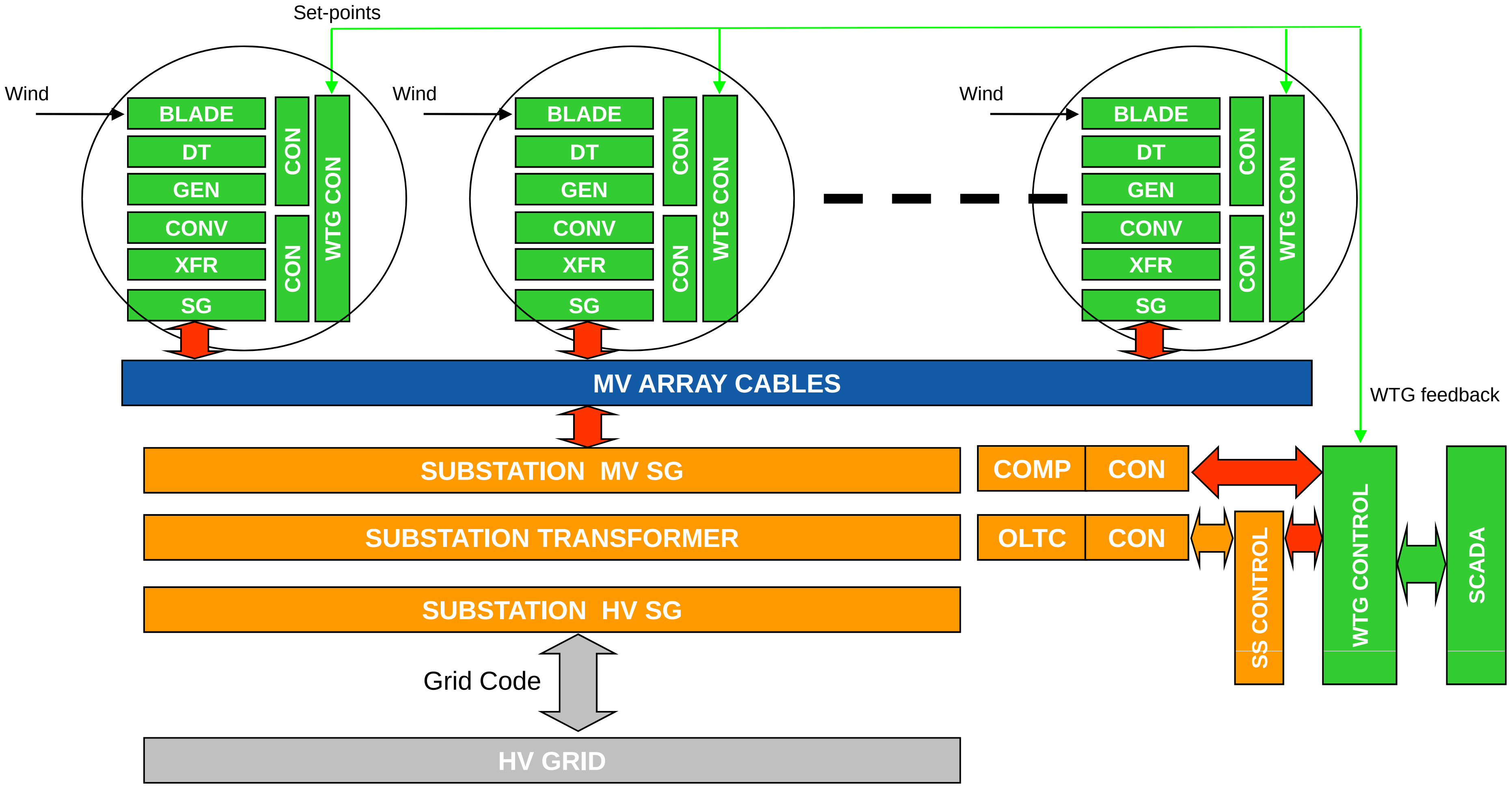
- Better and more reliable WTG through testing
- Higher availability
- Transparent test results and methods
- Validated simulation models

Wind Farm Performance Requirements



VATTENFALL

Contract structures…



Full-scale testing…?

Full Wind Farm Representation

FULL SCALE TEST

Not Feasible

Hardware-in-the-loop
+
Real-time simulation

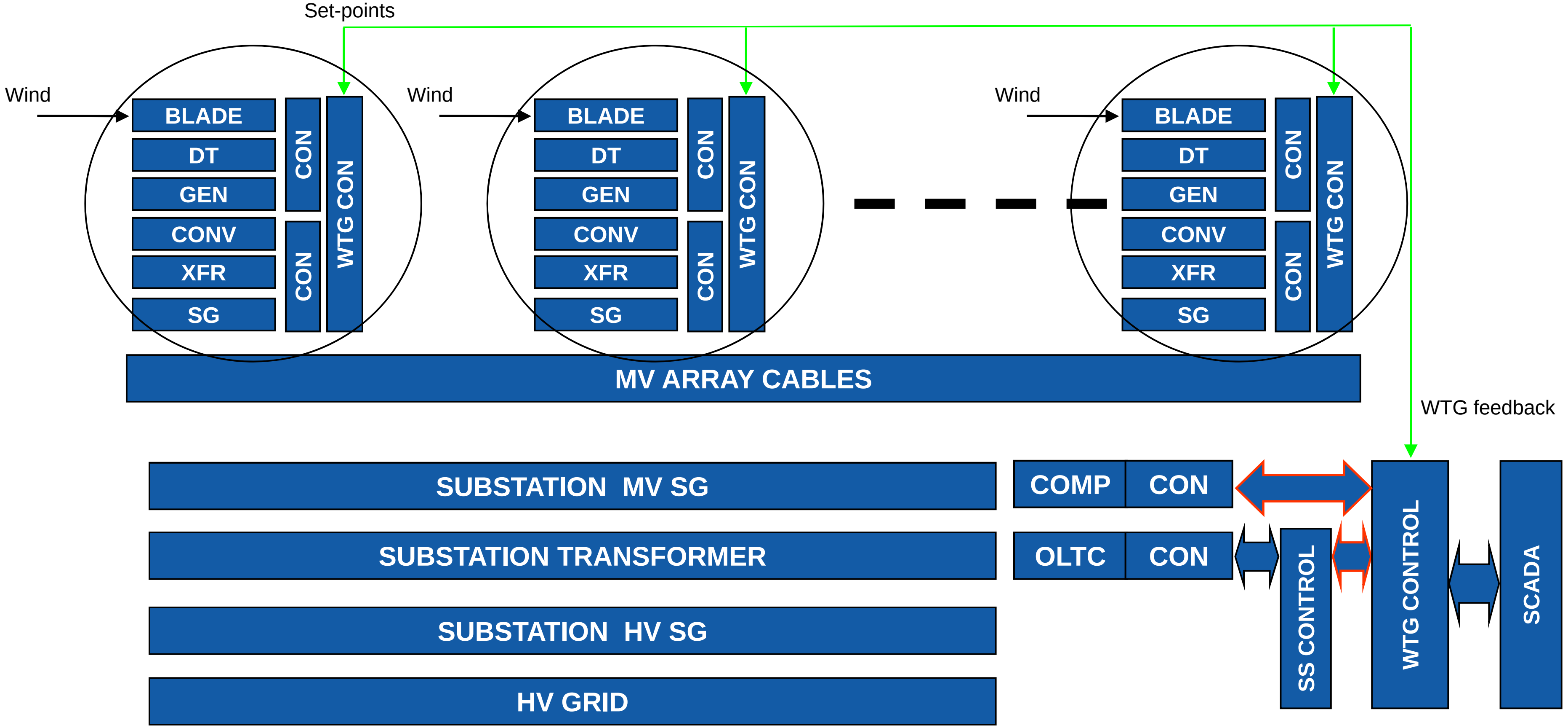
SIMULATION

Good enough ?

FULL SCALE WTG TEST

VALIDATED SIMULATION MODEL

Wind Farm Test - scope



Legend:

Physical Hardware | Emulated by HVDC | Real Time Simulation

Conclusions – Benefits for developers

- Financial impact for developers of 2nd order nature
  - Advantages by getting better and more reliable products from the wind turbine suppliers
  - Validated models for system simulations
  - Development platform for future control functions (revenues)

- Possible to get identical test conditions across different WTG suppliers
  - Ease of turbine selection for projects

- Possibility to test WTG under realistic operating conditions through WFC
  - Programmability and reproducibility

Conclusions – Functional Specification

- Include wind farm controller
- Use back to back converter to emulate grid
- Tests at WTG as well as wind farm level
- Use substation and compensation equipment controllers in HW
- Add real-time simulation capability

APPENDIX G

Vestas: Introduction to possible technical concepts for layout of the test facility

Testcenter Østerild

Introduktion til tekniske koncepter for udformning af Testfacilitet

15. oktober 2010, Lars Højbjerg Nielsen, Plant Modelling

Baggrund

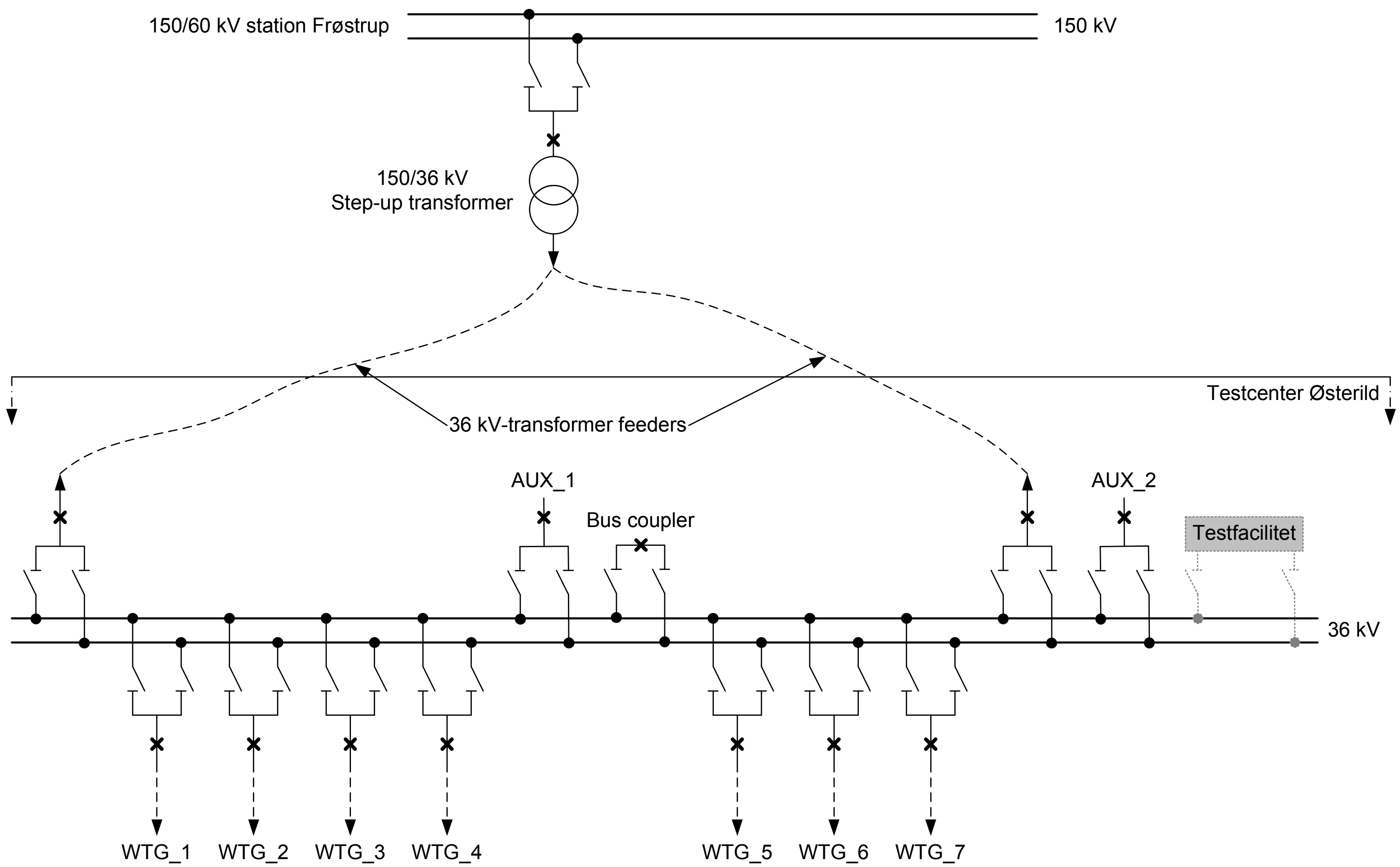
- I forbindelse med etablering af det nationale testcenter for vindmøller ved Østerild Klitplantage undersøges forskellige tekniske koncepter til afprøvning af vindmøllers netkompatibilitet.
- Den aktuelle testfacilitet til afprøvning af vindmøllers netkompatibilitet skal både kunne tilfredsstille gældende krav til afprøvning af *wind power plants* og samtidig være tilstrækkelig fleksibel til at kunne imødekomme fremtidens netkrav (grid codes).
- Testfaciliteten kunne understøtte udvikling og afprøvning af nye koncepter, f.eks. møller med nye generatortyper eller nye koncepter for effektelektronik.
- Testfaciliteten skal kunne anvendes ved validering og certificering af komponenter, simuleringsmodeller etc.

Relevante tests ?

- Test af aktiv- og reaktiv effekt reguleringsevne (fx step respons tests)
- Test af frekvensregulering
- Test af spændingsregulering
- Test af spændingsvariationsområder / spændingsasymmetri
- Test af frekvensvariationsområder
- Test af beskyttelsesfunktioner
- Test af Low Voltage Ride Through egenskaber
- Test af kortslutningsbidrag (symmetrisk/asymmetrisk)
- Test af Power Plant Controller (reguleringsfunktioner)
  - Aktive power regulering (balancering, gradient regulering, limiter etc.)
  - Frekvens regulering (spinning reserve etc.)
  - Reaktiv effekt regulering (Q-regulering, PF-regulering etc.)
  - Spændingsregulering
  - Low voltage Ride Through egenskaber (plant niveau)
  - ??
- ??

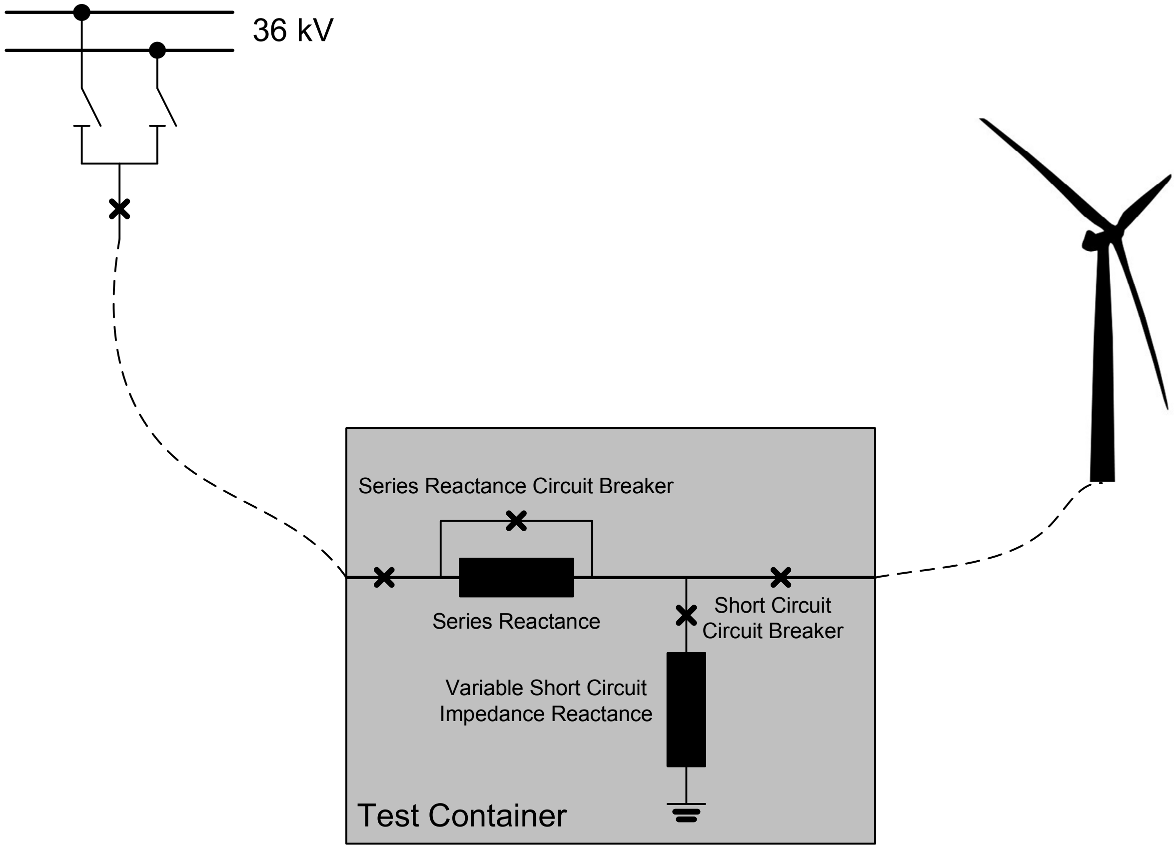
Testcenter Østerild

Vindmølle Industriens oprindelige oplæg til elektrisk layout



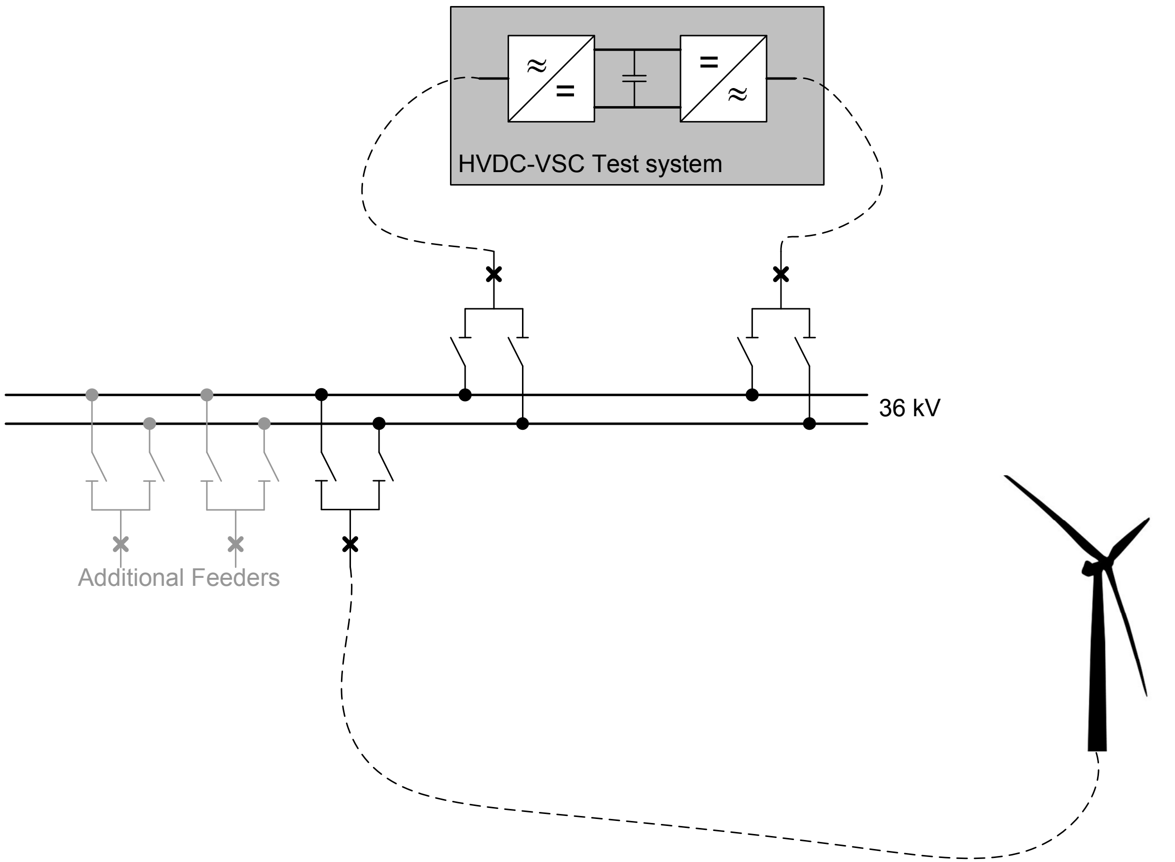
Mulige løsninger ?

Decentral testfacilitet (placeret ved den enkelte vindmølle)



Mulige løsninger ?

Central testfacilitet (placeret ved 36 kV-koblingsanlæg)



APPENDIX H

The importance of system earthing and earthing design for Østerild

SIEMENS

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Date	15.02.2011

Østerild
Test Facility for Grid Connection

This Document is some comments to the design of the grid used for the test facility.

Neutral grounding of the 33 kV system

Several studies has shown that the best compromise for reducing earth fault currents and transient over voltages is obtained by low-resistance grounding of the internal medium voltage cable grid. Therefore low-resistance system grounding is recommended to be applied in wind farms with an internal medium voltage cable grid.

Even though resonance grounding seems attractive this method has other disadvantages (risk of Ferro-resonance, more complex, and more expensive) which usually makes it not recommendable for wind farm collection grids.

Isolated system grounding is not recommendable due to risk of very high transient over voltages in case of single-phase earth faults followed by single-phase earth fault re-ignition.

Determination of earth fault current

For operation with low impedance neutral grounding the earth fault current should be:

- as high as necessary to ensure fast and selective tripping even in case of arc or fault resistances and

- as low as possible
  - to reduce burning and melting effects in faulted equipment,
  - to prevent high touch and step voltages and transferred potentials,
  - to reduce arc blast or flash hazard to personnel in close proximity to the ground fault
  - to reduce the voltage dip in low voltage systems supplied by the low impedance grounded system during a ground fault and
  - to prevent interferences on secondary equipment.

The 33 kV feeders of the test facility should be protected by overcurrent-time protection relays.

For detection of earth faults in the 33 kV system the earth fault stages IE>> and IE> of these relays can be used.

Because the earth current of a feeder under normal operation is equal or near zero the setting values of the earth fault stages can be set to currents smaller than the maximum load currents.

To consider additional arc or fault resistances the setting value of the earth fault stages should be only 50% of the minimum earth fault current calculated without consideration of fault impedances.

The setting value of the earth fault stages should be

- clearly higher than the capacitive earth fault current contribution of the longest 33 kV feeder
- at least 10% - 20% of the nominal current of the current transformer

For a 6 MW wind turbine a current in the range of 110 A per feeder will be generated.

The system must be designed for wind turbines up to 16 MW.

For a 16 MW wind turbine the current will be in the range of up to 280 A per feeder.

Current transformers with a nominal current of 300 A or 400 A should be used in the 7 feeder of the test system.

Setting the earth fault stage of the overcurrent time protection relay to 20% of the nominal value of the current transformer would result in primary values of 60 A resp. 80 A.

To have a safety factor of two between setting value and minimum earth fault current, the minimum earth fault current should be at least 120 A resp. 160 A. Therefore it is recommended to limit the maximum earth fault current to 200 A.

Design of equipment for neutral grounding

The neutral grounding devices should be designed to limit the maximum earth fault current to a value of 200 A.

For calculation of maximum earth fault current a voltage factor of c=1.1 according to IEC 60909 /2/ shall be considered.

The 150/33 kV transformer has a delta winding at the 33 kV side.

Therefore the neutral resistor can not be connected to this transformer.

Alternatively the neutral resistor can be connected to a stand-alone earthing transformer or an earthing transformer with a low voltage winding for auxiliary supply.

For the 33 kV system of the test facility it is recommended to use an earthing transformer with a low voltage winding for auxiliary supply of the converter test system.

Summary

Earth faults at the 33 kV feeders can be detected by earth fault stages (ANSI 51N) of the over current-time relays of the feeders.

In case of an earth fault at the 33 kV busbar the earth fault is fed only from the earthing transformer with the earthed 33kV neutral. Therefore this fault can not be detected by an earth fault stage of a protection device in the 150/33 kV power transformer feeder.

To detect earth faults at the busbar the earth-fault stage of the overcurrent time relay in the earthing transformer has to be used. This earth-fault stage should switch off the circuit breaker of the 150/33 kV power transformer. The earth fault protection of the earthing transformer gives also a back-up protection for earth faults at the 33 kV feeders.

To realize a back-up protection for earth faults at the busbar the displacement voltage measured at an open delta winding of the busbar voltage transformer or the neutral current measured at a single phase current transformer in the neutral connection between resistor and earth can be used.

It is proposed to install a single phase current transformer in the neutral connection and a separate overcurrent-time relay. This protection device should also be used for a thermal overload protection for the neutral resistor.

Insulation Coordination

Siemens has a long history for delivering insulation coordination studies for large wind farms.

In general all the studies show that the SIWL phase to phase of the 33 kV MW switchgear is the dimensioning factor for the insulation of the switchgear.

The limitation of the SIWL is done by applying arresters in the 33 kV network (phase-ground).

It is difficult to protect 3 phase encapsulated switchgears against phase-to-phase transients because it is not possible to install arresters between the phases. (In 3 phased insulated switchgears arresters are installed between phase and ground.)

To limit phase-to-phase over voltages by installing arresters between phase-ground are very difficult.

Single phase encapsulated switchgear do not have any problems with phase-to-phase over voltages due to their design. Therefore single phase encapsulated switchgear are used in several large wind farm projects.

Siemens recommend using this kind of switchgear for the Østerild test center.

Copies of the insulation coordination studies can not be handed over due to the confidentiality agreements Siemens have with our customers.

Kind regards

Peter Weinreich-jensen

Memo
Test Center Østerild. System earthing

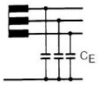
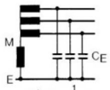
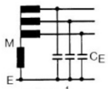
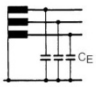
2011-02-17

It is proposed that there is made a system earthing study for the 33 kV system(s) of test center Østerild

The switchgear must include a possibility to connect system earthing to the system neutral point. There are several possible solutions for the system earthing. The overview here is taken from ABB Switchgear manual (ed. 11, page 107-108). The manual is available on
http://www02.abb.com/global/seitp/seitp161.nsf/0/26ed7fc021b62000c1256f570051b81a/$file/index_abb_de.html

3.5 Effect of neutral point arrangement on fault behaviour in three-phase high-voltage networks above 1 kV

Table 3-22

Arrangement of neutral point	isolated	with arc suppression coil	current-limiting *R* or *X*	low-resistance earth
		 $\omega L \approx \frac{1}{3\omega C_E}$	 $\omega L < \frac{1}{3\omega C_E}$	
Examples of use	Networks of limited extent, power plant auxiliaries	Overhead-line networks 10…123 kV	Cable networks 10…230 kV system e. g. in towns	High-voltage networks (123 kV) to 400 kV (protective multiple earthing in l. v. network)
Between system and earth are:	Capacitances, (inst. transformer inductances)	Capacitances, Suppression coils	Capacitances, Neutral reactor	(Capacitances), Earth conductor
$\lvert Z_0 / Z_1 \rvert$	$\left\lvert \frac{1/j\omega C_E}{Z_1} \right\rvert$	very high resistance	inductive: 4 to 60 resistive: 30 to 60	2 to 4
Current at fault site with single-phase fault Calculation (approximate) $E_1 = \frac{c \cdot U_n}{\sqrt{3}} = E''$	Ground-fault current I_E (capacitive) $I_E \approx j\,3\,\omega C_E \cdot E_1$	Residual ground-fault current I_R $I_R \approx 3\,\omega C_E(\delta + j\nu)\,E_1$ δ = loss angle ν = interference	Ground-fault current I_{k1} $I''_{k1} = I_R \approx \frac{3\,E_1}{j\,(X_1 + X_2 + X_0)}$ $\frac{I''_{k1}}{I''_{k3}} = \frac{3\,X_1}{2\,X_1 + X_0} = \frac{3}{2 + X_0/X_1}$	
I''_{k2} / I''_{k3}	I_{CE} / I''_{k3}	I_R / I''_{k3}	*inductive*: 0.05 to 0.5 *resistive*: 0.1 to 0.05	0.5 to 0.75
U_{LEmax} / U_n	≈ 1	1 to (1.1)	inductive: 0.8 to 0.95 resistive: 0.1 to 0.05	0.75 to ≦ 0.80
U_{0max} / U_n	≈ 0.6	0.6 to 0.66	inductive: 0.42 to 0.56 resistive: 0.58 to 0.60	0.3 to 0.42
Voltage rise in whole network	yes	yes	no	no
Duration of fault	10 to 60 min Possible short-time earthing with subsequent selective disconnection by neutral current (< 1 s)	10 to 60 min	< 1 s	< 1 s
Ground-fault arc	Self-quenching up to several A	Self-quenching	Partly self-quenching usually sustained	Sustained
Detection	Location by disconnection, ground-fault wiping-contact relay, wattmeter relay. (With short-time earthing: disconnection by neutral current)		Selective disconnection by neutral current (or short-circuit protection)	Short-circuit protection
Risk of double earth fault	yes	yes	slight	no
Means of earthing DIN VDE 0141	Earth electrode voltage $U_E \leq 125$ V Touch voltage ≦ 65 V		Earth electrode voltage $U_E > 125$ V permissible Touch voltages ≦ 65V	
Measures against interference with communication circuits DIN VDE 0228	Generally not necessary needed only with railway block lines	Not necessary	Overhead lines: possibly required if approaching over a considerable distance Cables: generally not necessary	

System earthing practice differs from country to country. Properly designed the system earthing will not affect the turbine performance, but inadequate designed earthing systems can lead to inacceptable overvoltages. Thus an earthing system study is proposed as well as an insulation coordination study is proposed. In case a test facility in installed, system earthing considerations must also be made for the wind turbine side of the test facility

Erik Koldby, ABB

APPENDIX I

Budget estimate for establishment and operation

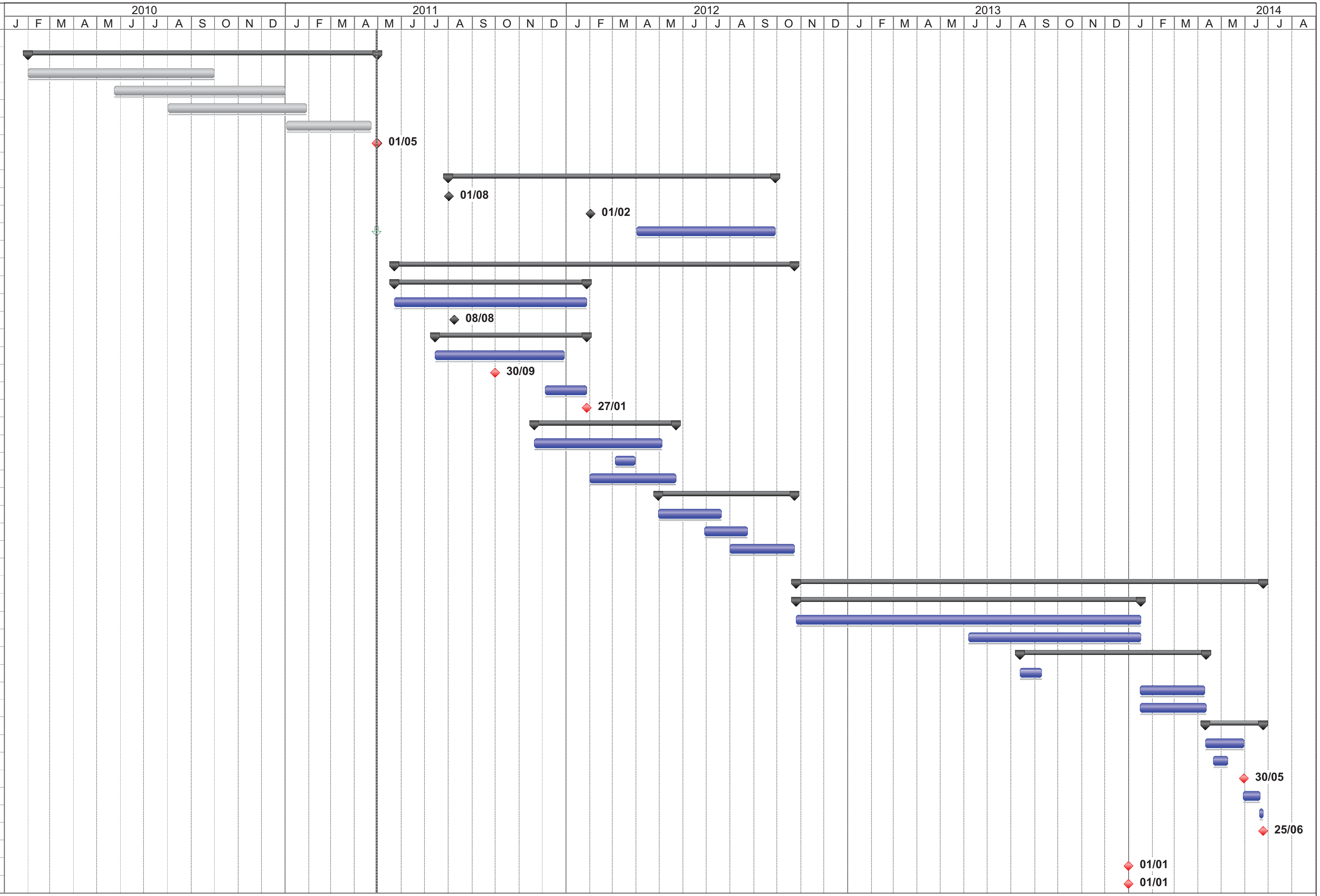
SUMMARY OF BUDGET COSTS FOR 16MW TEST FACILITY

	cost type	unit	av. unit cost	no. of units	budget cost
ESTABLISHMENT BUDGET COSTS IN Dkk					
Phase 2: Pre-construction					
Applications for funding from all sources	full	hour	1,023	1,100	1,046,598
Obtaining permissions necessary (e.g. for new buildings)	full	hour	912	150	136,735
Preparatory work for establishment contracts	full	hour	1,076	800	804,535
Pre-qualifying suppliers	full	hour	1,256	450	566,095
Writing of tender documentation	full	hour	1,226	1,550	1,888,285
Inviting tenders and assessment of tender returns	full	hour	1,215	360	415,308
Awarding of contract(s) to most suitable bidder(s).	full	hour	1,140	460	538,208
Expenses	full				614,000
Sub-total					6,009,763
Phase 3: Construction					
Aquisition of land	full				0
Buildings for switchgear, grid emulator, etc	full	m^2	10,000	300	3,000,000
Building services, landscaping, roads, architecture					1,000,000
Buildings and equipment for personnel	delta				200,000
MV switchgear (double busbar)	delta				2,700,000
Converter-based grid emulator, associated trafos and equipment	full				50,000,000
Short circuit (container-based) test equipment	full				18,750,000
Auxilliary equipment (e.g. measurement, comms, control, interface computers)	full				500,000
External cabling for the above equipment	full				840,000
Project management & design work	full	hour	1,226	1,400	1,639,505
Monitoring/supervision of construction	full	hour	1,112	900	840,455
Testing, commissioning & training	full	hour	1,047	650	667,440
Expenses					679,000
Project contingency	full	%		5	4,041,000
Sub total					84,857,400
Total for Phases 2 and 3 (rounded to nearest 1000)					**90,867,000**
Funding proportions (rounded):					
50% from grant source (e.g. GreenLabs)					**45,434,000**
~14% Vestas					**12,981,000**
~14% Siemens					**12,981,000**
~22% DTU					**19,472,000**
OPERATION AND MAINTENANCE COSTS IN DKK					
Phase 4: Operation					
Contract for MV switching and grid emulator operations (25 hour/year/stand)	full	hours	175	800	140,000
Contract for maintenance and repair of MV switchgear	delta	2 % of capital cost per year			54,000
Contract for maintenance and repair of converter-based grid emulator	full	2 % of capital cost per year			1,000,000
Contract for maintenance and repair of container-based test equipment	full	2 % of capital cost per year			375,000
Maintenance and repair costs of remaining equipment (contract/in-house)	full				75,000
Management personnel costs	delta	hour	150	1,100	165,000
Day-to-day technical operation personnel costs	delta	hour	300	800	240,000
Building maintenance equipment and personnel costs	delta	hour	75	500	37,500
Administration/accounts personnel costs	delta	hour	375	500	187,500
Insurance: personal liability, accident, building and equipment	delta	lump sum per year			150,000
Utility costs: electricity, water, etc.	delta	annual cost			120,000
Contribution to contingency fund					0
Total for Phase 4					**2,544,000**
Annual O&M costs per stand (rounded to nearest 1000)					363,000

APPENDIX J

Time schedule for implementation

ID	Task Name
1	
2	**1st Phase Activities: EUDP Project**
3	WP1 Functional description
4	WP2 Assessment of solutions
5	WP3 Organisational solutions
6	WP4 Business case
7	Final report
8	
9	**Østerild Test Centre**
10	Construction start
11	Grid connection & energisation
12	Handover of completed test stands
13	
14	**2nd Phase Activities: Implementation 1**
15	**Preparatory activities**
16	Ongoing project activities
17	Appointment of advisor
18	**Secure funding**
19	Writing of applications
20	GreenLabs submission
21	GreenLabs negotiation
22	Funding award
23	**Tender preparation**
24	Engineering activites
25	Pre-qualification process
26	Tender documentation writing
27	**Contracting process**
28	Invitations to tender
29	Assessment of tender returns
30	Contract negotiations and signing
31	
32	**3rd Phase Activities: Implementation 2**
33	**Equipment design and procurement**
34	Converter equipment
35	Balance of plant, cabling, etc
36	**Civil construction**
37	Building design
38	Building construction
39	Roads, landscaping, etc
40	**Test facility equipment**
41	Converter etc. installation
42	Cable pulling
43	Energisation
44	Testing & commissioning
45	Training
46	Hand over
47	
48	**4th Phase Operation**
49	Formation of operating entity



Project: Østerild Test Facility Date: 29apr2011	Task	Progress	Summary	External Tasks	Deadline
	Split	Milestone	Project Summary	External Milestone	

APPENDIX K

Use of transformer tap changers to reduce required capacity of test converter (Risø DTU)

Use of transformer tap changers to reduce required capacity of test converter

1. Introduction

The present short report briefly analyses the coordination between AC-AC converter and wind turbine side transformer at the new Risø DTU's test facility, in order to achieve a preliminary assessment of the voltage and current requirements for the AC-AC converter and point out the possible need for an offline tap changer on the transformer which lies between such converter and the wind turbine undergoing the test.

The schematic layout of the test facility that can be considered for the sake of this work is depicted in Figure 1. The AC grid feeds a transformer, downstream of which lies an electronic AC-AC converter based on self-commutating power electronic switches. The grid side of the converter can be reactive neutral towards the external network, while the wind turbine side must accommodate the PQ requirements of any required test. Between the electronic converter and the wind turbines is another transformer, which may have an offline tap changer in order to reduce the requirements to the maximum voltage of the wind turbine side of the converter.

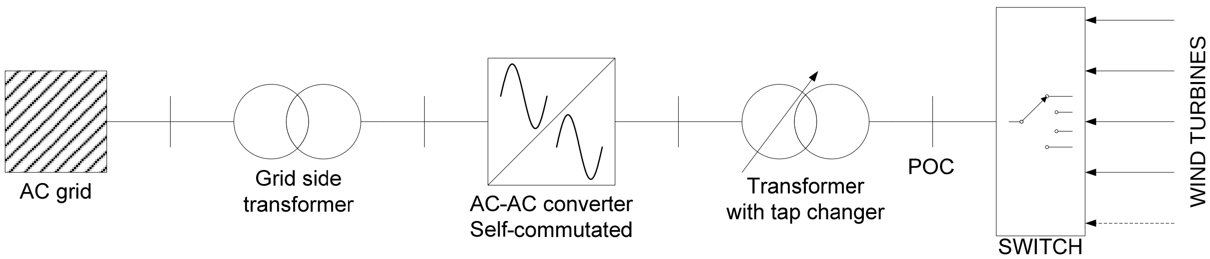


Figure 1 Test facility layout

The focus of this report is on the PQ capability test, in which the wind turbine is required to provide the desired active and reactive power characteristic. The reference shape of such capability, independently of the actual characteristics of the wind turbine, can be extrapolated from the grid code, and is here shown in Figure 2, where the rated active power of the wind turbine is used as base value for the per unit system. The rated power factor is $\cos\varphi = 0.9$, which leads the PQ diagram to be as in Figure 2.

The electronic converter must allow the POC to match the PQ requirements, so that it can be operated to carry out complete PQ capability measurements, respecting its designed maximum ratings, i.e. maximum voltage U_{max} and current I_{max}.

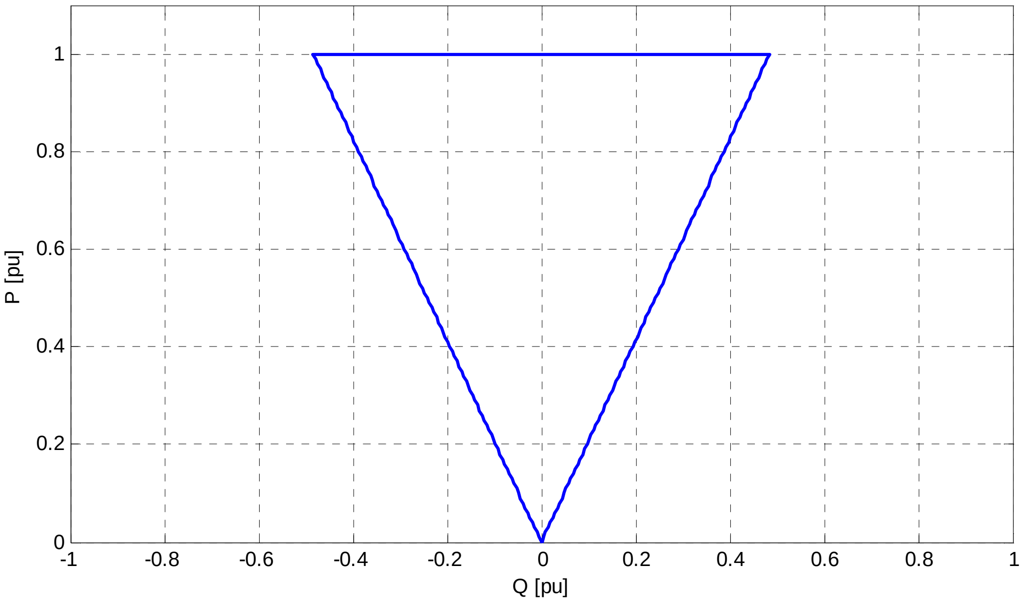


Figure 2 PQ requirement for a wind turbine based on grid code

2. Main hypotheses for the calculations - Equivalent circuit

A number of reasonable hypotheses can be formulated for this initial investigation, that allow for a simplification of the equations involved. The following assumptions are deemed to be sound:

- The voltage is controlled at the POC by the test facility and is thus considered constant at the desired value. Such voltage is therefore a given datum in the analysis.
- The series impedances of transformer and converter are purely inductive, neglecting any resistive loss.
- The shunt (magnetizing) reactance of the transformer, as well as its shunt resistance (core losses), are neglected.
- As a consequence of the two previous assumptions, the transformer can be modeled as the cascade of a series reactance and an ideal transformer.
- The converter internal voltage can be modeled as a sinusoidal (50 Hz or 60 Hz) voltage source, thus accounting only for the fundamental component.
- Three phase voltages and currents, as well as the components' parameters, are supposed to be symmetrical and balanced, so as to reduce the study to the single phase equivalent.

The assumptions above permit a simple equivalent circuit to be drawn. Referring to one phase, it can be sketched as in Figure 3. Converter internal voltage and reactance are indicated with U_C and X_C respectively, the transformer reactance is called X_T and the transformation ratio is m. The operation, as assumed above, is analyzed on the grid code-based PQ requirement in Figure 2.

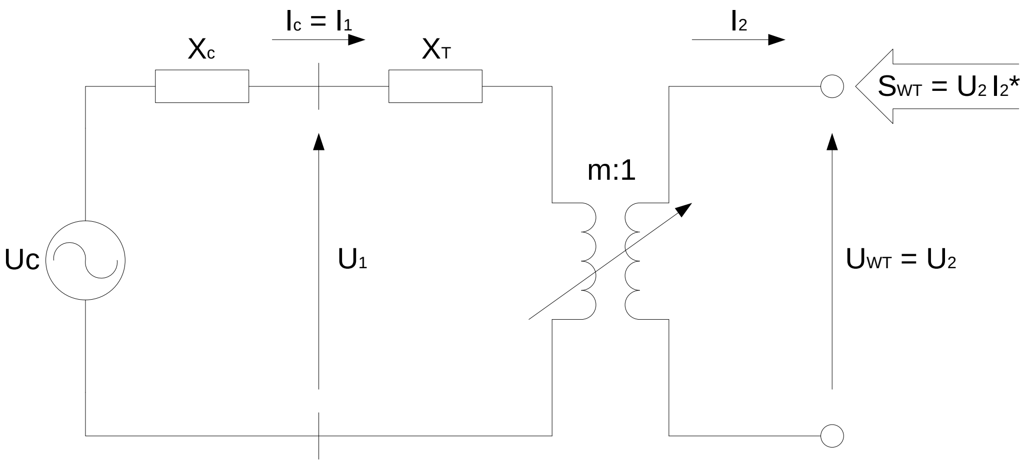


Figure 3 Single phase equivalent circuit

3. Main equations

As derived from the hypotheses introduced above, the transformer can be represented by the cascade of a series reactance (X_T) and an ideal transformer with ratio m. The input voltage and current of the transformer can thus be written as:

$$\begin{pmatrix} U_1 \\ I_1 \end{pmatrix} = \begin{bmatrix} 1 & j \cdot X_T \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} m & 0 \\ 0 & \frac{1}{m} \end{bmatrix} \cdot \begin{pmatrix} U_2 \\ I_2 \end{pmatrix} = \begin{bmatrix} m & \frac{j \cdot X_T}{m} \\ 0 & \frac{1}{m} \end{bmatrix} \cdot \begin{pmatrix} U_2 \\ I_2 \end{pmatrix}.$$

Then, the converter internal voltage and current are easily determined by:

$$\begin{pmatrix} U_C \\ I_C \end{pmatrix} = \begin{bmatrix} 1 & j \cdot X_C \\ 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} U_1 \\ I_1 \end{pmatrix} = \begin{bmatrix} m & \frac{j \cdot (X_T + X_C)}{m} \\ 0 & \frac{1}{m} \end{bmatrix} \cdot \begin{pmatrix} U_2 \\ I_2 \end{pmatrix}.$$

It is evident that the converter current can be modulated by tuning the transformation ratio, remaining firmly linked to the wind turbine current all over the PQ curve. Moving on the PQ curve, the converter voltage, on the other hand, traces a locus around the offset dictated by U_2, which extent is depending on the value of the reactances.

It is also interesting to compute the complex power the converter is demanded to supply, which is, in per unit:

$$S_C = U_C \cdot I_C^* = \left[m \cdot U_2 + j \cdot \frac{(X_T + X_C)}{m} \cdot I_2 \right] \cdot \frac{I_2^*}{m}.$$

Taking the POC voltage U_2 as a reference and substituting the generic expression $I_2 = |I_2| \cdot (\cos\varphi + j \cdot \sin\varphi)$, where $|I_2|$ is the actual turbine current, the equation thus gives:

$$S_C = |U_2| \cdot |I_2| \cdot \cos\varphi + j \cdot \left[-|U_2| \cdot |I_2| \cdot \sin\varphi + (X_T + X_C) \cdot \frac{I_2^2}{m^2} \right].$$

Such equation is the mathematical formulation of the conservation of complex power. The negative sign for the first term of the reactive component is due to the definition of φ.

4. Operation without tap changer on the transform

As stated above, the AC-AC converter must be able to move over the entire range of possible active and reactive power. Not only should it cover the constraints posed by the wind turbine, but also provide the reactive power that is consumed by the transformer leakage and magnetizing reactances, as well as the consumption of its internal impedance, so as to make sure that the POC comply with the PQ characteristic specified by the grid code.

At constant transformation ratio, that means that the converter is required, depending on the voltage in the POC, to span the area embraced by the lines drawn in Figure 4.

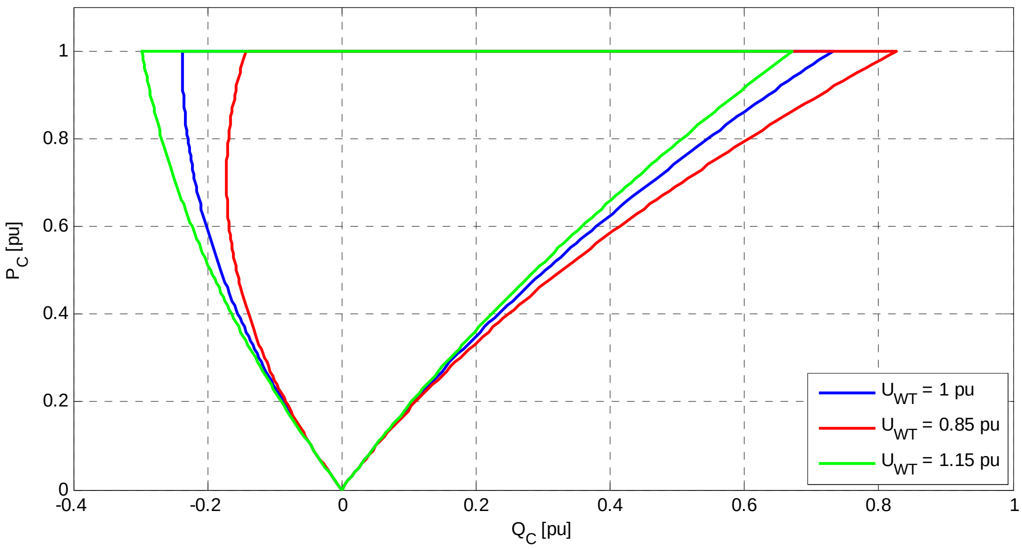


Figure 4 **PQ requirements for the AC-AC converter constant transformation ratio $m = 1$**

The plot above refers to a solution with transformation ratio $m = 1$, transformer reactance $X_T = 0.1\ pu$ and converter internal reactance $X_C = 0.1\ pu$. The voltage is varied in the range $0.85\ pu \leq U_{WT} \leq 1.15\ pu$, as those are considered to be the actual extreme values for PQ capability testing. It is noticed how the PQ curve for the converter is deformed, due to the reactive power consumed on the internal and transformer's reactance. Furthermore, the applied POC voltage also influences the shape of the curves. As obvious, for higher POC voltage the characteristic is pulled towards lower values of Q, since the lower current reduces the reactive power consumption of internal and transformer's reactance.

The converter voltage must obviously vary in order to accommodate the PQ requirement of the wind turbine. The variation range can be observed in Figure 5, where the amplitude of U_C when spanning the whole PQ diagram is depicted and maintaining constant rated transformation ratio.

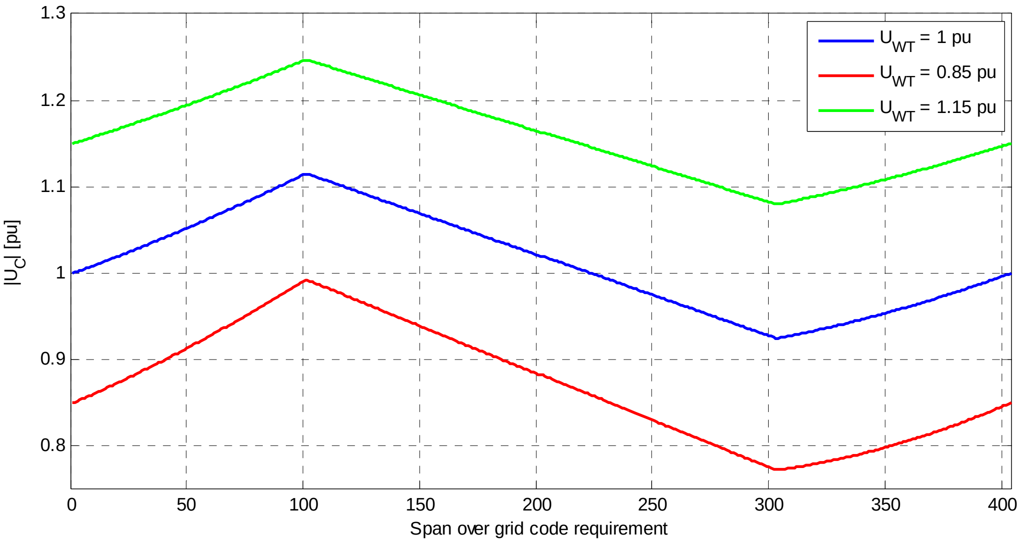


Figure 5 **Converter voltage amplitude moving on the PQ diagram with constant transformation ratio $m = 1$. The x-axis represents the position over the PQ curve, moving all along it.**

It can be noticed, as expected, that for higher values of the POC voltage, the converter valves are significantly more stressed. Figure 6 shows the converter current when the operational point moves along the PQ diagram shown in Figure 2.

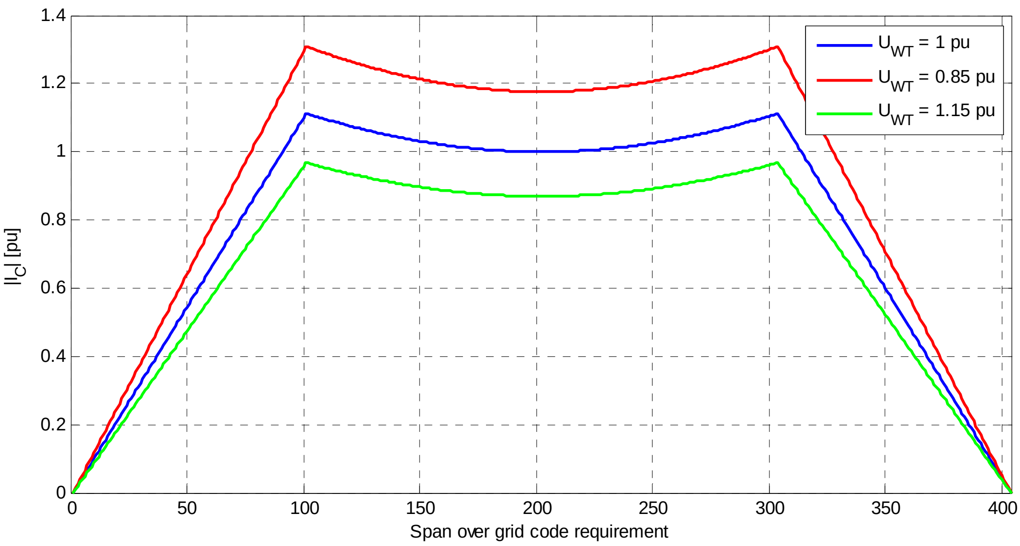


Figure 6 **Converter current amplitude moving on the PQ diagram with constant transformation ratio $m = 1$. The x-axis represents the position over the PQ curve, moving all along it.**

As expected, keeping the same PQ diagram, the converter current decreases when the POC – and thus converter – voltage is augmented, and vice versa. As a consequence, the stress of the valves – now referring to their current – is larger when diminishing the POC voltage.

5. Introduction of a tap changer in the transformer

In general, one could approach the design of the power electronic converter by making use of the worst cases reported in Figure 5 and Figure 6, extracting the maximum voltage and current respectively. Such design would however not be optimal, since both maximum voltage and current of the converter would be significantly higher than those at rated operation.

Alternatively, a tap changer can be introduced in the transformer, allowing the converter voltage and current to be stepped up or down according to the needs.

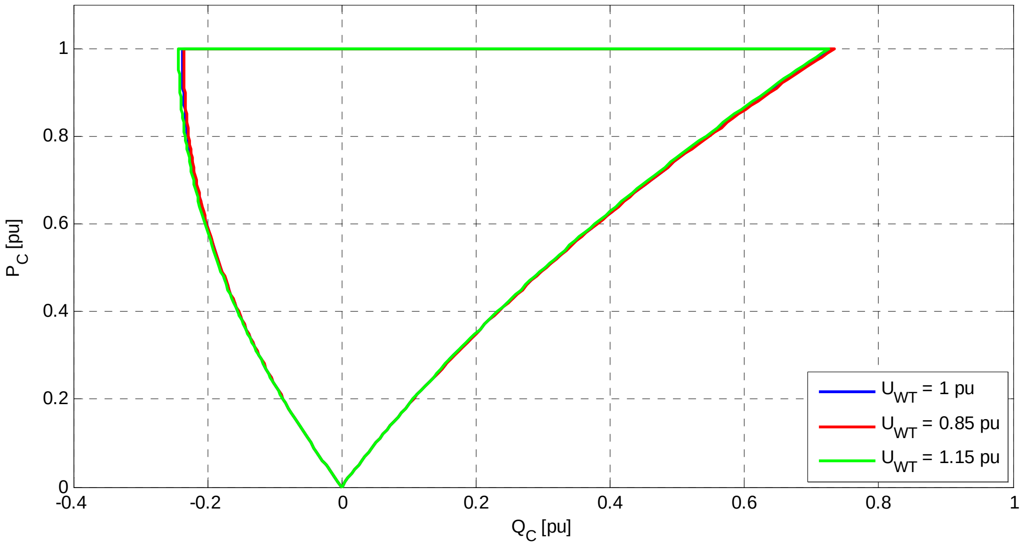


Figure 7 PQ requirements for the AC-AC converter with varying transformation ratio: for $U_{WT} = 1.15\ pu$ the transformer ratio is $m = 0.88$, while for $U_{WT} = 0.85\ pu$ it is $m = 1.17$

Figure 7 shows the PQ curve for the converter when the tap changer is installed on the transformer. It can be observed that the PQ curve for the converter can basically be rendered independent of the voltage.

In Figure 8 the converter voltage amplitude variation when moving over the PQ diagram is reported, changing the transformation ratio according to the POC voltage. As can be seen, tuning the transformation ratio can bring the voltage to behave similarly to rated conditions.

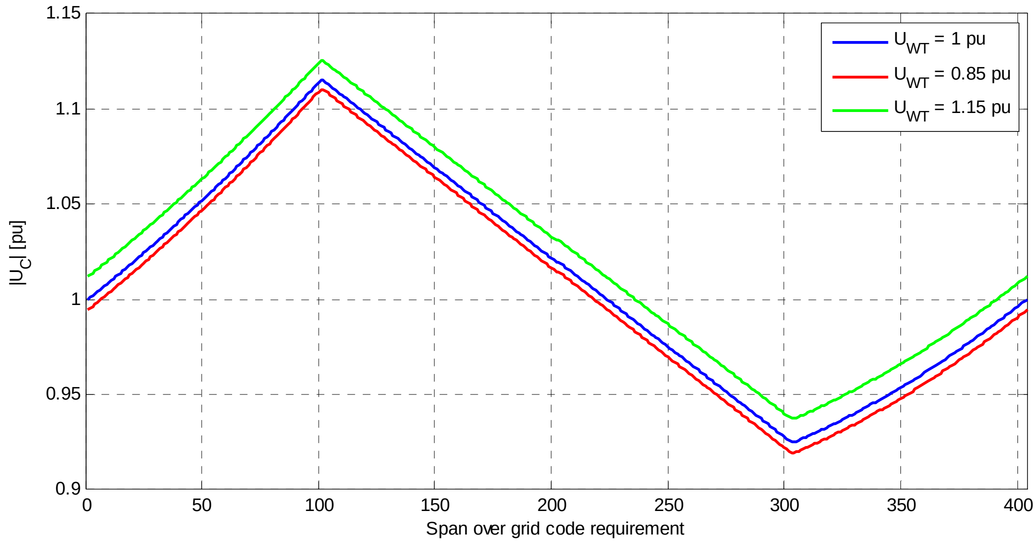


Figure 8 **Converter voltage amplitude when moving on the PQ diagram: for $U_{WT} = 1.15\ pu$ the transformer ratio is $m = 0.88$, while for $U_{WT} = 0.85\ pu$, $m = 1.17$. The x-axis represents the position over the PQ curve, moving all along it.**

In particular:

- When the POC voltage is maximum ($U_{WT} = 1.15\ pu$), a transformation ratio $m = 0.87$ can be used to have a voltage pattern equal to that at rated operation.
- When the POC voltage is minimum ($U_{WT} = 0.85\ pu$), a transformation ratio $m = 1.18$ brings the voltage pattern to be the same as at rated operation.

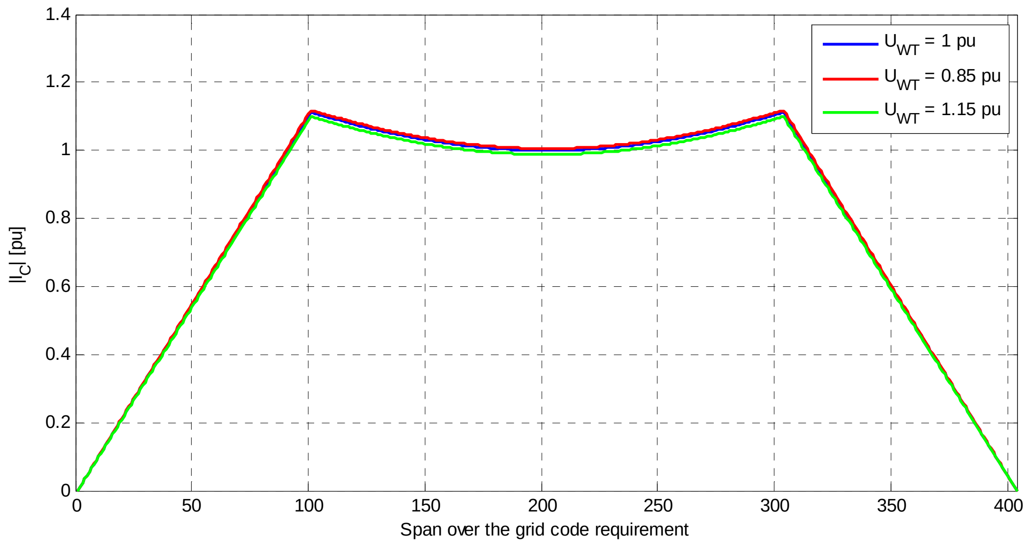


Figure 9 **PQ Converter current amplitude when moving on the PQ diagram: for $U_{WT} = 1.15\ pu$ the transformer ratio is $m = 0.88$, while for $U_{WT} = 0.85\ pu$, $m = 1.17$. The x-axis represents the position over the PQ curve, moving all along it.**

Figure 9 above reports the effect of the tap changer on the amplitude of the converter current, again moving on the PQ diagram depicted in Figure 2. The benefits are apparent even under this perspective, as the current profile results close to that at rated conditions.

A practical example – Realistic values for the test facility

For the sake of example, based on the analysis carried out above, some calculations can be made, starting from the assumption that the PQ requirement of Figure 2 must be matched at the POC and aiming at the determination of the maximum figures for the converter – i.e. voltage U_{max} and current I_{max}. The following data can be used as a first example:

- Rated turbine active power $P_n = 16\ MW$.
- Rated turbine power factor $\cos\varphi = 0.9$.
- Rated turbine voltage $U_n = 33\ kV$.
- Rated transformer primary side voltage $U_{Tn} = 10\ kV$.

With the figures stated above, and varying the POC voltage so as to be $0.85U_n \leq U_{WT} \leq 1.15U_n$, the converter valves would need to be designed on the following values:

- When no tap changer is installed on the transformer:
  - Maximum voltage $U_{max} \approx 12.5\ kV$.
  - Maximum current $I_{max} \approx 1.2\ kA$.
  - MVA rating $S \approx 26\ MVA$.
- When a tap changer is installed on the transformer:
  - Maximum voltage $U_{max} \approx 11.2\ kV$.
  - Maximum current $I_{max} \approx 1.02\ kA$.
  - MVA rating $S \approx 19.8\ MVA$.

In order to reduce the requirements as stated above, the transformer tap changer should be able to change the transformation ratio – in pu – between 0.87 and 1.18.

Notice that, in this case, line-to-line voltages are considered and the turbine rated active power is used as base value for the per unit notation, and bearing in mind that the analysis above was proceeded with a single phase equivalent diagram.

It is also worth to point out that the values reported above are not real figures, mainly for the following reasons:

- The actual value of the series impedances X_C and X_T has a significant effect on the calculated values, and such figures are not known.
- Many of the other data are assumptions, at the time being, since they are not known yet.
- The model was simplified in order to more clearly illustrate the situation. A more detailed model would obviously lead to a more exhaustive analysis and calculation.

6. Conclusion

As a conclusion, it is clear that the insertion of the tap changer would indeed bring some benefits about, as the maximum ratings for the converter internal voltage and current would be lowered, thus reducing the stress on the valves, limiting the losses and in turn decreasing the cost of the power electronic device. An optimal coordination between the components in the test facility could be reached, along with an optimal utilization of the characteristics of the converter.

It is worth to state that the tap changer should probably not be on-load, principally for two reasons:

- The PQ test is carried out for a given POC voltage, which is kept constant and therefore requires constant transformation ratio m during the measurement.
- The on-load operation aiming at controlling the POC voltage may conflict with the control action performed by the converter, possibly giving rise to voltage instability.

The insertion of the tap changer, on the other hand, increases the cost of the transformer. However, such drawback should be well surpassed by the benefit due to the reduction of the cost of the converter. A more thorough economic analysis must be performed in order to ascertain that an economic benefit be guaranteed.

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APPENDIX L

Literature survey summary (AAU)

Literature Survey Summary

This report presents the key points of a literatures survey for the project of ***Test Facility for grid connection characteristics of wind power plants***. The desired functions of wind turbine test facility are described with reference to the studies in literature.

1 Functional description of the Test Facility

1.1 Tests for a single wind turbine

1.1.1 Active and reactive power control [1-17]

To test whether the active and reactive power output of wind turbines could meet the grid requirements is one of the most important functions of the test facility. In references [1-17], the control schemes of the present popular wind generation systems including wound rotor induction generator, DFIG and PMSG have been introduced and demonstrated by simulation tools. The results of the abovementioned literatures indicate that the maximum power output, ramp rate limitation and set-point control may be significantly different with different control schemes and for different types of wind power generators.

1.1.2 Voltage control [18-25]

Voltage control ability of wind turbines influences the steady-state stability as well as transient stability of an electric power system, as shown in references [18-25]. The control strategies are significantly different in time scales for different types of wind turbine. These should be demonstrated by the testing facilities.

1.1.3 Frequency control & inertia response [26-38]

Nowadays, the control concepts that enable wind turbines to participate in grid frequency control mainly include:

- Pitch control together with the provision of reserve capacity by operating the wind turbine in part load mode;
- Inertia response which initiates the partial release of the kinetic energy immediately when the frequency drop is detected， and help limiting the frequency drop effectively.

Different control concepts may result in differences in effectiveness and power losses. Therefore, a test facility would be better to demonstrate the effects.

1.1.4 Voltage dips and swells, voltage phase angle jumps [39-53]

Voltage dips and swells might affect the wind power generators significantly due to their effect on the rotor current, rotor speed, the DC-link voltage, as illustrated in references [39-41, 43-52]. However, two aspects illustrated in references [42, 53] should be paid special attention while developing the test facility, the first one is that the voltage sag conditions experienced at the wind generator terminals can be significantly different from the conditions at the PCC, depending on the network characteristics. The second is that the negative-sequence component of the grid voltage increases when the voltage sag is associated with large phase-angle jumps, which may have significant detrimental impacts on wind turbines.

1.1.5 Voltage unbalance [54-57]

References [54-57] investigated the behavior of wind power generators to supply network voltage unbalance. Due to the high unbalanced currents generated, voltage unbalance affects both the generator and their control.

1.1.6 Low Voltage Ride Through: LVRT [58-70]

Low voltage rid through capability of squirrel-cage generator, DFIG and PMSG have been studied in references [58-70]. The solutions have been related to a dynamic voltage restorer for a squirrel-cage asynchronous generator, a crowbar circuit for a DFIG or PMSG, as well as other schemes including kinetic energy storage or pitch control. The variability of the wind power generators and their control strategies make the machine responses more complicated because of the complex transients during a low voltage ride through.

1.1.7 Low order resonances [71-74]

Low order resonance issues may be introduced by the compensation devices in wind power grid, and can be mitigated with flexible ac transmission system (FACTS) devices. However, there is still potential low order resonance as studied in reference [73]. Under different operation modes of the wind turbine and different capacity of capacitor banks, the orders and amplifications of resonance voltage distortion may vary to a large extent.

1.1.8 Harmonic emission assessment [75-77]

For harmonic emission assessment, the shape and the frequency range of the harmonic current spectrum, the variation of the harmonics with the wind turbine operating point, the statistical characteristics of their magnitude and phase angle are the most important aspects. While assessing the harmonic emission for wind turbines, both the continuous operation and the switching operation of wind turbines may have to be investigated.

1.1.9 Voltage fluctuations caused by the wind turbine [78-82]

Voltage fluctuations are often related to VAR requirements variation which may lead variation of power flow and network losses [82]. The aerodynamic aspects of a wind turbine in a wind power system (e.g., due to yaw error and turbulence) may be the cause of voltage fluctuations, but not the only cause. In middle voltage network, there normally have other fluctuating loads that may cause significant voltage fluctuations at the wind turbine terminals [83].

1.1.10 PQ capabilities at different voltages and frequencies [84-88]

For steady-state operations, wind turbines must be able to decrease or increase the active power output from a working point to a target value set by the transmission system operator. During faults, the facility should limit the active current within the regulated limits which varies according to different grid codes. In case of current saturation, reactive current limitation given by voltage controller saturation has priority over active current limitation. For voltages higher than the normal operation, the wind turbine may seek if possible, to maintain the active power level prior to the disturbance.

1.1.11 Operation during frequency variations [89-94]

References [89-94] proposed output wind power leveling during frequency variations to reduce the adverse effects on power system frequency deviation. Load power estimation method has often been used to predict the values of angular speed, torque and current during and after a frequency disturbance. Thus, load power is estimated by a disturbance observer and, output power command for wind farm is determined according to estimated load. This method requires the test facility to consider the data acquisition on the angular speed, torque, current and so on.

1.1.12 Operation at alternative system frequencies [95-98]

The output frequency of a generator is one of the important parameters that determine the generator's rating. The electrical output of the generator is normally maintained at a fixed frequency, 50 Hz or 60 Hz, to match the frequency of a standard electrical grid. However, with the development of power electronics, it is possible for wind turbine system to work under alternative system frequencies.

1.1.13 Protection strategies [99-107]

In the past wind power plants typically had a small power penetration and the behavior of the wind turbines during faults in the network was considered non critical and wind power plants were simply pulled out of the system. Protection requirement of a wind turbine was just restricted to simple current and voltage based measurement. However, the wind power has developed so fast in recent years that proper protection may have to be introduced apart from the basic requirements.

1.1.14 Start and stop scenarios [108-115]

Great concerns should be given to the system components namely the turbine, generator and drive train during the starting dynamics of wind turbines. The system transient during the starting period e.g. the hazardous torsional torques will damage the shaft connecting the wind turbine and generator. The pitch control both helps to catch the wind at the optimal angle of attack of the blade's airfoil and to turn the blades out of the wind when maximum speed is exceeded. The relevant performance should be investigated.

1.2 Tests at a wind farm level

1.2.1 Virtual wind farm

A virtual wind power system may mainly consist of the wind turbine simulator, drive motor, wind power generator, control devices and grid simulator.

1.2.1.1 Wind turbine simulator [116-119]

Simulations of wind turbine drive system are mainly focused on two fields: aerodynamics and the mechanical drive chain systems of wind turbines. More detailed component models by separately considering the units in the drive train system are the present concerns.

1.2.1.2 Grid simulator related literature [120-126]

Grid simulators are used to simulate the normal operational characteristics as well as the faults on power grid. The faults in grids result in the abnormality of the voltage, frequency, harmonics, depending on the short circuit capacity of the power transmission system, may be interacted with the active power, reactive power, voltage control and frequency control and protection strategies of wind power plants. Nowadays, the power grid could be simulated with power electronics, by controlling the power converters, various methods are achievable to simulate all kinds of grid faults, such as frequency variation, voltage dips and swells, flickers, voltage unbalance, harmonics, resonances etc.

1.2.2 Operational tests on SCADA and SCADA-interface systems [127-136]

Supervisory control and data acquisition (SCADA) systems usually refer to centralized systems which monitor and control entire sites, or complexes of systems spread out over large areas (anything from an industrial plant to a nation). Most control actions are performed automatically by Remote Terminal Units ("RTUs") or by programmable logic controllers ("PLCs"). Host control functions are usually restricted to basic overriding or supervisory level intervention. In this area, security issues and functions coordination and data exchange of distributed application system in different location are of most concerns. The test on SCADA and SCADA-interface systems would be one of the most important features.

1.2.3 Compensation equipment [19, 23, 137-142]

Compensation equipment including capacitors, SVC and STATCOM plays an important role in the integration of wind power plants. The developed test facility would provide tests ability on the var compensation ability in real power systems.

1.2.4 Wind Power Plant Controllers [92, 143-148]

Many wind power plant controllers including pitch controller, DC-link voltage control for DFIG and PMSG, maximum wind energy tracing controllers are needed for the steady operation of wind power generation. By measuring and calculating the related data, the grid-connection characteristics of wind power plants can be evaluated.

1.2.5 Varying Grid Strengths [103, 149-155]

Stability and power quality issues are quite different under varying grid strengths. The grid-connection characteristics of wind power plants could be testified under different short-circuit capacities.

2 Technical concepts for the Test Facility

Nowadays simulation tools are often used to investigate the system. With a real power network and test facility, the test results will be more reliable for the steady and safe operation of the wind power plants and the integrated power system.

Ideally, the developed test facility could be used at two levels i.e. the test of a single wind turbine level and the test of a wind farm level.

The test facility would be related with modern power electronics equipment which could provide the good flexibility and controllability, also appropriate reactive power compensation might be necessary.

The test facility may do operational tests on SCADA and SCADA-interface systems. Since SCADA plays an important role in controlling center operators and maintaining adequate situational awareness. The integration of the test results to SCADA-interface systems would effectively provide more efficient operation of modern power system with large wind power penetration.

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