Final report

1.1 Project details

Project title	Voltage control on the transmission grid using wind power at other voltage levels (VOLATILE)
Project identification (program abbrev. and file)	ForskEL Project nr. 2016-12486
Name of the programme which has funded the project	ForskEL programme
Project managing company/institution (name and address)	Department of Electrical Engineering, Technical University of Denmark Ørsteds Plads, Building 348, Kgs. Lyngby, DK 2800
Project partners	Royal Institute of Technology (KTH), Sweden Vattenfall
CVR (central business register)	30060946
Date for submission	

1.2 Short description of project objective and results

English Version
In a power system there is a need to keep a good voltage. This is often done by using the synchronous generators in the power plants connected to the transmission system. With large amounts of solar and wind power enters the system, then the amount of these centrally power plants will decrease. The question is then how to keep the voltage.
The volatile project is to use wind power stations on other voltage levels to keep the voltage on the transmission level. Methods concerning controller design, communication and parameter setting will be combined with impact studies on real networks in order to estimate the possibility to implement this option.
The project results consist of OPF algorithm of power systems with hybrid AC/DC grids and wind power, coordinated voltage control of wind power plant with HVDC connection, and evaluation of coordinated var/volt control of the Kriegers Flak project.

Danish Version
Det er nødvendigt at opretholde et passende spændingsniveau i elnettet. Dette er oftest gjort gennem kraftværkers synkron generatorer koblet til transmissions nettet. Med integrationen af store mængder af sol- og vindenergi i elnettet, falder mængden af centrale kraftværker. Deraf kommer spørgsmålet om hvorledes man kan opretholde spændingsniveauet.
Volatile projektets mål er at bruge vindfarme, forbundet til lavere spændingsniveauer i elnettet, til at styre spændingen i transmissions nettet. Metoder vedrørende regulator design, kommunikation og parameter indstilling kombineres med studier af indvirkningen på virkelige netværk, med det mål at kunne estimere mulighederne for at implementere en sådan løsning.
Projektets resultater består af en OPF algoritme til udregning af elnet, der indeholder hybride AC/DC netværker og vindenergi, en koordination of spændingsregulering af vindfarme med HVDC forbindelser samt en evaluering af koordineret var/volt regulering af Kriegers Flak projektet.

1.3 Executive summary

The volatile project is to use wind power stations on other voltage levels to keep the voltage on the transmission level. Methods concerning controller design, communication and parameter setting will be combined with impact studies on real networks in order to estimate the possibility to implement this option.

The project results consist of OPF algorithm of power systems with hybrid AC/DC grids and wind power, coordinated voltage control of wind power plant with HVDC connection, and evaluation of coordinated var/volt control of the Kriegers Flak project.

The project results will be used as background knowledge for the Multi DC project supported by the Innovation Fund. The results of the var/volt control scheme for the Kriegers Flak project will be used in the master controller of the project.

1.4 Project objectives

Wind power has grown strongly in recent years. For Sweden nuclear power will be phased out during the coming decades, which causes a need of new generators such as wind energy. In Denmark and other countries large amounts of wind power is currently in operation and it is expected that the amount will increase significantly.

In a power system there is a need to keep a good voltage. This is often done by using the synchronous generators in the power plants connected to the transmission system. With large amounts of solar and wind power enters the system, then the amount of these centrally power plants will decrease. The question is then how to keep the voltage.

The objective of the VOLATILE is to use wind power stations on other voltage levels to keep the voltage on the transmission level. Methods concerning controller design, communication and parameter setting will be combined with impact studies on real networks in order to estimate the possibility to implement this option.

The project was conducted by collaborating with KTH, Vattenfall and Energinet. The work in Denmark is focused on the voltage control of power systems with wind power connected by both AC and DC connections. Both theoretical and engineering work was carried out for voltage control of AC/DC grids with wind power.

The work started by reviewing the grid code requirements on var/volt control of wind power plants and voltage control methods. The communication infrastructure for voltage control was also reviewed.

The coordinated voltage control algorithm was developed for offshore wind power plants with HVDC connection. The consensus protocol based communication network was used for the coordinated control to realize distributed control. Model predictive control was used to optimize the set-points taking into account the uncertainty of wind power.

The coordinated var/volt control of the Kriegers Flak project was tested with many scenarios of the offshore grid and power exchange with the German side. The parameters settings were also tested to analyse the impact of parameterization on the dynamic performance of the control scheme.

The project evolved according to the project plan. There were no specific risks encountered during the project.

1.5 Project results and dissemination of results

The project results consist of 4 parts, i.e., voltage control methods, cost of different voltage support sources, communication infrastructure for different voltage control methods, and controller design.

1.5.1 Voltage control methods

This section will Report on voltage control method implemented in reality and grid codes.

Most of the transmission system operators (TSO) and distribution system operators (DSO) have started implementing regulations regarding the voltage control using distributed generation (DG). This process is not going fast. Its speed is mostly correlated with the increase of DG penetration in the system. From analyzed grid codes, it can be seen that the approach is still following conventional voltage control strategies. These strategies have similar form of Automatic Voltage Regulators (AVR) installed in big synchronous generator units in the system.

Regarding the grid owners, regulations related to voltage control differ. In this report, couple of grid codes are analyzed with respect to the voltage control and reactive support from the distributed generation (wind power plants).

A. Svenska Kraftnät, Sweden

In the development plan of Svenska Kraftnät [1] for period 2016-2025 it has been identified that the decommissioning of Nuclear power plants and shifting of power generation to underlying networks will produce a lot of problems regarding voltage control. For now, there are no strict regulations that define this area although it is expected that there will be some in the future.

Exchange of reactive power between the transmission grid and distribution grid is said that it should be set to zero. It is expected that this requirement will be subject to change in the future.

B. Vattenfall, Sweden

Swedish DSO Vattenfall have very limiting rules regarding use of wind farms for the reactive power provision and voltage control in the grid. The request is that the reactive power from these sources should be kept at zero. In other words, the wind power plants should operate at unity power factor. But, for other DG (small hydro, thermal, etc) it is said that they should be able to regulate their reactive power up to +/-30% of their nominal active power. According to this and improved reactive capabilities of wind turbines, it is expected that the code [2] will change involving the wind power plants in the voltage control in the future.

The voltage control strategy in the Vattenfall grids is also conventional. The voltage setpoints in the grid are adjusted manually from the dispatch center. Then this setpoints have to be reached by the local controllers which usually have the form of the classical AVRs.

C. ESB Network, Ireland

Ireland distribution system operator includes participation of wind turbine generators for voltage control and reactive support. According to their code [3], DG can choose to control voltage, reactive power or power factor. The choice of the control mode is dependent on the size of the generating units and connection type. Furthermore, the range in which the DG should keep their power factor is defined. Depending on the connection type and generator size it can vary between 0.95 and unity or 0.92 and unity power factor.

The maximum response time of the voltage controller is defined to be not more than 20 seconds.

The code does not explicitly define the type of the voltage controller. But, from the requested parameters of the dynamic model it can be seen that the controller should be of the droop or purely proportional controller type (typical control used in AVR).

Currently, reactive power market is being developed in Ireland, highlighting the importance of our project.

D. National grid, United Kingdom

The TSO of United Kingdom, National Grid, defines generating sources as synchronous (directly coupled with the system) and non-synchronous (not directly coupled). According to this definition, wind farms belong to the second category. It is said in the grid code [4] of this TSO that the second category generating sources should be able to supply rated active power with the power factor ranging from 0.95 lagging to 0.95 leading at the onshore grid entry point. Furthermore, it has been stated that the level of the reactive power limits defined for the rated power and 0.95 leading power factor should apply for all the active power outputs above the 50% of the rated power. For the active power outputs below the 50% of the rated power, reactive power limits should linearly decrease.

The code differs for the onshore and offshore power plants. Previously stated is applying for the onshore power plants. In the case of offshore power plants, it is stated that the reactive power exchange at the offshore grid entry point should be kept at zero.

Voltage control in the grid is achieved in the same matter described for the previously mentioned grid operators.

E. bdew, Germany

This German DSO has a similar code [5] like the other mentioned DSOs. It requests that all the generating plants should be able to work in the range of 0.95 lagging power factor to

0.95 leading power factor. Additionally, it is stated in their code that the plants should be able to keep the voltage on its terminals in the range from 0.9Un to 1.1Un, where Un is the nominal voltage of the grid. Accordingly, the reactive power capability curve is represented in U(Q) diagram.

F. Summary of Voltage Control

The grid codes of TSOs and DSOs are gradually adopting the regulations that will allow reactive support and voltage control from the wind power plants. As a driving force, reactive power markets are also developing in parallel confirming the importance of the topic.

Voltage control strategies implemented in the realty are mostly based on the conventional AVR design. This design represents basic proportional controller or as it can be seen from the different perspective, a droop controller. It is identified that more advanced control strategies will need time to prove their reliability and applicability to the real systems. Consecutively, the industry partners will need time to gain confidence in them. Therefore, future studies on new methods of controlling the voltage will have to be done and be confirmed on numerous case scenarios representing the real situations in the grids.

1.5.2 Costs of different voltage support sources

In this section, the costs of different voltage support sources are reviewed.

A. Voltage support by capacitors

Capacitors are passive reactive power support sources. The amount of the reactive power supported by a capacitor is depending on its terminal voltage. This is a disadvantage as the reactive power support capacity is decreased when it is needed the most. The advantages of capacitors for voltage support are their reliability and low costs.

The cost $/kVar of capacitors is decreasing as the size goes up. According to [6], the cost of a capacitor for reactive power support is related to its size by the following equation,

$$y(x) = 194.69 + 11.000x - 0.004x^2 . \quad (1)$$

For example, for a capacitor with 50 kVar size, the average cost is about 13 $/kVar.

B. Static Var Compensator (SVC)

Static var compensators (SVC) are dynamic voltage support sources. SVCs consist of shunt capacitors and reactors connected to the grid via thyristors. one disadvantage is similar to capacitors, i.e., the support capacity is decreased as the voltage goes down at the terminal. An advantage of SVCs is that they can respond to the voltage problems very quickly.

The average cost for SVCs is around \$30 ~ \$50 per kVar [7].

C. Static Compensator (Statcom)

Static compensators (STATCOM) are power electronics based dynamic voltage support sources. They use IGBTs to convert DC voltage to AC voltage and vice versa. The reactive power generated (or consumed) by STATCOM is through the switching of IGBTs. The response of STATCOMs is in mirco seconds, which is thousands of times faster than SVCs.

The average cost of STATCOM is 55~70 $/kVar [7].

D. Dynamic VAR

A dynamic VAR (D-VAR) system [7] is an advanced STATCOM. A D-VAR has a specialized software to control reactive power outputs in sophisticated ways under different voltage situations. An important advantage of a D-VAR is that it can overload up to 3 times of its rating power for a few seconds. Thanks to this advantage, a D-VAR can prevent different voltage caused system failures, such as voltage collapse, unexpected loss of loads and voltage stability issues.

The average cost of D-VAR is from 80 to 100 $/kVar [7]. And the cost decreases as the size goes up. Its size can be 2 MVA up till 100 MVA.

E. On Load Tap Changer

OLTCs are normally installed on HV-MV transformers. OLTCs themselves are not very costly; however, the maintenance cost is high. The usual lifetime for traditional OLTCs with contacts in oil has guaranteed 500,000 operations times [8]. For new OLTCs based on vacuum switches can have a lifetime up to 2 million operations.

1.5.3 Communication structure for different voltage methods

A. Power System Voltage Control with the Hierarchical Model – High level communication structure

Traditionally the voltage control of a power system was predominantly manual. It was done by setting the voltage set-points of the large power plants. The voltage profile was following the main generators, depending on the loads and the properties of the grid. To keep the system's stability the grid components where over dimensioned. In this way the transfer limit utilization was low, so that a sufficient safety margin for fluctuations and contingencies was given. However, this method is obviously expensive.

The main possibilities to influence the reactive power in the system are traditionally the manual switching of capacitors and reactors as well as OLTCs. If one considers the speed, changes happen in consumption or renewable energy generation, a manual operation seems quite slow and suboptimal. Also, the reactive power flow in a system is sensible against changes. In case of dangerous situations like faults or overloading, a regulation by hand could be even risky.

Besides the good opportunities to integrate WPP and HVDC lines into the power system's voltage control (VC), there are several advantages by using a hierarchical model. Some are mention in, where this coordinated, automatic, wide area voltage control is suggested:

- Less fluctuation of predefined voltage profile
- enlarged var reserves in emergency situations for a better system security
- less reactive power flow for more active power capacity
- lower risk of voltage instability and collapse
- active loss minimization thanks to reduced reactive currents
- the var sources can be better utilized
- ancillary services better controllable and measurable (market opportunities)

The concept of the hierarchical model is shown in Fig. 1. It is organized in three levels of system voltage regulation. An outer loop is taking a picture of the steady state with a State Estimation, SE. This information is handed to an OPF, which determines the optimum set-points. They are again forwarded to the highest level of VC.

The three levels are overlapping and closed control loops. They are decoupled through the speed of their dynamics. The primary level is the fastest one. The time constants of the controls are longer at the secondary level. Finally, the last one is also the slowest loop. Furthermore, they are separated spatially. From the control of the local bus at the lowest to the complete system at the tertiary level.

The primary level is also called primary voltage regulation, PVR. It controls the local bus voltages of synchronous generators and other VAR sources. The reactive power injection is managed by a closed control loop to keep the voltage at the defined value. These set-points are received from the secondary voltage regulation, SVR. Since it is the fastest control, its time constants are usually less than one second. An example of PVR is the AVR of a power plant.

As explained before VC is a local problem. Therefore, reactive power needs to be coordinated decentralized in a region. This is done at the secondary level or secondary voltage regulation. A control area is defined as strongly electrically coupled.

The strength of a bus is proportional to the short-circuit capacity, SCC. The SCC is defined as the maximum apparent power that can flow from the node into a zero-impedance fault at balanced 3-phase conditions. A strong bus has a high ability to maintain its voltage. As an example, the voltage at a Node with an infinite SCC would not change under all conditions. A strong electrical coupling means, that if the voltage changes at one bus, the voltage at the buses coupled to it would follow with only small deviations.

This will say that the strongest bus in a strongly coupled area can represent the voltage situations of the area. These buses are called pilot bus. The task of the SVR is to maintain the voltages at the pilot buses. The reference values are received from the tertiary level. This is done by setting the PVR set-points and by controlling the tap-positions of the OLTCs. The time constant of this control level is within 10 to 100 seconds.

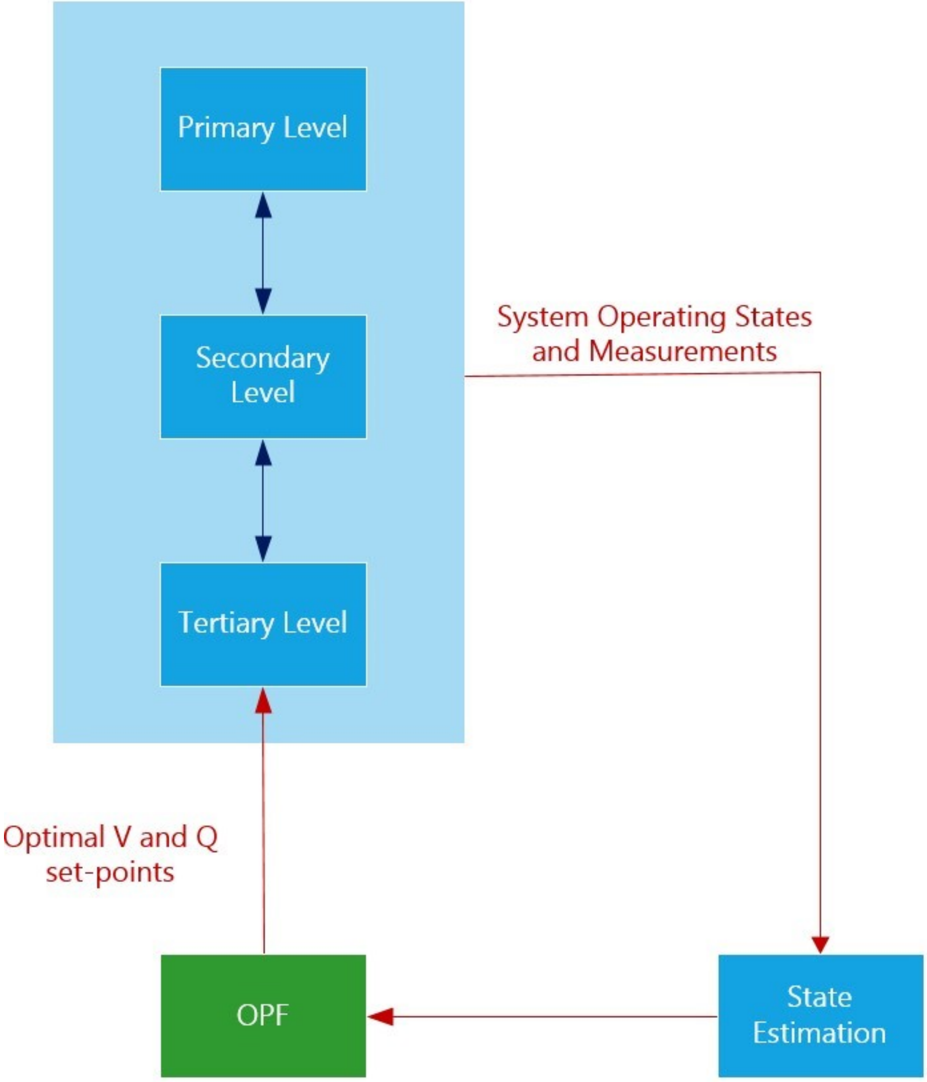

Fig. 1 Concept of the Hierarchical Model

The idea of the tertiary voltage regulation is to maintain the system-wide voltage profile at the optimum level. While controlling the reference values of the pilot nodes in the SVR zones, it coordinates the inter-area efficiency. Furthermore, capacitor banks are switched on and off on a daily basis. The time constant for the control loop is around 5 to 60 minutes. With TVR, the voltage stability and var margins can be maximized and transmission losses reduced. This is done by decreasing the tie-line var flows between the regions and by a reduced area boundary voltage difference. The best possible voltage profile is obtained by adapting the pilot node voltages to a forecast plan from an OPF.

To adapt the optimum reference values to the actual grid conditions, the system operating states and measurements are processed by a SE and forwarded to an OPF algorithm. It uses the real grid topology, the active and reactive power demand at the loads, the scheduled power production at conventional power plants and the generation of the renewable sources. As outcome the optimal set-points for voltage level and reactive power production are provided to the TVR. An optimal solution would be a real time OPF. However, the SE, which is delivered in minimal 5-minute intervals is not fast enough compared to the control dynamics.

B. Distributed cooperative voltage control for wind farms - Lower level communication structure

The typical structure of a wind farm with 20 WTs is illustrated in Fig. 2. The wind farm as shown in **Fejl! Henvisningskilde ikke fundet.** with 20×5 MW full-converter (FC)-WTs and $1 \times \pm 20$ MVar STATCOM is considered. The WTs are connected by three 33 kV feeders and placed with a distance of 1.5 km between two adjacent WTs. The STATCOM is placed at the MV side of the main transformer to provide reactive power support for the wind farm. For simplification, the set of reactive power source including WTs and STATCOM are denoted together by the set I. All WTs and STATCOM should be cooperatively controlled to achieve the following objectives.

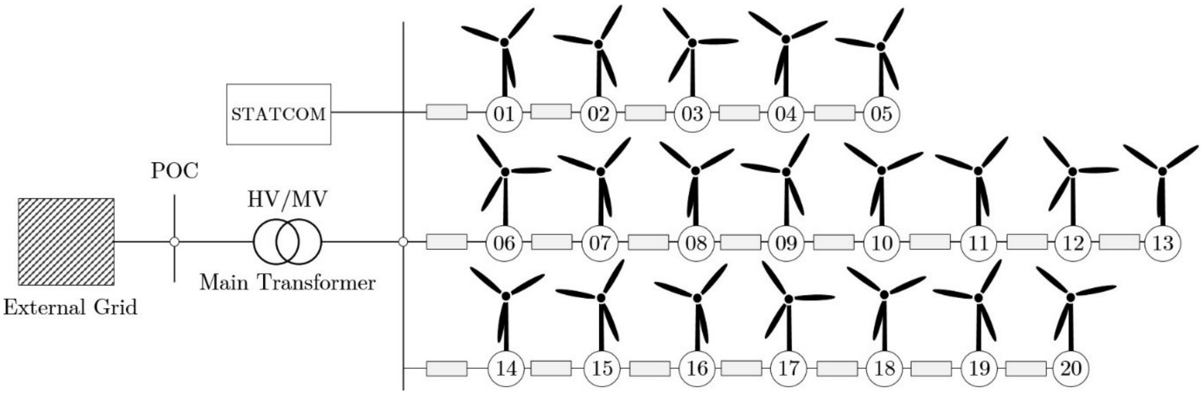

Fig. 2 The typical structure of a wind farm.

The structure of the control system is illustrated in Fig. 3. The $Q - V$ droop control is designed as the primary voltage control only based on the local information, which can provide fast reactive power support under emergency conditions. Each WT directly regulates its own terminal voltage and the voltage at the POC is directly regulated by the STATCOM. The secondary voltage control is developed based on the distributed averaging-consensus protocol. In the secondary control, each unit only exchanges information with their immediate neighbors. The secondary controller generates an additional incremental control command q to the primary controller.

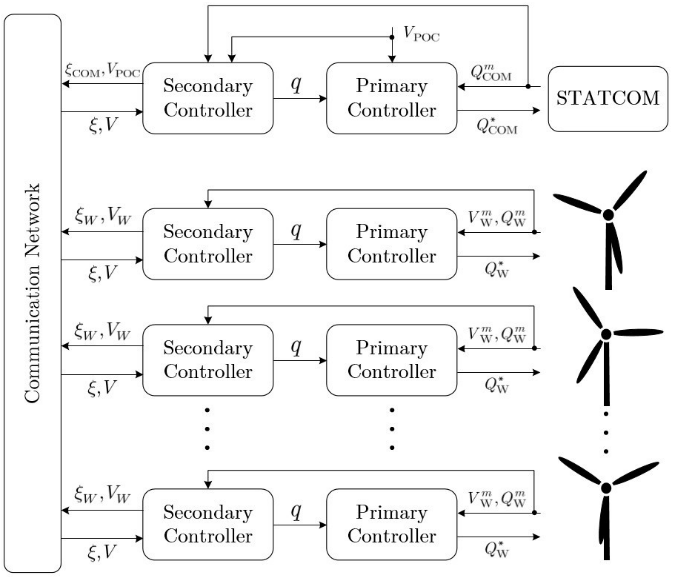

Fig. 3 Structure of the proposed distributed cooperative voltage control strategy.

As mentioned above, the basic requirement of the communication network is that the graph must be a connected graph, i.e., there must be a path in the communication graph between any two nodes. Moreover, to enhance the robustness of the communication network, all the possible $N - 1$ scenarios are considered in the communication network design. Hence, firstly, the network design problem can be transformed into a minimum spanning tree problem and can be solved by the Prim algorithm. The geographic distance between any two units is considered as the measure of the communication construction cost. Accordingly, based on the wind farm configuration in Fig. 2, the communication network topology is illustrated in Fig. 4. In this graph, in addition to the minimum spanning tree, two extra communication links $(05,13)$ and $(12,20)$ are designed to guarantee the $N-1$ principle.

Similar to the automatic generation control of bulk systems, the secondary voltage control of a wind farm is to compensate the voltage deviations as shown in Fig. 5.

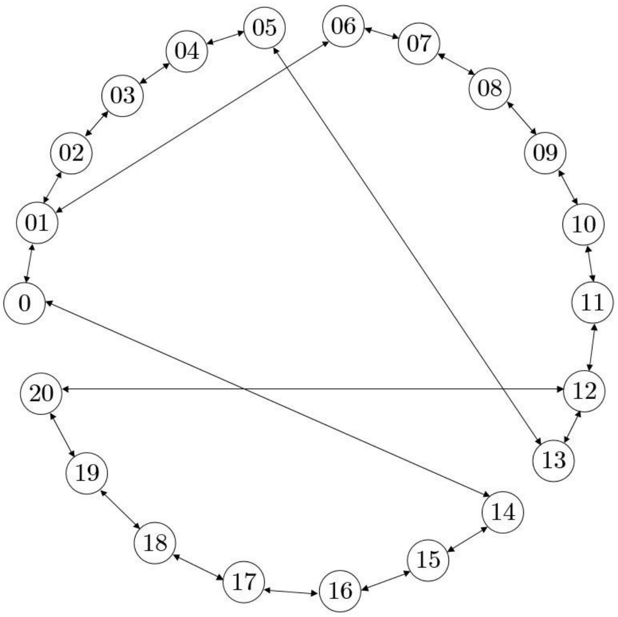

Fig. 4 Topology of the communication network. (The STATCOM is numbered by the Node 0 and WT01–WT20 are sequentially numbered by the Node 01–Node 20.)

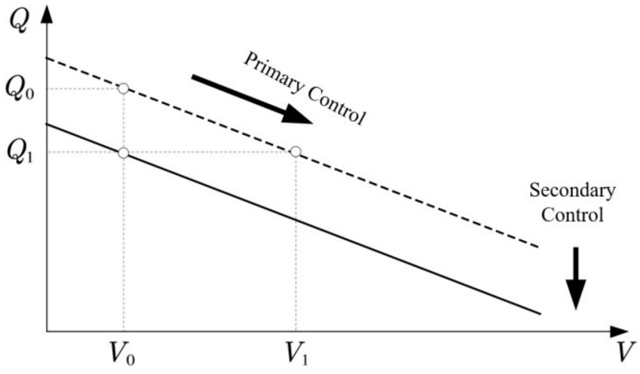

Fig. 5 Schematic diagram of primary and secondary voltage control.

Hence, a consensus-based secondary voltage control is implemented by adding the control input $q_i, \forall i \in \mathrm{I}$, to the primary droop controller. $Q^m{}_i$ is the measured reactive power output which is obtained through the low pass filter with the time constant of τ_m.

C. Distributed Coordinated Active and Reactive Power Control of Wind Farms – Lower level communication structure

The typical structure of a wind farm is shown in Fig. 6. Each WT is equipped with a distributed WT controller and a sparse, connected communication network is designed for the distributed power control scheme.

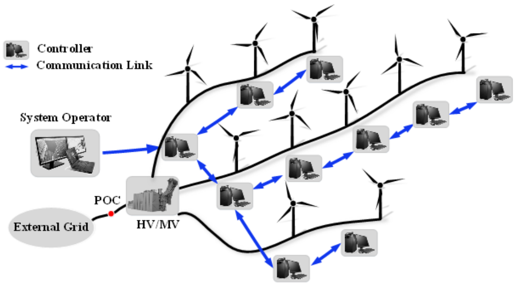

Fig. 6 Structure of a wind farm with distributed controllers.

The configuration of the proposed distributed coordinated power controller (DCPC) is illustrated in Fig. 7. The total available power of the wind farm is estimated by the distributed estimator which is executed every few seconds. The global reference information including the bus voltage reference V_{ref}, wind farm power reference P_{dem}, and voltage at POC V_{POC} are estimated by the distributed finite-time observers. The sensitivity coefficients of bus voltage with respect to power injections are given to each DCPC. For the sensitivity calculation, one option is to use offline power flow analysis and keep constant, which may lead to significant errors. Another option is updating the sensitivity in every control period, whereas it may lead to heavy computation and communication burden. Thus, considering the operation states cannot dramatically change in a short term, the sensitivity coefficients are updated with low frequency (in minutes) in this study. It is expected that the close-loop nature of MPC will compensate the infrequently updated sensitivity coefficients.

The schematic diagram of the D-MPC is shown in Fig. 8. The objective of the D-MPC for wind farms includes two parts: 1) active power dispatch; and 2) reactive power/voltage control. For active power control, the controller minimizes the fatigue loads of WTs while tracking the power demand of the wind farm required by system operators. Considering the larger grid inertia, small deviations are acceptable in the wind farm-wide power output. Thus, the power demand is considered as a soft constraint and explicitly expressed in the objective function. For reactive power control, the voltage at POC and terminal voltage of each WT are all taken into consideration. In addition, the reactive power sharing is also considered. To better regulate the voltages, the predicted active power variations on voltages is considered.

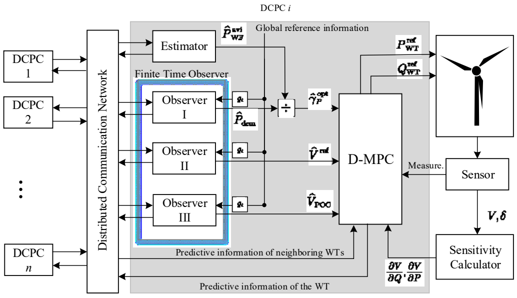

Fig. 7 Distributed coordinated active and reactive power control scheme.

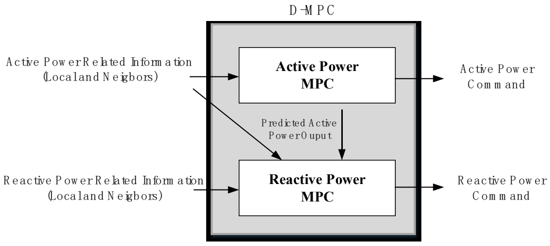

Fig. 8 Schematic diagram of the D-MPC .

A possible communication links is shown in Fig. 9 as an example of the low level communication structure.

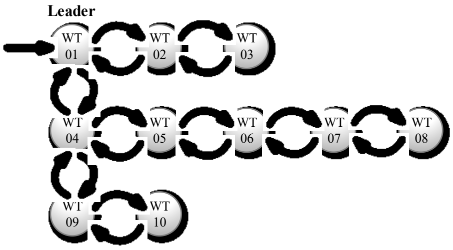

Fig. 9 Communication links of the WTs.

1.5.4 Controller Design

Traditional voltage control in the grids is based on automatic voltage regulators (AVR). These regulators are designed as simple droop controllers. Besides the common practice in industry, a lot of innovative control strategies have been proposed by academic community. Depending on their design, the control methods require different level of communication network complexity. From that point and the point of their design they can be divided into four groups:

Local, non-coordinated voltage control

This control strategy doesn't need any advanced communication network. The voltage control is based on the local measurements. The parameters of the controllers can be set in the offline optimal power flow analysis for different case scenarios.

Local, coordinated voltage control

As a difference to the previous group, these control strategies are using combination of centralized and local control strategies. The central controller supervises the actions of local controllers and in relatively large time intervals adjusts the parameters and set-points of the local controllers. These control methods required more complex communication infrastructure than the first ones.

Centralized voltage control

In the literature, these methods are also known as full-smart grid methods. The central controller performs remote control actions in the real time in this case. The control actions are derived from the available remote measurements in the grid using usually optimal power flow algorithms. Because of the nature of this control, it requires the most complex communication infrastructure among all the methods.

Multi agent voltage control

These methods are based on multi-agent control strategies and distributed control. They usually require communication links between each two neighbouring nodes of the system (agents).

The work in the VOLATILE project has included identification of control boundaries with respect to the grids physical and operational limits. Identification of control boundaries is very important step in the design of efficient and reliable voltage control strategy. The results have shown that the coordination of different elements of the grid is of the great importance if the most efficient and reliable voltage control is to be obtained.

1.5.5 Dissemination of Results

The dissemination of the project results includes,

- Organizing a workshop with industry partners
- Attending 4 conferences to present the results from the project
- Publishing and submitting 6 journal papers
- Delivering 5 master theses
- Delivering 1 PhD special course report

Workshop

Reactive Power Management Workshop – Possible Support to TSO from DSOs with Wind Power
Oct. 30th 2017
Organized by KTH, EECS
Participants, DTU Elektro, DTU Wind Energy, Vattenfall, e.on, ElLEVIO, SVENSKA KRAFTNAT

Conferences
2017 4th International Conference on Power and Energy Systems Engineering (CPESE 2017), Berlin, Germany, Sept. 25-29, 2017
2017 IEEE Innovative Smart Grid Technologies – Asia (ISGT-Asia), Auckland, New Zealand, Dec. 4-7, 2017
16th Wind Power Integration Workshop, Berlin, Germany, Oct. 25-27, 2017
2018 IEEE PES General Meeting, Portland, OR, USA, Aug. 5-9, 2018

Journal papers

1. S. Huang, Q. Wu, Y. Guo, and X. Lin, "Bi-Level Decentralized Active and Reactive Power Control for Large Scale Wind Farm Cluster," *International Journal of Electrical Power and Energy Systems*, submitted.
2. S. Huang, Q. Wu, Y. Guo, X. Chen, B. Zhou, and C. Li, "Distributed Voltage Control Based on ADMM for Large-Scale Wind Farm Cluster connected to VSC-HVDC," *IEEE Transactions on Sustainable Energy*, submitted.
3. Y. Guo, H. Gao*, Q. Wu, H. Zhao, and J. Østergaard, "Coordinated Voltage Control Scheme for VSC-HVDC Connected Wind Power Plants," *IET Renew. Power Gener.*, in press.
4. V. Akhmatov, Q. Wu, and T. Takarics, "Reactive power and voltage control interaction and optimization in the Danish largest wind power plant at Kriegers Flak," Journal of Physics: Conference Series, Vol. 1102, pp. 1-11, 2018.
5. D. I. Döring, D. Dhua, S. Huang, and Qiuwei Wu, " Voltage Support in Hybrid AC-DC Grid by Wind Power Plants and VSC," International Journal of Electrical and Electronic Engineering & Telecommunications, Vol. 10, No. 4, pp. 165-171, Oct. 2018.
6. D. Dhua, S. Huang, and Q. Wu, "Optimal Power Flow Modelling and Analysis of Hybrid AC-DC Grids with Offshore Wind Power Plant", *Energy Procedia,* Vol. 141, pp. 572-579, Dec. 2017.

Conference papers

7. V. Akhmatov, Q. Wu, A. Kotsonias, and J. M. Røge, "Parameterization and Dynamic Analysis of Coordinated Voltage Control for Offshore Wind Power Integration," in Proc. Wind Power Integration Workshop 2017.
8. D. Dhua, S. Huang, and Q. Wu, "Load Flow Analysis of Hybrid AC-DC Power System with Offshore Wind Power," in Proc. ISGT Aisa 2017.

Master thesis

9. Tibor Takarics (ongoing), Evaluating robustness of overall reactive-power and voltage control using Wind Power Plant Controllers and AVR/RPC at Kriegers Flak
10. Bo Duan (2018), Transmission Grid Voltage Support through Wind Power at Other Voltage Levels
11. Rafael Calpe Domens (2017) Coordinated Voltage Control of Offshore Wind Power and Multi-Terminal DC Grid
12. Andreas Kotsonias (2017) Reactive Power and Voltage Controller Parameterization for Kriegers Flak O˙shore Grid with Wind Power
13. Jeppe Meldgaard Røge (2017) Reactive Power and Voltage Controller Parameterization for Kriegers Flak Offshore Grid

PhD Special Course Report

14. Alessandro D'Ambrosio (2018) Modeling of Kriegers Flak Offshore Grid in Real Time Digital Simulator (RTDS)

1.6 Utilization of project results

The project results will be used as background knowledge for the Multi DC project supported by the Innovation Fund. The results from the collaboration with Energinet will be implemented in the real coordinated var/volt control of the master controller for the Kriegers Flak project.

1.7 Project conclusion and perspective

In the future power systems with high penetration of wind power, specially in Denmark, it will be essential to use the var/voltage control capability of wind power plants to maintain good voltages in the whole system. It is very important for the secure operation of the power system.

In the future Danish power system, there will be more offshore wind power. The connection to the in-land could be a combination of AC and DC grids. It is important to coordinate all the var resources including the wind power plants, DC stations, and other var resources in order to optimize the var allocation among them and maintain sufficient fast var margin to handle disturbances in the system.

Model predictive control is a good tool for the var/voltage control of the power systems with wind power. It can determine the current set-points taking into account the situations of the future steps. It can mitigate the voltage fluctuations in the system and keep sufficient fast var resources to handle disturbances.

1.8 References

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Annex

Relevant links