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Training for power system performance with distributed wind power generation

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Abstract: The performance of power supply systems is significantly influenced by large amounts of wind power generation. Control centre operators of transmission and distribution systems have to cope with unpredictable generation, rapidly changing power flows, an increase of voltage problems and have to be trained to the occurring phenomena to maintain the system's security in order of reliable power supply. For this reason an operator training simulator has been upgraded to model in operational detail the influence of distributed wind power generation. The simulator has proven its capability in diverse operator training courses and gives realistic insight in the performance of the power system and allows to develop and train new operational strategies in how to cope with today's challenges of power system operation.

Key-words: Distributed Generation – System Operation – Operator Training – Training Simulator – Training Courses

1 Operating power systems with high amount of distributed wind power generation

Distributed generation, from the viewpoint of electric power system operation, is connected to occurrences such as

- unpredictable in feed power (especially in the case of stochastically operating regenerative sources)
- unaccustomed power flows
- problematic voltage profiles

While these effects are inevitably dominating the operation of small and detached power systems, in consideration of the installation of very large wind farms they also get increasing significance for large transmission systems. In countries like Denmark and Germany where the use of renewable energy sources is highly subsidised the amount of especially wind power is rapidly increasing, reaching values which notably impact the operation of the power system on all voltage levels. System operators and regional transmission operators are facing new operational challenges to cope with this situation.

From operational point of view experience shows that these unpredictable power sources can impact the way of

- managing reserve power,
- online generation adjustment and system balancing,
- dealing with unusual fast changing power flows combined with critical overloads,
- handling voltage profiles with limited MVAr sources,
- disturbance handling and emergency management.

The possibilities to handle these problems in the phases of operational planning and explicitly during real time operation of the power system are limited:

- During the phase of **operational planning** it is difficult to **prognosticate** the yield of available wind power energy sources
- During **online-operations** there is a lack of information in the control centres. Usually no online measurements are available for wind power infeeds at the medium/low-voltage levels. At the high voltage level measurements are available depending on the size of each particular installation (e.g. Offshore wind farms).
- **Short term analysing** and adjustment is limited due to the lack of information and the lack of control possibilities.

The technical performance of the power system changes, too. Wind converters may have a different reactive power performance compared to synchronous generators usually used in conventional power plants.

Additionally the configuration of the grids is changing with implementation of large scale wind power infeeds:

- HVDC-Installations are used to connect wind farms to the grid,
- in order to cope with problematic voltage profiles compensation devices such as static var systems (e.g. SVCs) are installed,
- in smaller systems energy storage systems are installed.

To cope with these new requirements operators of the control centres have to be trained to handle the impacts of wind power generation in order to guarantee a secure and reliable power supply [1]. A full scale operator training simulator has been upgraded and extended

- to demonstrate the occurring phenomena of wind power generation,
- to train control centre operators with regard to handle these phenomena and
- to study new operational strategies and new system equipment performance as well

in the control centre's time frame, i.e. SCADA system time resolution. The extended Training simulator has proven its capability in a number of training courses which were performed for control centre operators from system operator's and regional control centres' level [2].

2 Operator's training simulator adopted and extended to fit new training requirements

2.1 New Training Requirements

During the last decade a lot of experience regarding operator training in more than 200 training courses with over 1000 participating operators from all levels of system operation has been generated. The increase of wind power generation forces to adjust the topics and the contents of courses regarding ongoing operator training. Additionally the existing OTS has to cope with the new training requirements to ensure the quality of the training. The objective of the courses is to get the control centre operators acquainted with the operational performance of wind power generation embedded in an electricity supply system under real time conditions covering the 'normal' system state and the 'abnormal' system states as well. This requires to model the performance of wind power generation on a detailed level exceeding the representation as a simple injection model.

Distributed wind power generation is highly fluctuating, dependent on the current wind speed at each single wind converter. So the need for a new wind speed model arises in addition to required models for the conversion of wind energy into electrical power. Due to the fact, that the wind speed within the geographical area covered by a power system is usually locally different, the wind speed model implemented has to handle these local differences. It has to provide individual real-time wind speed values for each location of wind power generation. Further more it is necessary to propagate geographically limited gusts in defined areas of the power system.

In addition the interaction of wind power generation in combination with a 'conventionally' controlled power system (e.g. power/frequency control, adjustment of voltage profiles using reactive power, etc.) forces to model 'conventional' control opportunities for wind power generation also.

Adequate operational diagrams and surfaces have to be provided to display the information of the wind power infeeds and to allow control interactions initiated manually by the operators or automatically by 'conventional' equipment (e.g. automatic generation control). This of course requires to a certain extend that wind power infeeds are under remote control of the control centre. This is in most cases of course beyond today's design of wind power infeeds. Most infeeds are designed to deliver maximum active power output without taking care of the frequency balancing and the maintenance of voltage profiles respectively the MVAr household. Having the above mentioned requirements in mind the extended OTS is capable

- to demonstrate the influence of wind power generation on the conventional power system,
- to train operators to the real time phenomena within the operational time frame,
- to give operators hands on knowledge and experience in operating power systems with high grade of wind penetration,
- to get operators acquainted with operational strategies and decision making in order to react to the fast changing system conditions caused by large scale wind power generation
- to develop new operational strategies and methods of operation by integrating wind power generation into conventional control schemes,
- to develop new combined control schemes respecting the combination of controllable conventional power production and unpredictable wind power generation.

The extensions which had been necessary to cope with above requirements are briefly outlined.

2.2 Operator's Training Simulator

The extended OTS is able simulate the technical performance of power systems with wind power infeeds, both large scale interconnected system and small island-systems.
Briefly described, the existing simulator (OTS) consists of three principal components:

a) The SCADA environment comprises the process data handling and the operational user interfaces.
b) The power system calculation engine simulates the physical performance of the entire power system under consideration of the actual topology retrieved from the SCADA system and the physical parameters of all embedded equipment.
c) The telemetric line interface is used for the connection of, and the data exchange with, the technical equipment models such as generation units, load performance, switching and protection devices, automatic tap changers, etc..

Additional features of the OTS are:

- Representation of power system control's hierarchical organisation comprising several control centres in parallel.
- Splitting of grid control and generation control each represented in specifically customized control centres.
- Capability of technical equipment models as well as power system calculation engine for both 'normal' and 'abnormal' operational conditions up to system restoration after full blackouts.
- Powerful scenario management.

The comprehensive operational simulation requires an initial data model representing the necessary detail for practical training. Information to be collected in order to parameterise the simulation models comprise data of the grid (SCADA), all conventional and distributed (wind) generation units, interconnections, loads and protection. Furthermore, organisational data and the overall operational control hierarchy (e.g. System Operator, Regional Operator and Distributor) are needed in order to provide the particular individual operational surfaces. The simulator's data model is filled with this information, and the calculation engine is parameterised internally. Subsequent automatic generation of central process database and individual control centre surfaces prepare the simulator for use. All training participants act on an individual replica of 'their' particular part of the total system. The set up of the training simulator also covers the provision of a superior trainer's desk which allows supervising and controlling the complete power system and the control entities modelled as well. The trainer has full insight into all performed actions as well as an overall view on the entire system. Powerful tools for base-case and scenario definition and setting even during the training sessions on the one hand limit the time for training preparation and on the other hand allow 'lively' training sessions by initiating spontaneous events [3].

2.3 OTS extensions

To cope with the new operational challenges caused by distributed wind power generation and new grid devices additional models as well as appertaining control structures were implemented, so that the OTS is able to simulate the power system's performance realistically from operator's point of view. The realised concept provides modular *component blocks* [4] consisting of

- models for stochastic primary sources, e.g. a wind speed model for geographical zones,
- wind converter models (induction generators, doubly fed induction generator, synchronous generators with IGBT-converters) for both single and wind farm installations,
- models for two-point-DC-Transmission system (i.e. from operational point of view - thyristor based converters or VSC-converters),
- models for reactive power compensation devices (SVC, conventional devices as capacitors and coils).

All model components were integrated into the existing OTS environment. Major steps are seen in:

- The process database was extended to be able to supply data to and dump data from the models to the process database.
- The component blocks developed were integrated, making use of the clearly defined interfaces between the OTS and the models.
- The wind speed model was integrated.
- Additional OTS-modules for simulating appertaining control structures and the operational behaviour were implemented (i.e. Start Up process, auxiliary power supply, synchronisation model).
- Basic generator/converter protection features and other controls mechanisms were implemented (e.g. reverse power protection, primary controller, under-/over frequency-protection).
- Finally wind converters DC-transmission converters were considered in the OTS mid-term frequency model.
- The OTS trainer- and user-interfaces were extended to visualize the status and to control the new devices during training sessions.

3 Application of the extended OTS

As mentioned above the extended OTS has proven its capability in a number of training courses so far. Therefore the OTS has been set up with a real existing power system in full operational detail comprising

- a high voltage transmission grid operated by the system operator,
- the connected regional transmission grids operated by a certain number of regional control centres,
- the distribution level with the connected loads,
- the set of conventional power production units connected to the high voltage transmission grid and the regional transmission grids,
- the wind power generation units.

The wind generation units are represented as large scale wind farms feeding into the regional transmission grids and as smaller wind farms or single wind generation units which are feeding into the distribution level.

A complete set of measurements (i.e. P, Q, U, I,) in each single feeder even at the distribution level and all generation bays was added to gain full visibility of the whole power system. Furthermore the OTS was set up in the multi control centre mode to represent the hierarchical operational structure of all participating control centres (i.e. System operator, several regional operators, generation operators). This set up allows to run lively training sessions not only giving the operators insight into the technical performance of the power system but also train the coordination of, and the interaction between the diverse control centres in realistic manner.

3.1 Training scenarios

Within the training courses several scenarios were used covering 'normal' system state and 'abnormal' system states as well. Starting with a scenario representing 'normal' day-to-day operation introduces the sources of the power flows to the operators. Questions arisen were:

- Where are the limits of the power system, and under which circumstances is the system's performance critical?
- What interactions of 'conventional' and wind power sources are required to prevent 'abnormal' system states?
- How to cope with wind power generation in case of emergencies?
- To what extend do the wind power infeeds effect the voltage profiles in the entire system?
- To what extend are devices overloaded?

In the beginning of the scenario the wind power generation was set out of service to get the operators acquainted with the usual power flows of the 'conventional' power system. Due to the replica of the real entire power system under regard operators learn how to handle these power flows in their 'own' system. In the ongoing scenario the wind power generation was increased, first with low gradients, after that with high gradients of wind speed changes. Trying to get answers to the arisen questions above the failure and overload protection modules (e.g. distance and differential relays, over-current relays) of the OTS were set out of functionality in all scenarios. Further the scenarios were run with a constant load profile of the power system, i.e. no load deviations and no use of load curves, in order to maximise the insight into generation and the interrelation of conventional and wind power infeeds.

The extract shown in Fig.1 should give a brief impression of a scenario performed in a training session.

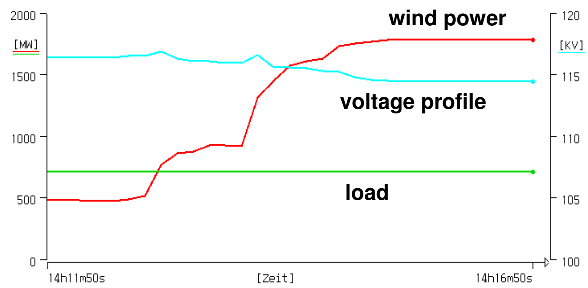

Fig.1 Extract of training scenario

The scenario demonstrated the effect of distributed wind converters on the systems' voltage profile. It dealt with a regional transmission grid, and respectively with the regional control centre's view, with constant load. The wind converters in this region are mainly equipped with induction generators. (Other regions are equipped with doubly fed induction or synchronous generators or a mixed up.) Within five minutes a wind front passes the geographical area of the grid. The output of wind power generation increases with high gradients and exceeds the load demand. As the active power output increases, the reactive inductive power consumption caused by the induction generators increases, too, leading to decreasing voltages. Both, the high amount of generated power and the voltage drop as well result in the operation of the transmission lines at their capacity limits. Furthermore the generated power exceeding the load demand causes reverse power flows in the regional transmission and the high voltage transmission grid as well. In case of congestions system operator's and regional transmission control centre operators have to find appropriate solutions. It is obvious to mention that the possible solutions are underlying the legal framework (e.g. grid code, grid connection rules, market rules, etc.) of today's liberalised electricity supply world. These prevailing conditions were respected in the training courses.

3.2 Training performance and results

During the session several strategies were tested to mitigate the congestions boosted by the voltage drop created by the wind converter induction generators.

The consumption of reactive power of induction generators could not be controlled. For compensation purposes nearby reactive power sources have to be under control of the operators. These could either be conventional generation which could deliver continuously controllable reactive power, limited by contracts or the generator capability diagram, or by the use of capacitor banks, if installed. In the training session it turned out that wind power infeeds on the distribution level are usually not sufficiently compensated. The amount of reactive power has to be delivered by compensation devices or conventionally controllable generators on the higher voltage levels and additionally by operating the tap changers on the high voltage / regional transmission system's transformers. The combination of automatic tap changing transformers connected to the distribution level and the unpredictable generation by wind converters forces operators to very often perform different control actions in the grid (switching and tap changing) and on the conventional generators (setpoints for reactive power output) to **maintain the voltage profile** within the dedicated limits.

The different types of wind converters have different reactive power characteristics. Doubly fed induction generators allow the control of reactive power within limited bands, IGBT-driven converters have extended control characteristics. Making use of the extended control possibilities for wind power infeeds added to the OTS – the definition of reactive power bands for voltage control – it was demonstrated that these types cause significantly less operators' actions maintaining the voltage within the limits. As known from conventional voltage controllers the reactive power delivery of the generation does not impact the automatic voltage regulation by tap changing transformers. This lead also to a smoother voltage profile in the transmission and regional transmission grid.

The entire grid is – as common to power supply systems - designed for a power flow direction from the high voltage transmission level where are the main conventional generation infeeds are connected to, via the regional transmission to the distribution level. As the amount of wind power generation, especially when feeding into the distribution level, exceeds the system's load demand (see Fig.1), the **power flow reverses.** The power is than delivered from the distribution level to the transmission level. This effect can cause congestions in the regional transmission system and the high voltage transmission system as well, as demonstrated in the scenario (see Fig.1).

First it was demonstrated, which amount of wind power in the distribution grid could be generated without affecting the transmission resp. the regional transmission grid. In a second step the wind power generation was increased until it exceeded the load demand to demonstrate the reverse power flows. At least the wind power generation was increased to high values to demonstrate the occurrence of congestions in the regional transmission and the high voltage transmission system as well. This scenario gives the operators insight into the power system's limits and from operational point of view which amount of (locally) wind power generation cause **congestions** and device **overloads**.

One possible solution to clear congestions is the **redispatch** of generation. According to the legal framework – in most countries the wind power generation output could only hardly be influenced – the redispatch is limited to the use of conventional generation units. All entities, which are affected by the redispatch, e.g. grid and production operators, have to develop strategies of mutual interaction according to the legal framework. The control centre operators are trained in using these cross-company-strategies. The impacts of **redispatch**-actions on the system are seen immediately and can be tuned. In the session it turned out that redispatch is not only a technical challenge for all operators, also proper communication between all entities involved and the coordination of all required operational actions is obligated.

As line **overloads** both on the distribution level and transmission level become critical, operational strategies to reduce distributed wind generation according to the legal framework were trained. If a generation management facility is obligated at particular wind power generation units, the system operator and regional transmission operators have the possibility to reduce wind power infeeds in defined geographical zones in defined steps. In combination with the above trained redispatch actions on conventional power production, operators are forced to apply deviated strategies. During the session the application of these **power reduction strategies** in different geographical zones were performed. It turned out that the use of this wind generation management for redispatch requires full insight into the whole production area. This is usually only given in the system operator’s control centre which means that redispatch becomes a system service. Due to the installation of the wind generation management system usually in the regional transmission control centres and the missing complete set of information in the system operator’s control centre the reduction of wind generation first is recommended. Otherwise all the required information have to be displayed on system operator’s control level.

3.3 Future advances and refinements

Additionally to these ‘normal’ daily operation strategies for ‘emergency’ operation are major topics of interest. Operation then focuses on disturbance clearing on the distribution and/or transmission level with influence of wind power infeeds, up to network **restoration** after a total black out, making use of available wind power infeeds. In the future grids will be extended by two-point-DC-links, in order to handle the enormous amount of wind power fed into the system. These links allow exactly defined setpoints for active power ex- or import and will enhance **redispatch** possibilities.

In dealing with the management of appreciable distributed generation of stochastic nature, recent advances in two different areas merit particular attention [6]. The first area is the **short term prediction** of the primary energy resource. For the island of Crete, for example, the wind generation is forecasted as one-day ahead as well as three-day ahead predictions, which look very promising for refinements [7]. The second area is the online **Flexible Electric Load** (FEL) management, as an advanced Demand-Side Management (DSM) measure. Advances and refinements in those two areas show additional directions to further optimise the system operation and address the needs in the liberalized environment, adding novel features in the next version of OTS.

4 Conclusion

The described OTS, which can handle distributed wind power generation and new operational devices has proven its capability to cope with today’s new challenges of power system operation. The OTS allows to examine the overall system's technical performance involving all organisational entities and to derive and verify operational strategies to deal with the new operational challenge “wind power” in today's power systems.

To study these effects individual OTS scenarios for the power system under regard were developed and performed to give the control centre operators insight in power system’s performance affected by wind power generation and to derive operational strategies regarding:

- congestion management,
- redispatch-strategies,
- managing reserve power,
- active and reactive power control strategies regarding wind power infeeds.

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