ACTUAL DEVELOPMENTS IN THE FACTS CAPABILITIES OF WIND ENERGY CONVERTERS ACCORDING TO LATEST FAULT RIDE THROUGH REQUIREMENTS FOR DISTRIBUTION SYSTEMS IN GERMANY

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ABSTRACT

Renewable generation and in particular wind farms replace more and more conventional generation facilities. It is hence logical that also system services such a reactive power provision and voltage control have to be provided more and more by the new renewable generation plants. In particular in Germany the 2009 revision of the German Renewable Energy Sources Act imposes for the first time very detailed specifications about steady state reactive power contribution and -control, as well as dynamic grid support during grid faults. Wind farms with ENERCON Wind Energy Converters (WECs) can fulfil these stringent demands and had been awarded the first WEC-type-certificate according to these German connection conditions in 2009. The present paper describes the reactive power capability and Fault Ride Through (FRT) performance these WECs that responds specifically to the above mentioned requirements.

***Index Terms** - Certification, FACTS Capabilities, Fault Ride Through, Wind Energy Converter*

INTRODUCTION

Many countries seek to increase the share of renewable energies in local electricity production. Wind power is a key component in these plans replacing more and more conventional power plants. The electric networks that they are connected to have historically been designed with regard particularly to the physical behaviour of directly coupled synchronous generators and dispatchable primary energy sources. Many power system operators require Wind Farms (WFs) to have similar performance characteristics in order to facilitate their integration into the grid. Wind Energy Converter (WEC) technology development during the last years has focused on this requirement and today modern WFs are able to stabilize the grid under normal operation and contingency conditions. Due to their sophisticated FACTS control system WECs from the mentioned manufacturer have in certain aspects superior performance characteristics than conventional generation such as hydro or thermal power plants. In the following sections we will describe different features of this FACTS control system and its benefits for optimized grid integration of wind power plants into power systems.

ELECTRICAL DESIGN AND FACTS CONTROL SYSTEM OF THE WEC

The aerodynamic rotor of the WEC is directly, i.e. without an intermediate gear box, connected to the rotor of a high-pole field-excited ring generator. The variable frequency alternating current (AC) output at the ring generator's stator terminals is connected to the grid through a full-scale power converter. The last mentioned consists of a rectifier, a DC link and multiple, identical, parallel DC-AC inverters. Their number depends on the rated active power output and the required reactive power capability for the corresponding WEC. This means that the rotors and ring generators rotational speed is completely decoupled from the power system frequency allowing a wide operating speed range. This flexibility in rotor rpm is vital for an optimum yield under changing wind speed conditions. Additionally the decoupling avoids negative impact from electrical events in the power systems (e.g. short circuits) to the mechanical structure of the WEC, as well as it allows to damp the impact of wind gusts to the generated power.

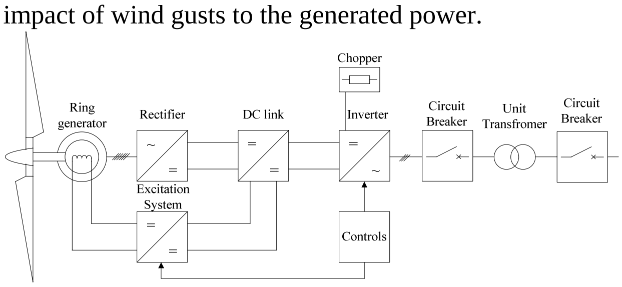

Fig. 1. Simplified electrical diagram of any type of the Wind Energy Converter (WEC)

The electrical performance of this type of WEC towards the grid is defined by its inverters with the associated FACTS control system that regulates the current output to the grid [3]. The performance of the inverters – and thus the entire WEC – can be basically described as a controlled source of current.

REACTIVE POWER CAPABILITY

A simplified but valid assumption for the steady state operation of power systems is that deviations of the grid voltage from the rated value are mainly influenced by the reactive power flow. The ability of a WF to export or import reactive power to or from the grid is therefore essential for voltage control purposes. Whether the reactive power from a WF is really necessary to keep the voltage within a certain bandwidth depends on the local grid conditions. The ratio of the grids short circuit power under n-1 conditions to the rated power of the wind farm to be connected (S_{SC_n-1}/P_{WF_rated}) is a first indicator. The smaller this ratio is, the more significant will be the WF's impact.

In the following, the injection of reactive power corresponds to the behaviour of an overexcited synchronous generator, the absorption to an underexcited synchronous generator.

The WEC can be adjusted to either operate at constant power factor or at constant reactive power output within the limits of the corresponding PQ diagram (see Fig. 2). Set points for both values can be adjusted at the WEC directly, or they can be send remotely via the SCADA System to the WEC.

By default the WEC can inject or absorb the full amount of reactive power between 20% and 100% of its rated active power output during steady state operation. The value of the maximum (injection) and minimum (absorption) available reactive power slightly depends on the WEC type. Below 20% of the rated active power output, the reactive power is reduced linearly; see pentagonal shape in Fig. 2.

In case a wider reactive power range is needed the WEC can be equipped with the so-called "Q+ Option", leading to a higher value of minimum and maximum reactive power. The shape of the PQ-diagram (see Fig. 2) is still pentagonal.

Some system operators require the dynamic and continuous provision of reactive power, where

- Dynamic means no steps in reactive power output,
- Continuous means a provision over the full active power operating range of the WEC, i.e. between 0% and 100% of the rated active power output

WECs equipped with the STATCOM Option can fulfil such requirements by adding additional hard- and software to the already existing power electronics in the WEC. Irrespective of the prevailing wind speed the WEC can then act like an STATCOM, i.e. inject the full amount of reactive power even if the WEC-rotor is not turning. The corresponding PQ diagram shows a rectangular shape, (see Fig. 2).

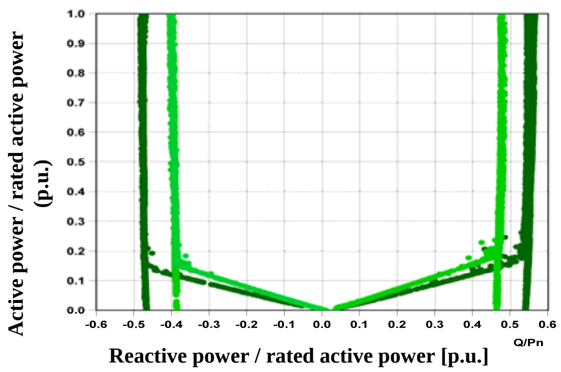

Fig. 2. Reactive power capability of the WECs in standard configuration (smaller Q range), with the Q+ Option (wider Q range) and STATCOM Option (Q range vertically extended to P=0)

CLOSED-LOOP CONTROL

Usually only the overall performance of the WF towards the grid is relevant. A closed loop control of electric parameters such as active power (P) or reactive power (Q or voltage U or power factor cosφ) has to be implemented for the complete WF at its point of connection (PoC) to the power system.

Several central closed-loop controllers are offered, amongst which the Farm Control Unit (FCU) is the fastest and most powerful device. It provides the WFs with the capability to control at a specified point of reference the active power output and/or the reactive power output respectively an associated parameter such as the voltage or the power factor. Voltage and current transformers installed at the PoC provide measurement values to the FCU. Based on this feedback and depending on the project-specific dimensioning of the gains and time constants of the FCU, new set points for the active and/or reactive power are calculated and then sent to all the WECs in the WF via a dedicated fibre optic bus. A settling time for the reactive power of down to one second at PoC is achievable. In order to achieve such a fast response of the WF to a sudden voltage change it is mandatory to know the minimum complex short circuit power at the PoC. Without such information about the power system that the WF is connected to, it is impossible to guarantee a defined and fast time performance of the controller.

Set points for the controlled electrical parameter can be sent to the WF via several types of online communication interfaces, using typical protocols resp. signal technology of system operators, such as OPC XML, IEC60870-5-104, clean contacts or current signals. For a safe operation also reasonable default values for P and Q have to be determined for the case of communication failures.

FAULT RIDE THROUGH PERFORMANCE

Only a few years ago operators of distribution and transmission systems required WFs to galvanically disconnect immediately from the network during under voltage conditions, caused by e.g. short circuits. With the increasing number of WECs connected to the networks, more and more system operators started to demand WFs to remain in operation and connected to the grid during such events in order to avoid system collapse, which might occur due to imbalance between power generation and -load after such a fault. This is known as Under Voltage Ride Through (UVRT), Fault Ride Through (FRT) or Low Voltage Ride Through (LVRT) requirement

The main aim of FRT is usually that a WF has to remain connected and in operation despite a short voltage dip. Going further into details FRT may also include requirements to:

- Return to the full injection of active power within a defined time after fault clearance. This is to avoid a potential collapse of the power system as a result of the

missing active power output after fault clearance.
- Support the power system *during* the fault with a specific current injection. Depending on the physical needs of the power system this is usually mainly a *re*active current requirement, however sometimes also certain minimum requirements for *active* current injection exist. [4], [5]

Requirements for FRT have been drafted in many countries since 2003. Sometimes they leave the impression that they had been just copied from other system operators without adapting them to the specific physical needs of the power system they shall apply to. In particular requirements for unbalanced faults are quite complex to define properly. The typical voltage-over-time-curves known in many today's grid codes can only reflect symmetrical conditions. If the requirements shall apply also to unbalanced faults it is mandatory to define precisely what is the reference voltage to trigger FRT, to determine the desired (reactive) current injection and how reactive current is defined for such unsymmetrical conditions.

As a response to such FRT requirements, ENERCON offers the so-called "UVRT Option". This consists of additional hard- and software which enables the WEC to remain in operation and connected to the network for up to 5s during balanced and unbalanced voltage dips down to 0V. In addition, the WEC is able to remain in operation for up to 5s during balanced and unbalanced over voltages.

This manufacturer specific "UVRT" offers multiple modes, where each of those modes stands for a different current injection behavior during a fault.

One of those UVRT modes is the so-called "QU Mode" (QUM), which has been developed in order to address up-to-date requirements for connection to the distribution and the transmission system in Germany [1], [2]. The basic principle of this QUM consists of supporting the voltage at the PoC during a fault by injecting (or absorbing) an additional symmetrical reactive current to (or from) the grid during under (or over-) voltage conditions. According to [1] and [2] the numeric value of this additional reactive current is calculated based on the deviation of the positive sequence component of the voltage at fault occurrence from the 1-minute average value of the positive sequence component of the voltage prior to the fault.

For symmetrical faults, the maximum total reactive current is at least the value of the rated active current. For unsymmetrical faults, the maximum total reactive current is at least 40% of the rated active current. The injection of reactive current during the grid fault is given priority over the injection of active current [1].

Measurement results for a WEC operating in QUM are shown in Fig. 3 for a three-phase and in Fig. 4 for a phase-to-phase fault on the medium voltage side of the unit transformer. Due to the Δy-vector group of the unit transformer the unsymmetrical faults appear on the low voltage side as a different, but still unsymmetrical fault. The three graphs in Fig. 3 and Fig. 4 show each:

- In the upper graph the three line-to-ground voltages based on the rated line-to-ground voltage
- In the graph in the middle the positive sequence voltage based on the rated line-to-ground voltage
- In the bottom graph the active current represented by the continuous and the reactive current by the dashed line. Both are based on the rated current.

It can be seen that the additional injected reactive current in case of the three phase fault is higher than for the two-phase short-circuit. This is because of the lower value of the residual positive sequence voltage for the balanced fault and is in line with the above description and the requirements [1] and [2].

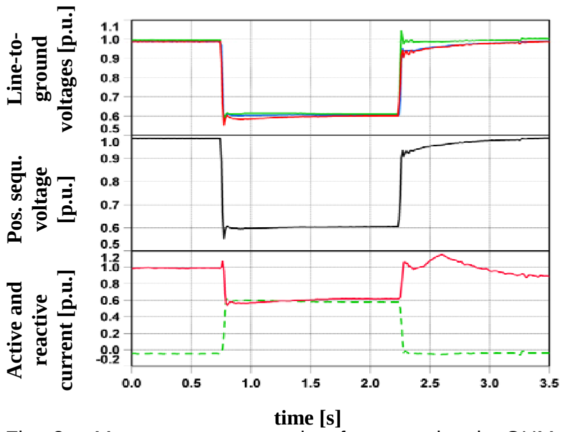

Fig. 3. Measurement examples for operation in QUM during a three-phase fault on medium voltage side of unit transformer.

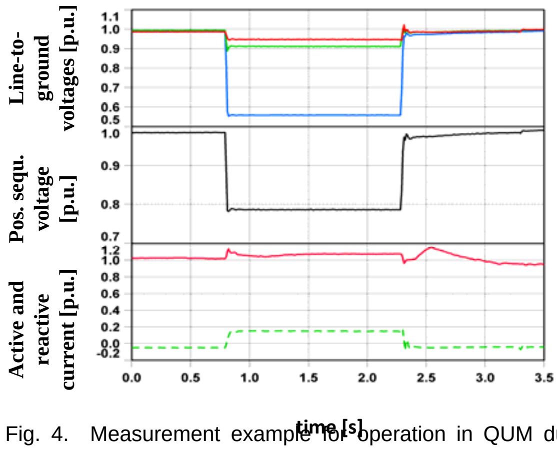

Fig. 4. Measurement example for operation in QUM during a phase-to-phase fault on medium voltage side of unit transformer

Another UVRT mode is the so-called "Zero Power Mode" (ZPM). This can be chosen for balanced and unbalanced under voltage conditions and is by default used for over voltage conditions starting from an adjustable trigger level (e.g. 1,2 p.u.). While operating in ZPM, the WEC remains in operation but does not feed in any active or reactive current to the grid (see Fig. 5). The electrical energy produced during ZPM is dissipated in a dump-load (see Fig. 1 chopper). After the fault has been cleared, the active and reactive current are ramped back to the pre-fault values within an adjustable time.

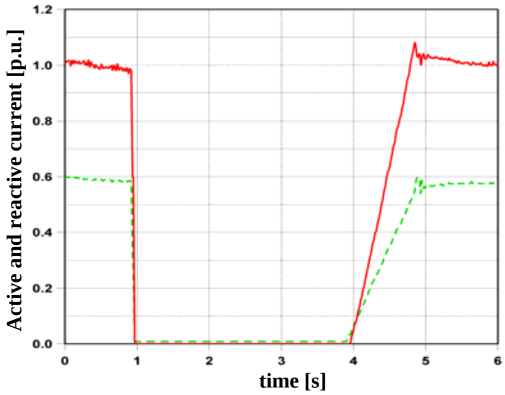

Fig. 5. Measurement example for operation in ZPM during a three-phase fault on the medium voltage side of the unit transformer

Fault Ride Through versus the Risk of Islanding

Particularly in radial (distribution) power systems it is possible to imagine cases, where a substation trips a faulted radial feeder in order to clear a fault, but on the remote end of the radial feeder the active power production of a WF and the active power consumption of local loads are by coincidence in a balanced situation. As long as voltage and frequency on the WEC terminals are within the allowed limits, the WEC can not easily detect that it is feeding current into an islanded grid. This might hence lead to a temporary island operation of parts of this feeder, which certainly has to be avoided. The probability that such situations really occur in practice is extremely low, but shall not be discussed here further. For a worst case scenario it is sufficient that this is theoretically possible. Any FRT requirement that obliges the injection of active and/or reactive current might lead to such an unintentional island situation. Typical means to avoid this are a ROCOF relay (Rate Of Change Of Frequency) or a vector surge relay. Both may operate well, but depending on the frequency deviations and voltage vector surges during regular operation in this specific power system, they might also unintentionally trip a WF. Another possible solution is intertripping between the substation and the WF, which is technically more reliable, but in practice too costly, respectively extremely tricky, due to needed communication to several substations to which the WF might be connected to (grid feeder operation in an open ring).

The most reliable way to eliminate such risks of island operation completely is to set the WF to the above described Zero Power Mode (ZPM). Without current injection by a distributed generator (e.g. WF) the establishing of an island operation because of this WF is impossible. However, this means that the WF in a radial distribution system is not supporting the grid voltage during a (remote) grid fault, as it does not inject any (reactive) current. This conflict of aims has to be investigated project specifically, in order to determine the UVRT settings that are optimum for the security of the power system.

CONCLUSION

This work presented some of the various options that WECs from the named manufacturer offer for an optimized integration into power systems. Requirements in international grid codes show that these options are used today in different markets around the world and help to ensure a stable and reliable network operation. Due to the FACTS control system the WECs are already capable of adapting the active and reactive power output during normal and contingency conditions to very specific needs.

For an optimum integration of WFs into power systems the physical characteristics and needs of the power system should be considered, as well as the potential impact of the WF to it. This affects at least (but is not limited to) the steady state reactive power capability, its control and the FRT performance. A key parameter to determine the potential impact of the WF is the ratio of the (minimum) short circuit power at the PoC to the WF rated power.

It is technically and economically reasonable to differentiate connection condition requirements depending on what WF is connecting to what PoC. Asking from all WFs exactly the same very high technical capabilities may lead to useless investments in projects where sophisticated performance isn't of any use for the power system. Equally, asking from all WFs exactly the same moderate technical capabilities might lead to insufficient grid support at weak grid connection points.

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