Inertial Response Provided by Full-Converter Wind Turbines

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Abstract

The need of increasing renewable energy sources in electrical systems leads to the discussion of the technical limitation of the non-conventional energy sources, such as solar and wind, that are dependent from the obvious intermittent natural resource.

One of these technical limitations that are very important for grid operators is the capacity of wind turbines (WTs) to contribute with Inertia response in order to support the grid frequency, mainly in case of disturbances, in particular to under frequency events.

The present paper will present the result of the development of a new feature that allows a full-converter WT to contribute with under frequency events for some seconds, almost independently from the wind resources.

It will also show the validation of this feature with measurements from a real wind farm in Canada.

Keywords: *inertial response, frequency control, full-converter wind turbine*

1 INTRODUCTION

The usual WTs technology doesn’t have the capacity to increase its active power output in response to under frequency events, unless the active power is previously limited on purpose, different from the conventional synchronous generation (thermal or hydro) that have an inertial constant greater than zero. With the increase of installed wind power plants (WPPs) into the electrical system the grid operator is obliged to operate the system with a lower level of inertial constant, which can lead to a critical point where the frequency behavior of the system cannot be maintained in a secure level. That required some grid operators to ask the WT to provide inertial response functionalities. This paper will present some examples of grid code requirements that already oblige the WTs to have this functionality. Based on one of these requirements ENERCON developed the Inertia Emulation feature [1] that will be also described in the paper. At the end, measurements from a real wind farm will show how it was verified that the ENERCON full-converter technology is able to comply with the grid code, increasing its Active Power in the events of under frequencies.

2 FREQUENCY CONTROL IN POWER SYSTEMS

The frequency of a power system is an important operating parameter, and needs to be kept nearly constant during the system operation including during contingency events. In large power-systems, the frequency of the system depends on the balance between generated and consumed active power. In the event of a lack of generation, the frequency is reduced. This could occur for example due to a fault at a major generating station, or the loss of an important transmission line. Every grid operator has defined worst-case contingencies, for which a large number of simulations are carried out to evaluate the frequency dynamics. If the frequency drops below a certain threshold, wide-ranging load shedding schemes are activated, leaving towns, cities and sometimes entire regions without power. Several physical factors and a complicated array of controls contribute to maintaining the grid frequency within acceptable parameters. The fastest type of response comes from the inertia of rotating machinery on the system (i.e. synchronous generators and motors), which feed additional power into the system if they are being decelerated due to a lower system frequency. The next fastest response comes from the speed governors of conventional power plants, which increase primary power supply in response to a drop in rotational speed of the main shaft, typically with a proportional droop-type control. The response time of these controls is on the order of several seconds, depending on the type of power plant. At much longer time-scales, automatic generation control and operator intervention restore power system frequency to nominal. The interactions between the physical concepts and the control systems are complex but well-understood for conventional power systems with many synchronous generators and loads [2]. However, with the increasing replacement of conventional power plant by WTs and other inverter-based units, the amount of inertia in the system decreases, which may be problematic for the frequency dynamics of a power system in the first few seconds of a contingency like the loss of a large generation unit. This has resulted in the definition of requirements for WT control systems to respond with a power increase if a large frequency deviation is detected.

3 INERTIAL RESPONSE REQUIREMENTS

3.1. Hydro Quebec Transénergie (HQT) - Canada

The power system from Quebec is not synchronously connected to any other AC network and the expected wind power installation represents 10% of its peak load and 25% of its low summer load. Hence lack of inertia is a very important topic in the system. This way, since 2006, HQT requests that WPPs with rated output greater than 10 MW must be able to increase their active power by at least 5% for about 10s in response to severe frequency dips [3]. ENERCON presented the Inertia Emulation (IE) feature based on this requirement in 2008. Recently HQT has started the assessment of IE performance based on measurement results obtained from WPPs that are in commercial operation. Some of those results will be presented in this paper.

3.2. Eirgrid – Ireland

The power system in Ireland also experienced an expressive increase of renewables penetration and since the its geographical situation limits the synchronous connection with other systems, the lack of inertia is a very significant issue. Despite not requiring the IE feature in the Grid Code, the Commission of Energy Regulation have already published the technical definitions of the synthetic inertia (called Fast Frequency Response) to be considered as ancillary service.[4]

3.3. European Network of Transmission System Operators for Electricity (ENTSO/E)

European system operators are working in a general grid code to be used as basis for all countries. The idea is to have a document published with minimal requirements that will be complemented by each local need. The latest draft of this requirements for generators [5] address the topic of frequency regulation which could allow system operators to require emulate inertial response from WPP depending on their size and geographical location.

3.4. Operador Nacional do Sistema Elétrico (ONS) – Brazil

The WPPs responds today for around 4,5% of the total installed electric generation capacity in the power system in Brazil [6] with around 6GW of installed power. And according to projections from ABEEOLICA based on the results from the last auctions, this value will achieve 17 GW until the end of 2019. The increase of this energy source represents to the Brazilian grid operator (ONS) several technical challenges. One of them is to maintain the security in the system and guarantee the frequency stability in a system with less inertia capacity. Mainly in areas that the wind energy will represent almost the same amount of power than the hydro plants. For this reason, ONS is changing the Brazilian grid code and already added in the auctions rules [7] the requirement that all WPPs to be connected in the transmission system need to provide at least 10% of the installed capacity during events of under frequencies using the resource of synthetic inertia.

4 IMPLEMENTATION OF INERTIA EMULATION IN FULL-CONVERTER WTs

4.1. Basic electrical design

The basic electrical design of any type of ENERCON WT is identical. The hub of an ENERCON WT is connected directly, i.e. without an intermediate gear box, 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 latter consists of a rectifier, a direct current (dc) link and multiple inverters, the number of which depends on the nominal active power output and the required reactive power capability for the corresponding WT. This means that the ring generator is decoupled from the power system allowing a wide operating speed range. The electrical performance of an ENERCON WT on the grid is hence defined by its inverters and the associated FACTS control system which regulates the output current to the grid. The input parameters for the control system are the voltage and the frequency. Both parameters are measured at the low voltage side of the unit transformer.

4.2. Inertia Emulation Controls

ENERCON IE is implemented using a control system that responds to a drop in grid frequency by temporarily increasing active power beyond the available power from the wind. The energy for this increase is drawn from the rotating masses of the WT such as the generator, the shaft and the blades.

The system frequency is constantly measured by the ENERCON WT control system. A value of the system frequency below a certain threshold or trigger level $f_{inertia,trigger}$ is indicative of a contingency event on the electrical network like the loss of a large generation unit. IE reacts to a frequency $f < f_{inertia,trigger}$ by commanding a pre-defined power increase for the period $t_{inertia,max}$, see Fig. 1. This power increase helps reduce the load-generation imbalance in the power system for the first several seconds during a contingency event, until frequency support can be provided by the governor response of conventional generation units. Hence, response of the WTs will help to improve the frequency nadir and to reduce the negative gradient of the grid frequency.

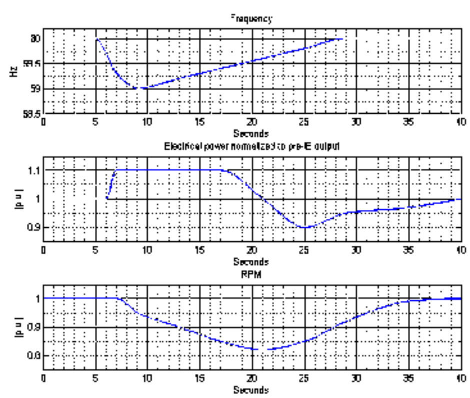

Figure 1 - Idealized ENERCON Inertia Emulation response to an under-frequency event at below-nominal, constant wind speed.

The amount of additional power output $P_{inertia}$ above the power output at the time of IE activation $P(t = 0)$ depends linearly on the deviation of the system frequency from its nominal value (up to a lower frequency threshold $f_{inertia,min}$), and can be set to values up to 10% of P_n. The power output reaches the increased IE set-point after 0.5s – 1s.

As a result of the significant impact of the parameters on the WT response to an under-frequency event, a careful tuning taking into account the objectives of the system operator, specifics of contingency events, as well as the system dynamics and the response of other generating units needs to be carried out. This is emphasized in several studies examining the impact of fast frequency support by WTs on various power systems **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.**.

5 MEASUREMENT RESULTS

ENERCON installs high-frequency measurement equipment in selected WTs and WPPs. As part of the validation process for IE, data of individual WTs and a WPP during real under-frequency events were recorded in this way. The results in this section illustrate the ability of both WTs and WPPs to increase active power supply significantly above the available power from the wind for a defined period of time.

5.1. Wind Turbine level

Fig. 2 shows the IE response of a WT that operated at about 30% of rated power just prior to the activation of IE. The active power output is 31% of P_n when IE is triggered, and 37% of P_n at the moment when $f_{\text{inertia,min}}$ is reached. The defined power increase for this WT for a frequency below $f_{\text{inertia,min}}$ was 6%. The WT maintains constant power until the frequency rises above $f_{\text{inertia,min}}$ again. Crossing this threshold triggers a decrease in WT active power. Based on the setting for $t_{inertia,max}$ the WT exits IE and returns to normal operation after 10 seconds. Fig. 3 shows the IE response of a WT to the same under-frequency event as in Fig. 2, however for a WT that operated at rated power just before IE activation. The active power output is 100% of P_n when IE is triggered, and 106% of P_n at the moment when $f_{\text{inertia,min}}$ is reached. This means the WT is operating above its nominal power for 10s. It can be observed that there is no power drop following the deactivation of the IE response, since the additional energy could be retrieved by decreasing the blade pitch angle.

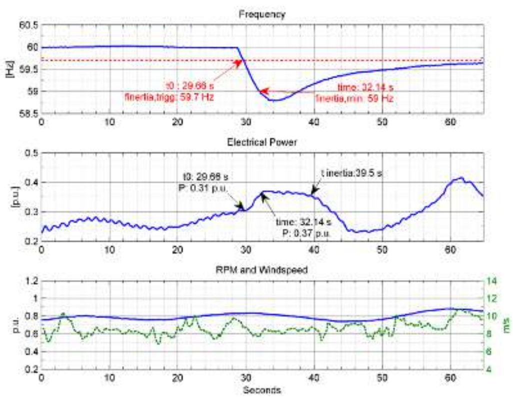

Figure 2 - Lower power band WT measurement.

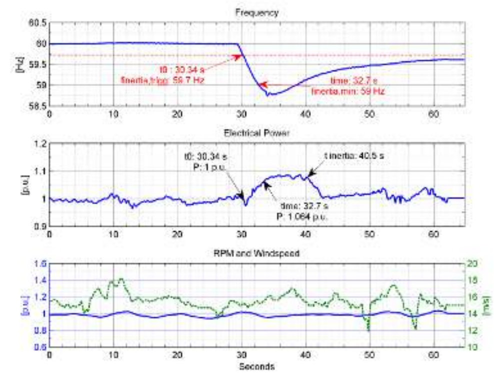

Figure 3 - Nominal power band WT measurement.

5.2. Wind Power Plant level

Fig. 4 shows the IE response of the WPP from which the WT data in the previous subsection was taken, for a different under-frequency event. At the time of the contingency event, the WPP was operating at about 22% of its nominal power, which is in excess of 120 MW. The WPP increases its power production from 22% P_n up to 28% P_n and maintains this value for the following 10s. The noise in the frequency and power signals, which is visible at around 1 'oltage.

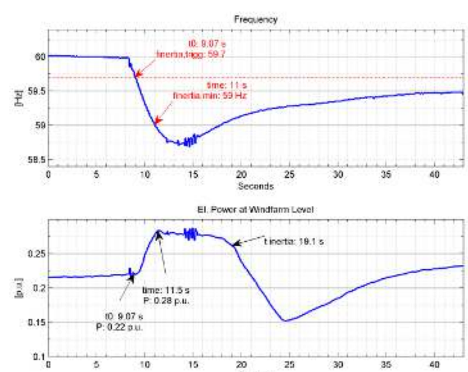

Figure 4 – Lower Power Band WPP measurement.

6 CONCLUSION

This paper shows that despite of the inherent behavior of intermittent energy generation source that the wind turbines presents, it is also possible with advanced control techniques to increase the active power in case of severe frequency disturbances (under frequency).

The ENERCON Inertia Emulation feature was presented including also real measurement results in a commercial wind farm that proved this inertial control responds as expected.

It is important to point that this kind of feature allows wind turbines to present a closer behavior to conventional generation which can be interesting for the grid operator, who will gain in system security and also to the wind industry that will be able to increase the participation of this source in the power system.

However, it is also important that, while the WT manufacturers are working on improving their controls, Grid Operators should work in their side to properly address inertial response in their future requirements considering the experience gained with the installed feature in their grid. That means, after asking the WTs to provide inertial response, a close cooperation between Grid Operator and WT manufacturers can help the system to get the optimum solution in terms of technology.

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BIOGRAPHIES

Danilo Caldas – Born in Rio de Janeiro, Brazil on 25th March 1982. Received his Electrical Engineering Degree for the "Universidade Federal do Rio de Janeiro" (Río de Janeiro - Brazil) and participated in a double-degree program obtaining also a Generalist Engineer Degree for the "École Centrale Marseille" (Marseille - France).

He joined ENERCON in 2008 working for Site Assessment Department in Wobben Windpower, and since 2010 is the responsible for the Sales Grid Integration department in Latin America, being responsible for aspects related to wind farm grid connection in this region. He is active in some Brazilian working groups related to grid integration of wind farms from CIGRE and ABEEOLICA.

Markus Fischer – Born in Stuttgart, Germany on 08th September 1982, received his Dipl.-Ing. Degree in electrical engineering with specialization in power systems from the University of Stuttgart, Germany in 2009. From 2007 until 2009 Markus participated in a double-degree program and obtained an additional Masters degree in electrical engineering specializing in energy and power system science from the École Supérieure d'Électricité (SUPELEC), Gif-sur-Yvette, France in 2009.

He started working for ENERCON in the Sales-Grid Integration department in March 2009. Since 2014, he is the Regional Manager Grid Integration for Canada, Northern Europe, East Asia and Oceania being responsible for aspects related to wind farm grid connection in those markets. He has published several papers at various international conferences such as the IEEE PES GM and the IEEE PES T&D, has contributed to the second edition of the book Wind Power in Power Systems and is a member of the CSA Wind Turbine Technical Committee."

Sönke Engelken – Born in Bremen, Germany on 25th July 1984. Received a Ph.D. in Electrical and Electronic Engineering from the University of Manchester, UK, in 2012, with a thesis on robust control theory. Prior to this, he obtained a M.Sc. in Advanced Control and Systems Engineering, also from the University of Manchester, and a B.Sc. in Electrical Engineering and Computer Science from Jacobs University, Bremen, Germany, in 2008 and 2007, respectively.

He has been working in the Advanced Controls department of WRD GmbH since 2012, where his work focuses on control systems development for wind energy systems. His research interests are in the application of modern control techniques to wind energy converters, grid integration of renewable energy systems, and robust control. He has published numerous papers in refereed journals and conference proceedings. He is a member of IEEE, IET and VDE.