European Association for the Development of Renewable Energies, Environment and Power Quality

International Conference on Renewable Energies and Power Quality (ICREPQ'09)

Valencia (Spain), 15th to 17th April, 2009

Comparison of European Interconnection and Operation Requirements for Wind Farms

Marcela-Martínez-Rojas[1], Andreas-Sumper[1], Oriol-Gomis-Bellmunt[1], Roberto-Villafáfila-Robles[1], Eduard-Valsera-Naranjo[1], Antoni-Sudrià[1 2]

[1]Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA-UPC)
E.U d'Enginyeria Tècnica Industrial de Barcelona - Dept. Ingeniería Eléctrica
C/ Comte d'Urgell, 187. 08036 Barcelona, Spain. Tel: +34 934137432
[2]IREC Catalonia Institute for Energy Research
E.U d'Enginyeria Tècnica Industrial de Barcelona - Dept. Ingeniería Eléctrica
Josep Pla 2, B3, ground floor. 08019 Barcelona, Spain. Tel: +34 933560980
e-mail: marcela.martinez@citcea.upc.edu, sumper@citcea.upc.edu, gomis@citcea.upc.edu,
roberto.villafafila@citcea.upc.edu, eduard.valsera@citcea.upc.edu, asudria@irec.cat

Abstract. The necessity to provide clean energy, along with the latest technology developments in the field of wind turbines, have been reflected by building bigger wind farms. This, combined with the integrated operation between wind farms and the grid, involves all the electric system affecting different aspects as transitory stability, voltage regulation, energy reserve management and the electric market. Most UE transmission system operators (TSO) have responded introducing technical regulations for wind farm interconnections. The present paper presents a comparison of some European grid codes for wind farms (WF), and their operative implications.

Key words

Wind farm, grid code, connection requirements, voltage control, frequency control.

1. Introduction

The necessity of new sources of energy and the growth of renewables has changed the control needs of electric systems. The first wind farms (WF) were considered as groups of isolated wind turbines; a local and simple management was enough without complex control systems. The relative low cost and mechanical simplicity of fixed speed wind turbines (WT), based on the squirrel cage induction generator, made them common.

With the increase of wind power, the squirrel cage induction generator began to have negative impact in the power system stability. This type of generator requires a reactive magnetization current that is taken directly from the grid and is not able to ride through voltage disturbances [1], [20],[22]. In the event of voltage sags most wind farms were tripped off, involving serious problems for the system stability.

The need for more robust systems able to ride through disturbances and participate of the grid stability boosted the incorporation of power electronics and the development of new wind turbine generation concepts, resulting in variable speed wind turbines[21]. Among them, the most common technology used today is the doubly feed induction generator (DFIG). The DFIG is a wound rotor induction generator, in which the stator is connected directly to the grid and the rotor is connected to the grid by means of a back-to-back power converter [17], responsible for the control of the generator torque. Besides, it can control the production of reactive power, allowing voltage control capability [19], [9]. The power converter is usually rated to 20-30% of the generator power, which implies lower cost than fully rated converters, but having a limited speed range operation.

The new variable speed WT technologies included the use of synchronous generators for full speed range operation using full power converters.

With all this technological changes and the necessity to maintain the stability in the power systems, Transmission System Operators (TSO) have integrated into their grid codes control requirements for wind farms [23], [5], [6], [14].

The continuous change of grid codes experienced in the last years [12], [7], [8], motivate a continuous review and study. This review can be useful for:

- Wind turbine producers and WF developers, giving them an overview about existing requirements and guidance for technology development.
- Countries with a recent interest in wind energy, to attract their attention to the main issues.
- Direct the research work in this direction, responding to the TSO and WF developers needs.

In this paper, the grid codes of the countries with more installed wind energy (Denmark, Germany and Spain) and some others with significantly expansion of renewable energies (UK, Ireland and France) are compared. The structure of grid codes and control issues, principally frequency and voltage control, are presented. As well as the principal technological implications and future work.

2. Grid code comparison

IEEE is one of the principal references for technical standards. At the end of 80's IEEE published the standard *Guide for Interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems.* It presented the first guidance notes in matter of power quality, equipment protection and safety for distributed networks. At the same time in countries as Denmark and Germany started to develop some rules for WF connection. Latter at 90's these rules were collected in a national level. Finally in 2002 the *IEEE standard for Interconnecting Distributed Resources with Electric Power System* were published [1].

Actually each country has a specific regulations concerning WF or is working on them. Their principal aspects were presented following.

Denmark
Energinet.dk responsible of electric transmission system in Denmark (result of a merger between Eltra, Elkraft System, Elkraft Transmission and Gastra), have created a connection code divided in two levels, for connection points above and below to 100kV. In general the control requirements demand the possibility of increase or decrease the active power production between 20% and 100% of the power available. For the reactive power control requires that changes take place in a maximum time of 10s [6].

Germany
E.ON the main German utility has been continuously upgrading its Grid Code for high and extra high voltage connections, and more recently has established a series of requirements that relate specifically to Offshore Grid Connections [14], [15].

UK
In the UK the Energy Networks Association (ENA) and National Grid set out the operational and technical requirements for connection [23]. At the same time, they seek to give WF developers guidelines allowing them to fulfill the requirements of network [2].

Ireland
In the case of Ireland, the Commission for Energy Regulation (CER) approved the proposed Wind Grid Code the 1st of July of 2004. The Wind Grid Code was produced by ESB National Grid (ESB-NG). The code refers to frequency control setting for wind generators remain continuously connected to the rank nominal of frequency $49.8 - 50.2$ Hz, up to 60 minutes between $47.5 - 52$ Hz and 20 s for $47 - 47.5$ Hz. Additionally, the code requires a regulation margin P-f upwards and downwards, with a maximum rate of change for the WF from 1 to 30 MW/min [5].

France
In France, the official circular of October 27^{th}, 2006 sets out the operation requirements of a generation unit [16].

Spain
In Spain through P.O. 12.3 developed in 2006 the requirements for response to voltage dips of wind power plants setting out. This document establishes the acceptable power consumption for different faults in the system. In 1998 were defined with P.O. 1.6 security plans to ensure safe and reliable operation of the system. Actually there is under discussion a document for wind and photovoltaic systems. It established that wind turbines must remain connected at least during 3s with frequency falls below 48.0 Hz, and be able to withstand 47.5 Hz instantly. Also require voltage and frequency capabilities [4].

3. Frequency control

Production adjustments are necessary to maintain the balance demand-generation, and then the frequency of the system within the margins of operation. This control, carried out by conventional plants, is divided in two according response times. This control functions are the primary and secondary control. The primary control seeks the balance between generation and demand, and also to guarantee the recuperation of the frequency in a time lower than 30 seconds. On the other hand, the secondary control has to assume the tasks of the primary control after the primary control has worked, till 10-30 minutes. The secondary control require slower increases or decreases of the generation than the primary control.

Therefore, actually the TSO demand that WF that are connected to the grid have to be able to adjust their active power production with the aim to give frequency support to the grid.

An important factor is that in order to have control capacity the WF should be able to make adjustment of production upwards and downwards. It means that al least some of the WT operates below the nominal power point of operation, if not all, in case they are not energy storage systems [11]. That represents an economical disadvantage for the owner of the WF.

A typical example of frequency curve characteristic is showed in figure 1 [8]. The frequency range at which the wind farm should give support adjusting its production has to be established for each grid operator. In figure 1 ESB-NG fixed each point of the curve, margins and rates or power adjust production in order to perform frequency control. To determine each of the parameters aspects like specific characteristics of each WF, the operation conditions and its location are taken into account. In general, the characteristic determines that when the frequency falls below of the dead-band the system shall to ramp up the active power. No changes have to be carried out while the frequency remain into the dead-band, and when frequency rises the active power has to be reduced. Finally, no power output are allowed for over frequencies [5].

Table 1 shows the conditions for regulating power for some of the TSO. As shown in the table in the case of Eltra and Elkraft there is different production adjust for each of voltage levels.

In Spain, at the moment, it is not required that the wind power plants participate in the frequency control. However the CEGRE, control centre for renewables, can to demand decreases in active power production in order to maintain the security of the electric system. Reductions in generation may be due to voltage deeps, power balance or surplus power generation that can not be integrated into the system [18]. On the other hand, actually there are under discussion some requirements about frequency control capabilities. It seeks that the WF have the capacity to raise and reduce their generation according to frequency changes. This frequency control should respond according to $-\frac{\triangle f/f_{base}}{\triangle P_p/S_n}$, it may take values between 0.02 and 0.06 p.u. Besides, the active power increases should be at least $\triangle P = 0.1 p.u.$ in 250ms. [4].

Each country defines its own disconnection boundaries. This requirements set up the frequency levels at which the wind turbines should remain connected to the grid, as it can be seen in figure 3.

4. Voltage control

In order to maintain safety levels in the network nodes TSO must control the voltage throughout the system. As part of the voltage control an important issue is the regulation of reactive power exchanged with the network, which is fixed in most countries agree on values for the power factor to be kept, as shown in the table 2. It also can be done by fixing a Q-U characteristic for the connection point, which has to be implemented in the WF control system. The slope of this curve depends on the system wind penetration.

In the Spanish case, the reactive power production is regulated through a time table for the power factor. This table specifies the power factor that has to be maintained in the connection point for periods of peak, flat or valley. It also differentiates between winter and summer, since there are considerably differences in the consumption profile.

As far as voltage thresholds to remain connected are concerned, each operator has established time limits and thresholds, depending on the characteristics of the network.

For example for the French case the network code provides that for greater changes than 5 % of the rated voltage is due to stay connected as long as possible [16].

In Spain the wind power plants have to remain connected when short circuits in the electrical system cause voltage dips. The definition of the profile, magnitude and duration of them depend on the percentage of wind power versus short circuit power at the connection point [3].

A common factor in the monitoring requirements for wind farms is to receive and follow a voltage, reactive power or power factor set point as has been mentioned [6], [14], [8]. To complete the role of supporting network each grid code defines acceptable response times. In these minutes or seconds the necessary changes have to be done to comply with the TSO demand. Likewise if is necessary include compensation elements, these should be taken into the control process.

In Denmark for example Eltra and Elkraft stipulate that reactive power adjustments should take place in less than 10 seconds [6]. In the case of ESB-NG for Ireland, the response time is longer, 1 min [5].

In Spain a document that demand during faults to give at least a minimum reactive current according with the WF capacity, in less of 40 ms is under discussion [4].

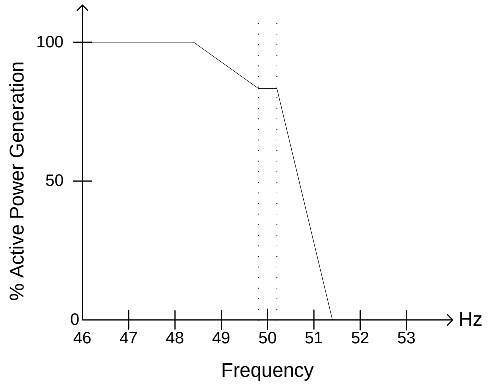

Figure 1: Power-frequency characteristic curve

5. Technical implications

The necessity to participate in the support of the grid process has made the transmission grid operators to demand the ability of the WF to receive a set point of operation and follow it.

The knowledge of the state of all the wind turbines is an important and critical factor to carry out the grid connection requirements because the correct operation of the wind farm depends on the control of each one of the wind turbines, especially for voltage control issues. Therefore the communication between aero-generators and central control is an important aspect. As the SCADA has restrictions for the speed of communication, it becomes necessary to carry out actions that will make decisions on adjusting production locally and thus arrive to the response times.

As it can be seen in figure 2, actual requirements demand a hierarchical system in which the deciding factor is the communication between the lower level control, wind turbine control, and the superior control, the central control or WF control.

For power and frequency control it is necessary to have secondary energy reserves. The energy storage systems are a good option for this. The most common are the short-term technologies, like flywheels, batteries, advanced capacitors and superconducting magnetic energy storage [10]. The configuration of these systems could be as a aggregated unit or installed in each wind turbine, and a combination of these two is also a possibility.

The ability of WF to simulate the inertial response of the conventional generators are being increasingly taken into account by TSO. As well as the possibility to participate in the damping of power swings (Power System Stabilizer-PSS).

Table 1: Active power response required for frequency control

Active power adjust		
Country	Frequency Hz	Active Power %
Denmark	≤ 49.0	100%
	$[49.0-49.9)$	$(1+\frac{f-(f_{ref}+\Delta f_{d-})}{f_n-(f_{ref}+\Delta f_{d-})})100\%$
	$[49.9-50.1)$	Rated power
$\geq 100kV$	$[50.1-51.0)$	$(1-\frac{f-(f_{ref}+\Delta f_{d+})}{f_\phi-(f_{ref}+\Delta f_{d+})})100\%$
	≥ 51.0	0
Denmark	≤ 48.7	100%
	$[48.7-49.85)$	$(1+\frac{f-f_{d-}}{f_n-f_{d-}})$
	$[49.85-50.15)$	Rated power
$\leq 100kV$	$[50.15-51.3)$	$(1-\frac{f-f_{d+}}{f_\phi-f_{d+}})$
	≥ 51.3	0
Germany	$[47.5-49.5)$	$\leq 0.1f+3.95$
	$[49.5-50.2]$	100%
	$(50.2-51.5]$	$20\times P_{available}\frac{50.2-f}{50}$
France	$(47-49.5)$	$>90\%$
	$[49.5-50.5)$	Rated power
	$[50.5-52]$	Reduction
UK	$(47-49.5)$	$\geq 0.02f+0.01$
	$[49.5-50.5]$	100%

Table 2: Reactive power requirements

Country	Request
Ireland	pf 0.93 leading - 0.85 lagging
Germany	pf 0.95-1-0.925 leading 0.95-1 lagging
Spain	Time table [13]
France	$U>1.05U_N Q>95\%$ $U<0.95U_N Q>95\%$
UK	0.95 leading - 0.975 lagging (at P rating)

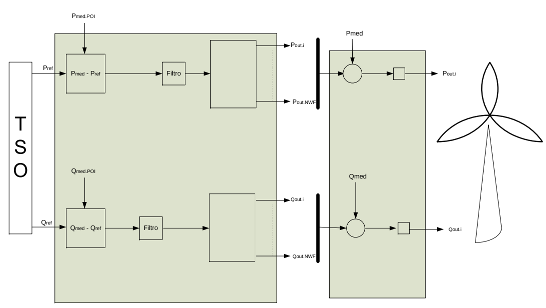

Figure 2: Hierarchical sketch for Wind Farm control

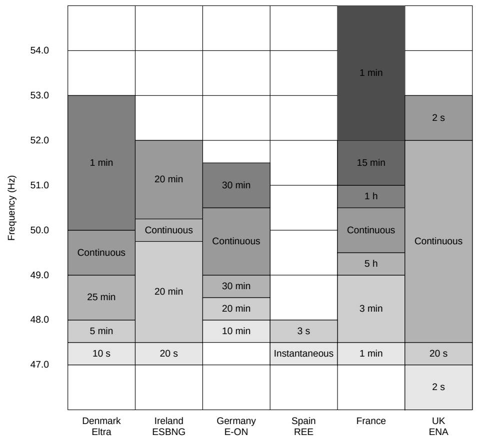

Figure 3: Time which the WF must remain connected for different frequency levels

6. Conclusions

With the recent growth of wind energy and their integration into the network, it becomes necessary to start considering the wind farms (WF) as an active part in the current power systems. Wind energy should no longer be considered as a minor source of generation, but as a compact unit power generation. These new wind power plants must be able to assume, if not the complete control functions at least all the main. Technological advances given in the last decade make possible to achieve control functions, until quite possibly to take part in the automatic generation control (AGC).

The requirements for grid connection of wind farms differ between countries and each power system has different control necessities as well. In general, all the WF requirements are based on the conventional sources regulations. The principal aim is that wind power plants could participate in the regulation process and support for the grid. All the grid codes are in constant revision, according with the power system needs and the technological developments.

References

[1] Ackermann, T. *Wind Power in Power Systems.* Wiley, 2005. 1, 2

[2] Company, N. G. Guidance notes for power park developers. grid code connection conditions compilance: Testing & submission of the compilance report. Tech. rep., National Grid, 2005. 2

[3] de Industria y Energía, M. P.o. 12.3 requisitos de respuesta frente a huecos de tensión de las instalaciones eólicas. Tech. rep., Ministerio de Industria y Energía, 2006. 3

[4] de Industria y Energía, M. P.o.- 12.2 requisitos técnicos de las instalaciones eólicas, fotovoltaicas y todas aquellas instalaciones de produccioón cuya tecnología no emplee un generador síncrono conectado directamente a la red. Tech. rep., Ministerio de Industria y Energía, 2008. 2, 3

[5] EirGrid. Eirgrid code. version 3.1. Tech. rep., EirGrid, 2008. 2, 3

[6] Eltra, and System, E. Regulation tf 3.2.5 wind turbines connected to grids with voltages obove 100 kv. tecnical regulation for the properties and the regulation of wind turbines. Tech. rep., Eltra, 2004. 2, 3

[7] Erlich, I., and Bachmann, U. Grid code requirements concerning connection and operation of wind turbines in germany. In *Proc. IEEE Power Engineering Society General Meeting* (2005), pp. 1253–1257 Vol. 2. 2

[8] Fagan, E., Grimes, S., McArdle, J., Smith, P., and Stronge, M. Grid code provisions for wind generators in ireland. In *Proc. IEEE Power Engineering Society General Meeting* (12–16 June 2005), pp. 1241–1247. 2, 3

[9] Lei, Y., Mullane, A., Lightbody, G., and Yacamini, R. Modeling of the wind turbine with a doubly fed induction generator for grid integration studies. *IEEE Transactions on Energy Conversion 21*, 1 (March 2006), 257–264. 1

[10] Li, W., and Joos, G. Comparison of energy storage system technologies and configurations in a wind farm. In *Proc. IEEE Power Electronics Specialists Conference PESC 2007* (17–21 June 2007), pp. 1280–1285. 4

[11] Lubosny, Z., and Bialek, J. Supervisory control of a wind farm. 985–994. 3

[12] Matevosyan, J. Wind power integration in power systems with transmission bottlenecks. In *Proc. IEEE Power Engineering Society General Meeting* (24–28 June 2007), pp. 1–7. 2

[13] MITYC. Real decreto 661/2007, de 25 de mayo, por el que se regula la actividad de producción de energía eléctrica en régimen especial. Tech. rep., Ministerio de Industria, Turismo y Comercio, 2007. 4

[14] Netz, E. Grid code. high and extra high voltage. Tech. rep., E.ON Netz, 2006. 2, 3

[15] Netz, E. Requirements for offshore grid connections in the e.on netz network. Tech. rep., E.ON Netz, 2008. 2

[16] officiel de la République Francaise., J. Texte 29 sur 142. Tech. rep., Ministère de l'économie des finances et de l'industrie, 2006. 2, 3

[17] R. PENA, J. C. C., AND ASHER, G. M. Doubly fed induction generator using back-to-back pwm converters and its applications to variable-speed wind-energy generation. *Procidings Inst. Elect. Eng., Elect. Power Appl. 143* (1996), 231–241. 1

[18] REE. Integración de la energía eólica en condiciones de seguridad para el sistema. Tech. rep., REE, 2007. 3

[19] RODRÍGUEZ-AMENEDO, J. L., ARNALTES, S., AND RODRÍGUEZ, M. A. Operation and coordinated control of fixed and variable speed wind farms. *Renewable Energy 33* (2007), 3. 1

[20] RODRIGUEZ AMENEDO, J., BURGOS DÍAZ, J. C., AND ARNALTE GÓMEZ, S. *Sistemas eólicos de Producción de Energía Eléctrica*. Rueda S. L., 2003. 1

[21] SLOOTWEG, J., DE HAAN, S., POLINDER, H., AND KLING, W. General model for representing variable speed wind turbines in power system dynamics simulations. *IEEE Transactions on Power Systems 18*, 1 (2003), 144–151. 1

[22] SUMPER, A. *Dynamic performance of fixed speed wind turbine generating systems during system fault events*. PhD thesis, Universitat Politèctnica de Catalunya, 2008. 1

[23] TRANSMISSION, N. G. E. Grid code. Tech. rep., National Grid, 2008. 2