

# DYNAMIC STABILITY INVESTIGATIONS OF THE FAULT RIDE-THROUGH CAPABILITIES OF A WIND FARM

Arthur Ekwue, Oona Nanka-Bruce and Jhansi Rao  
PB Power, Westbrook Mills, Godalming, GU7 2AZ,  
UK

Damien McCool  
Scottish Power (Renewables & Major Projects),  
Spean Street, Glasgow G44 4BE, UK

## Abstract

**The development of renewable energy sources will increase the amount of generation connected to distribution networks and this raises some technical issues, such as: fault ride-through capabilities; voltage control and power quality; system stability etc.**

**This paper reports on results of the dynamic studies carried out to demonstrate the compliance of a wind farm to meet the fault ride-through requirements of the National Grid Code in UK.**

**Keywords:** *renewable energy sources, system development and operation, grid integration, grid compliance, dynamic response of a wind generator turbine*

## 1. INTRODUCTION

The UK Government has set targets for reducing greenhouse gas emissions and increasing the proportion of new forms of electricity generation. The target is that by 2010 10% of electrical energy consumed will be provided by renewable sources and 10 GWe capacity of combined heat and power (CHP) plants. The bulk of electricity in UK is generated by large generating plants, i.e. of at least 100 MW capacity. But many of the new forms of plant (such as renewables or CHP) produce much less than 100 MW output, and then their small size makes it uneconomical to connect them to the transmission system. Hence these distributed generating plants will be connected at the distribution level.

Advantages of Distributed Generation:

- Optimally located distributed generation resources can reduce or postpone the need for investment in the transmission and distribution infrastructure.
- Transmission and distribution losses reduction
- Improvement in power quality and system reliability.

The development of renewable energy sources will increase the amount of generation connected to the distribution networks and this raises some technical issues, such as: fault ride-through capabilities; voltage control and power quality; system stability; etc.

### 1.1 Reactive Power Issues

Current wind generation technology has different electrical characteristics from conventional thermal, nuclear and hydro plant when large numbers of wind generators are installed on the network. The use of induction generators in place of the traditional synchronised generators delivers a significant increase in reactive power which must be managed by the network operators. The increased reactive power on the network can prevent the connection of further wind generators to the network unless active steps are taken to absorb the reactive power.

### 1.2 Inertia and Frequency Response

Frequency is controlled to a certain degree by generators responding automatically to changes in power output. However, the current wind generation technology does not offer the same flexibility as conventional plant for balancing requirements or meeting frequency management requirements. Whilst the inertia and frequency response issues may not be critical with the current penetration of renewable generators, there could be potential problems for the network operators as the penetration increases towards the 2010 targets.

### 1.3 Intermittency

As wind generation output is significantly more intermittent than conventional plant, it would not be possible to depend on a generation portfolio exclusively composed of wind plant. Wind generation must be balanced with sufficient spinning and non-spinning reserve from conventional plant to ensure continuity of supply.

### 1.4 Fault Ride-Through Capabilities

As the penetration of renewable generation such as wind energy increases, the need to address the fault ride-through capability issues will become more critical. Hitherto, the wind turbines were allowed to trip when a voltage dip occurs. The wind turbines will now be expected to remain connected to the grid both during and after a fault. Upon voltage recovery, the wind turbines

are not expected to consume excessive reactive power when re-exciting the generator, as this may result in a further voltage dip [1].

### 1.5 Voltage Control and Power Quality

The random fluctuations of the power generated by large wind farms can result in network voltage dips and rises if either the wind farm or the network is not providing support to the system with some form of voltage control. Voltage control and power quality problems can arise when generators embedded within the distribution networks start or stop generating power. If not properly regulated this may even cause other network users to suffer voltage fluctuations outside the acceptable statutory limits, and inject unwanted harmonics into the voltage waveform.

### 1.6 System Stability

Wind generation may displace existing conventional methods of generation which historically have provided the necessary response characteristics to maintain the overall integrity of the transmission system. Instability problems could arise under certain system operational conditions such as light demand periods; e.g. during the summer under windy conditions the new generators would meet a significantly higher percentage of the demand than is usual. The instability can be resolved by ensuring the new generation sources meet the strict criteria of the new GB Grid Code.

### 1.7 Protection Issues

It is not expected that the integration of the wind farm into the grid would interfere with the ability of the grid's protection scheme to function effectively [2].

### 1.8 Grid Code Compliance

As wind energy is projected to form a substantial part of the British generation mix, it was recognised that the technical capabilities of wind farms needed to match those of the traditional generators in providing support to the network. Therefore the three Great Britain Transmission Licensees (National Grid Company in England and Wales; Scottish Power and Scottish Hydro Electric Transmission Limited) have revised their Grid Code requirements. The National Grid Company has produced Guidance Notes for wind farm power park developers [3] to:

- record compliance with the Grid Code Connection conditions; and
- demonstrate such compliance through testing as required.

The four compliance tests required are:

- Steady-state reactive power capability across the voltage range to establish the ability of the wind farm to operate within specific power factors.
- Voltage control and reactive power stability i.e. the ability to provide continuously acting and stable automatic voltage control over the entire operating range of the power park.
- Frequency response to establish the power park's capability to continuously modulate active power to contribute to frequency control.
- Fault Ride-Through, Fault Contribution and Power Recovery i.e. the ability of the wind farm to remain connected to the network during severe faults at the point of connection (POC).

### 1.9 Studies

This paper reports on the results of the dynamic studies carried out to demonstrate the compliance of a wind farm to the fault ride-through requirements only. Two series of studies were carried out:

- Mode A - The simulation of a three-phase solid fault at a grid supply point and then evaluation of the power flow profile within the farm. The results of this study are analysed with respect to the Grid Code Connection Requirements for short-circuit faults of up to 140 msec duration.
- Mode B - The simulation of a series of balanced three-phase voltage dips as indicated in the Grid Code and calculation of the power and voltage profiles within the wind farm. The results of these studies are analysed with respect to the Grid Code Connection Requirements for voltage dips greater than 140 msec duration.

The studies were conducted using PSS/E v30.2 software running under Microsoft XP on an Intel PC computer. The wind farm network topology; cable parameters and circuit lengths were modelled in PSS/E format whereas the machine parameters were generated through IPLAN files supplied by the manufacturer. These comprised PSS/E user models of the generators and associated control and protection equipment.

The studies confirmed that the wind farm remained connected to the network and was capable of riding through the system faults, thus meeting the Grid Code's requirements.

### 1.10 Main Contributions of the Paper

The use of a realistic-sized practical network as described in Appendix A comprising of eight wind turbine generators.

Detailed procedure for conducting fault ride-through studies using commercially available power system analysis software such as PSS/E.

## 2. LITERATURE REVIEW

According to Strbac [4], the main challenges of integrating wind energy into the grid network are:

- Real time system balancing requiring the need for flexibility and increased reserve
- Generation capacity adequacy – what are the implications of increased maximum credible instantaneous loss of generation from the current level of 1320 MW?
- How much transmission capacity is required to transport wind power efficiently since the existing system has been developed for conventional generation?
- What are the system stability implications?

Some of the solutions for grid integration include [2]:

- Use of classical squirrel cage induction wind turbine generators (WTG).
- Use of induction WTGs with dynamic slip control.
- Induction or synchronous WTGs connected to the grid through power electronic converters.
- Doubly Fed Induction Generators (DFIG).

Two forms of WTG have been studied recently in the literature:

- Fixed-Speed Induction Generator – FSIG and
- Doubly Fed Induction Generator - DFIG

Though the FSIG provides a simple, rigid and cost effective solution for integrating wind farms to the grid [5], there could be problems in meeting grid code requirements because of their ability to absorb large amounts of reactive power. However, this non-compliance can be addressed by incorporating dynamic reactive power compensation via SVC or STATCOM [6]. Because this machine is of fixed-speed operation, it is impossible to produce the potential maximum power. There is no known method to control their generator torque and a small change in speed will cause a large torque change.

The main advantages of a DFIG include [7, 8]:

- Ability to vary the speed of the machine thus controlling its torque
- Reduction in the cost of the inverter
- Increase in efficiency of wind energy extraction
- Fast voltage recovery following a fault due to its ability to control reactive power

However, the DFIG has a more complex drive train and often the need for greater pitch control [9]. Since from practical considerations the advantages outweigh the disadvantages, it therefore follows that DFIG will become a viable industrial option.

## 3. CASE STUDY & RESULTS

The network model of the wind farm shown in Figure A.1 in Appendix A was connected to the main grid of a utility via appropriate cabling; this is not shown in the figure for confidentiality reasons. The wind farm consists of eight wind turbine generators rated at 850 kW.

The simplified PSS/E Classical Generator Model, GENCLS, was used for the dynamic representation of all the utility generators. Alternatively, the equivalent source representation of the fault in-feed technique may be utilised instead. The GENCLS is the classical constant voltage behind transient reactance generator model and can be used “as an effective short circuit current source in setting up approximate equivalents of segments of large interconnected power systems that are far removed from the area of specific interest” [10].

Both the steady state and dynamic models of the wind turbine machines from the manufacturers and their associated control equipment were established using the PSS/E version 30.2; the model was developed for a simulation time step of 10 msec.

### 3.1 “Mode A” Requirements

The purpose of this Study reported below was to simulate a three-phase solid fault at the nearest supergrid substation (275 kV) of the utility at time 1 sec for 140 msec and then evaluate the power flow profile within the wind farm. The results of the study were analysed with respect to the Grid Code Connection Requirements to investigate the fault ride-through capability of the wind farm.

According to Reference 3, the compliance requirements of the Code under this condition are:

- the wind turbine must remain transiently stable and connected for all supergrid phase voltages down to a minimum 0%

- the maximum possible reactive current should be generated without exceeding the transient rating limit of the turbine
- within 0.5 second following the fault clearance and restoration of the supergrid voltage to at least 90% of the nominal, the active power output must be restored to at least 90% of the level available immediately before the fault.

The results are shown in Figure 1 below for bus TX-WTG1:

- red - active power flow expressed in per unit
- blue- reactive power flow expressed in per unit
- green – speed
- pink - voltage

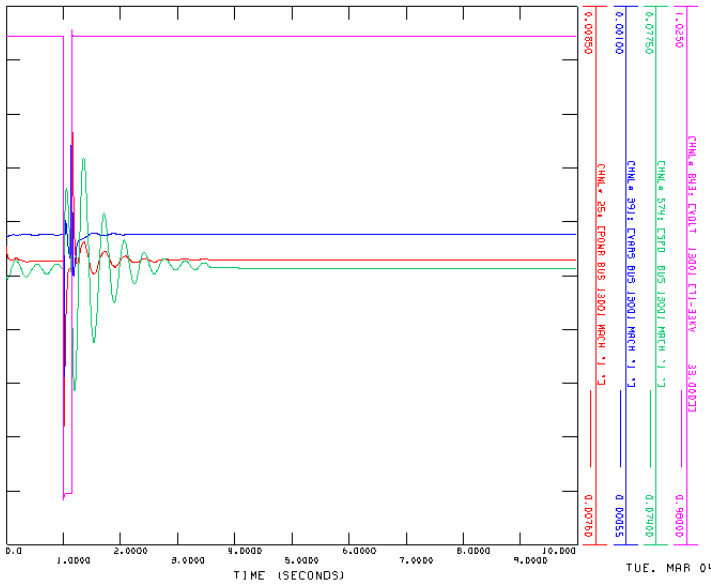


Figure 1 – The plots for generator bus TX-WTG1 for solid three-phase fault for 0.140 sec

### 3.2 “Mode B” Requirements

According to Reference 3, the compliance requirements of the Code under this condition are:

For supergrid voltage dips of duration greater than 140 msec, the wind farm has to remain connected to the system for any dip-duration on or above the heavy black line of Figure 2;

For supergrid voltage dips of duration greater than 140 msec, the wind farm has to supply active power to at least 90% of its pre-fault value within 1 second of restoration of the voltage to 90% of the nominal; and

During voltage dips lasting more than 140 msec, the active power output of a wind farm has to be retained at least in proportion to the retained balanced supergrid voltage.

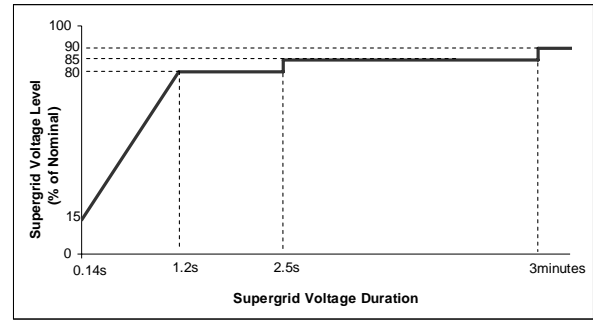


Figure 2 – Required Ride-Through Capability for voltage dips greater than 0.14 sec [11]

Faults were applied to the nearest 275 kV busbar (same as for Mode A) of severity and duration to meet the expected requirements of the Grid Code Connections Compliance. Table 1 below identifies the faults applied, their duration and the retained voltage at the 275 kV busbar. The shunt reactive MVA applied was determined by a running series of PSS/E TYSL (switching studies) simulations.

Study Number	% Retained Voltage at 275 kV busbar	Fault Duration	Shunt Reactive MVA Applied
1	30%	0.384 sec	10,125
2	50%	0.710 sec	4,450
3	65%	0.955 sec	2,500
4	80%	2.5 secs	1,250
5	85%	3 minutes	950

Table 1 – Shunt reactive MVA applied for various fault durations

The results of the Study Numbers 1-5 from Table 1 are shown in Figures 3-7 below. Only the active power powers are shown because of constraints on the number of pages for submission to this conference.

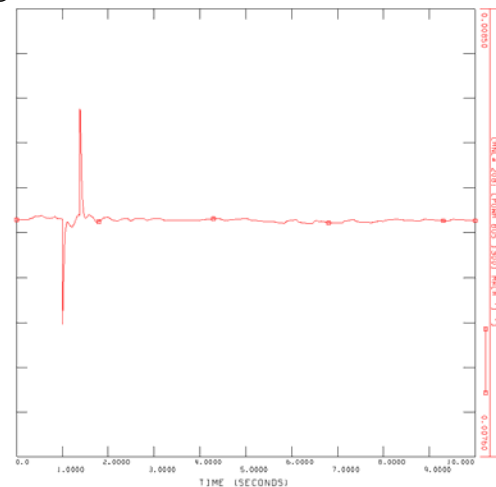


Figure 3 – The power plot for generator bus TX-WTG1 for 30% retained voltage for 0.384 sec

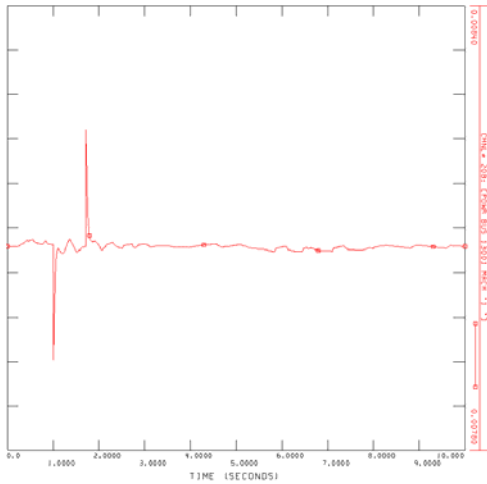


Figure 4 – The active power plot for generator bus TX-WGT1 for 50% retained voltage for 0.710 sec

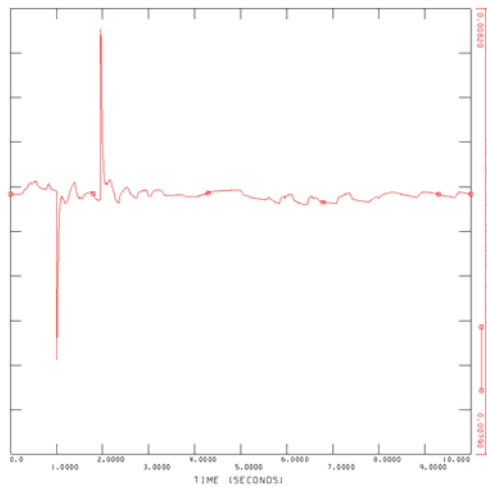


Figure 5 – The active power plot for generator bus TX-WGT1 for 65% retained voltage for 0.955 sec

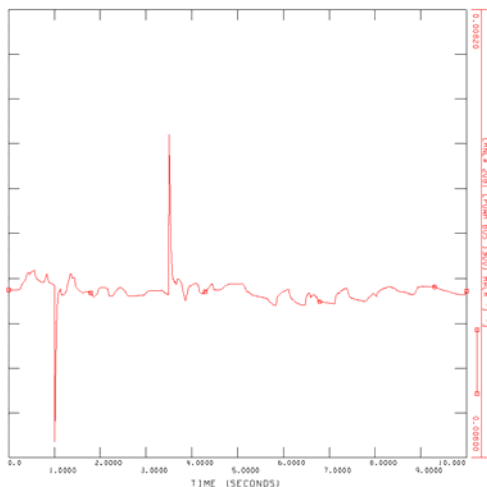


Figure 6 – The active power plot for generator bus TX-WGT1 for 80% retained voltage for 2.5 sec

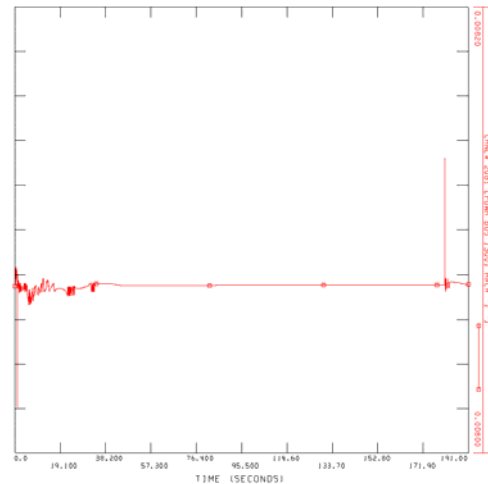


Figure 7 – The active power plot for generator bus TX-WGT1 for 85% retained voltage for 3 minutes

#### 4. CONCLUSIONS

The series of studies documented in this report has investigated the compliance of the wind farm in meeting the fault ride-through requirements of the GB Grid Code. The Wind Turbine model provided by the manufacturer was used as is; no validation was carried out on the model. The settings of the Double-Fed Induction Generator (DFIG) controllers were also used as provided.

The studies indicated that the wind farm remained connected to the network for system faults lasting up to 140 msec. The studies also demonstrated that the wind farm is capable of riding through the 275 kV system faults studied, those being: -

- 30% retained volts for 0.384 sec
- 50% retained volts for 0.710 sec
- 65% retained volts for 0.955 sec
- 80% retained volts for 2.5 sec
- 85% retained volts for 3 minutes.

The wind farm therefore meets the required ride-through capability of Figure 2. The fast voltage recovery may be due to the ability of the DFIG to control reactive power [8]. As the generator remains connected to the grid, a large amount of reactive power is absorbed whereas the active power fluctuates after fault clearance.

#### 5. REFERENCES

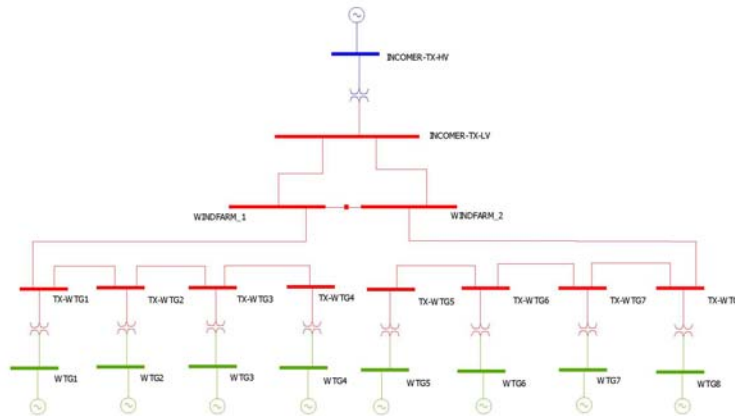
1. McGrow L (2006), “Wind Power satisfies Network Demands”, The Engineering and Technology Power Engineer Magazine, April 2006
2. Bousseau P, Fesquet F, Belhomme R, Nguéfeu S and Thai T (2006), “Solutions for the Grid Integration of Wind Farms – a Survey”, Wind Energy published by John Wiley vol. 9, pp 13-25

3. Guidance Notes for Power Park Developers (2007), Grid Code Connection Conditions Compliance: Testing & Submission of Compliance Report – Issue 1.1
4. Strbac G (2007), “Integration of wind power in the GB electricity system” presented at the Thinking Networks Conference, 27 March 2007
5. Xu L., Lao L and Sasse C (2006), “Comparison of using SVC and STATCOM for wind farm integration” IEEE International Conference on Power System technology, pp 1-7
6. Jenkins N (2007), “Dynamics and Stability of Renewable Energy Sources” presented at the Thinking Networks Conference, 27 March 2007
7. Holdsworth L, Jenkins and Strbac G (2001), “Electrical Stability of Large Offshore Wind Farms”, Proceedings of the IEEE AC-DC Power Transmission Conference, 28-30 November, pp 156-161
8. Perdana A, Carlson A and Persson J. (2004), “Dynamic Response of Grid-Connected Wind Turbine with Doubly Fed Induction Generator during Disturbances” Nordic Workshop on Power and Industrial Electronics, Trondheim
9. Enslin et al (2003), “Integrated approach to network stability and wind energy technology for on-shore and off-shore applications” 24th International conference for Power Electronics, Intelligent Motion and Power Quality, Nuremberg, Germany. 20-22 May 2003
10. PSS/E-30.2 Program Application Guide: Volume II page 13-5
11. Chondrogiannia S, Barnes M and Aten M (2006), “Technologies for Integrating Wind Farms to the Grid” Interim Report submitted to the DTI Technology Programme

## 6. ACKNOWLEDGEMENTS

The authors are grateful to the Management of PB Power and Scottish Power for permission to publish this paper. The discussions held with Dr Charles Lynch (Principal Engineer/Director, Power Analysis Ltd) on the subject of this paper are appreciated.

## APPENDIX A



**Figure: A.1 – Wind Farm Electrical Model**

### Cable Data

From	To	Cable Type	Number of cables in parallel	Conductor size(mm <sup>2</sup> )	Voltage kV	Rating A	R ohm/km	X ohm/km	Length m
TX-WTG1	TX-WTG2	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	330
TX-WTG2	TX-WTG3	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	100
TX-WTG3	TX-WTG4	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	420
TX-WTG5	TX-WTG6	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	394
TX-WTG6	TX-WTG7	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	421
TX-WTG7	TX-WTG8	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	417
WINDFARM_1	TX-WTG1	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	422
WINDFARM_2	TX-WTG8	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	415
INCOMER-TX-LV	WINDFARM_1	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	793
INCOMER-TX-LV	WINDFARM_2	Cu/XLPE 3x 1core	1	95	33	165	0.41	0.158	420

### Transformer Data

Voltage ratio	Rating(MVA)	Z%	X/R	Winding Type	Tap
132/33 kV	40	10%	28	YNd1	+/- 15%

### Busbar Data

Name	Nominal Voltage kV	Name	Nominal Voltage kV
INCOMER-TX-HV	132	TX-WTG5	33
INCOMER-TX-LV	33	TX-WTG6	33
TX-WTG1	33	TX-WTG7	33
TX-WTG2	33	TX-WTG8	33
TX-WTG3	33	WINDFARM_1	33
TX-WTG4	33	WINDFARM_2	33

Fault in-feed at the grid supply point is 4308 MVA with X/R ratio of 5.9

The generator transformer and dynamics data were supplied by the manufacturer. These are confidential so are not shown.