Electric Power Systems Research 64 (2003) 41–51

ELECTRIC POWER SYSTEMS RESEARCH

www.elsevier.com/locate/epsr

Contribution to a dynamic wind turbine model validation from a wind farm islanding experiment

J.K. Pedersen [a], K.O. Helgelsen-Pedersen [a], N. Kjølstad Poulsen [b], V. Akhmatov [c,*], A. Hejde Nielsen [a]

[a] *Department of Electric Power Engineering, Building 325, Technical University of Denmark, DK-2800 Lyngby, Denmark*
[b] *Department of Mathematical Modelling, Building 321, Technical University of Denmark, DK-2800 Lyngby, Denmark*
[c] *NESA Transmission Planning, NESA A/S, NESA Allé 1, DK-2820 Gentofte, Denmark*

Received 21 February 2002; received in revised form 23 May 2002; accepted 12 June 2002

Abstract

Measurements from an islanding experiment on the Rejsby Hede wind farm, Denmark, are used for the validation of the dynamic model of grid-connected, stall-controlled wind turbines equipped with induction generators. The simulated results are found to be in good agreement with the measurements and possible discrepancies are explained. The work with the wind turbine model validation relates to the dynamic stability investigations on incorporation of large amount of wind power in the Danish power grid, where the dynamic wind turbine model is applied.

Keywords: Islanding experiment; Wind turbine model; Verification; Dynamic simulation tool PSS/E

1. Introduction

Denmark has currently about 2500 MW wind power capacity in on-land and few offshore sites [1], which corresponds to 27% of power consumption (in average). Further construction of two large-scale offshore wind farms has been announced. The first large offshore wind farm in Denmark of 150 MW rated power is under construction at Horns Rev in the area of the western Danish system operator, ELTRA, [2]. This will be followed by the first in the area of the eastern Danish system operator, ELKRAFT System, large offshore wind farm at Rødsand by the year 2003 [3].

The installed capacity in on-land sites and in small, but many combined heat-power (CHP) units will increase as well, where the power production and controlability of the conventional power plants are reduced. In the years to come, the power production pattern in the Danish power system will change from the power supply from conventional power plants—as it is known today—to a power supply mix, where about 30–40% of power consumption (in average) is covered by wind power. In other words, the power technology will undergo changes from a well-known technology built-up about conventional power plants to a partly unknown technology—wind power. Then, it will be focused on maintaining power system stability and voltage stability, for example, at a short circuit fault, ensuring power supply safety and other important tasks [4] as amount of wind power increases drastically. This leads to necessity of dynamic stability investigations and implementation of technical solutions found from these investigations, which are carried out using sufficiently detailed models of electric power systems and models of electricity-producing wind turbines.

Correctness and credibility of the technical solutions found from the dynamic stability investigations depend on several factors, but first and foremost on the development of realistic models of electricity-producing wind turbines [5].

At NESA Transmission Planning, where the dynamic stability investigations dealing with incorporation of large amount of wind power in the eastern Danish power system are taking place for the system operator

* Corresponding author
E-mail address: va@eltek.dtu.dk (V. Akhmatov).

0378-7796/02/$ - see front matter
PII: S0378-7796(02)00144-X

ELKRAFT System, the dynamic simulation tool PSS/E is applied. With the simulation tool PSS/E, it is possible to make stability investigations using sufficiently detailed and realistic models of large power systems, but the tool PSS/E has no representation of electricity-producing wind turbines of sufficient complexity among its standard models yet [5–7]. Purposing the dynamic stability investigations, a number of dynamic models of grid-connected wind turbines of different complexity and of different wind turbine concepts have been developed and implemented in the tool PSS/E at NESA Transmission Planning [4,5,8]. Verification of the wind turbine models applied in the dynamic stability investigations is an unavoidable part of the model development process and currently taking place where measurements are available.

In this paper, the simulating results with use of the model of stall-controlled, fixed-speed wind turbines equipped with induction generators are compared with measurements from an islanding experiment carried on the Danish wind farm at Rejsby Hede [9]. This paper is primarily dealing with validation of the dynamic wind turbine model, its considerations and simulating results. The results of comparison between simulation and measurements and possible discrepancies are explained. The details of the islanding experiment, and the measuring and estimating technique are given in [9], which is why the details about measuring are omitted in this paper.

This work is seen as a contribution to verification of the models of grid-connected wind turbines implemented in the simulation tool PSS/E at NESA Transmission Planning and applied in practical stability investigations with relation to incorporation of large amount of wind power in the eastern Danish power system.

This work may have relation for users of dynamic simulation tool PSS/E as well, when use of dynamic simulations and especially the tool PSS/E become a part of power system stability investigations with the incorporation of large amount of wind power into power grids around the world [4,7].

2. Experiment

The islanding experiment was carried out on 3 September 1997 on the Rejsby Hede wind farm [9], located in the south of Jutland, which is in the ELTRA area. Only information about the experiment, which is necessary for understanding of validation, is given here, whilst a detailed description of the experiment might be found in [9].

The wind farm consists of 40 stall-controlled electricity-producing wind turbines equipped with induction generators of 600 kW rated power each. The induction generators are no-load compensated with the capacitors of 150 kVar each. Through the 15/0.69 kV transformers, the wind turbine induction generators are connected to the 15 kV internal cable network of the wind farm consisting of two sections with 18 and 22 wind turbines, respectively. These two groups of wind turbines are shown by the two equivalents, for drawing simplification.

Further, a Statcom is grid-connected to the wind farm internal network. Through the 60/15/15 kV tertiary transformer, the wind farm is connected to the 60 kV local power network and, then, through the overhead lines to the 150 kV transmission power system, as shown in Fig. 1.

Initially to the islanding experiment, the switchgears SW1, SW2 and SW3 were off, and the consumers in Hojer and Ballum received electric power from another part of the power network (not shown in Fig. 1).

All these descriptions above relate to the local 0.69–15–60 kV power network of the experiment connected to a relatively strong transmission power system, which is marked by the unit E at Bredebro (see Fig. 1).

During the islanding experiment, the phase currents and the phase voltages were measured in sites A and B—from these two sections of the wind farm, and in site C—from the Statcom, as marked in Fig. 1. Further, the voltage angle and the electric frequency in site B were estimated from the measurements by the technique described in [9].

The switchgear SW4 was opened 0.4 s after the start of the experiment, and this is called the moment of islanding. From this moment, the wind turbines and the local network were in islanded operation till the wind turbines were tripped by their protective relays. The wind turbines were tripped somewhere at 1.32 s after the experiment start, presumably by over-frequency. This means that the duration of islanded operation was approximately 0.92 s.

It is noticed that the Statcom stopped operation and tripped almost immediately (by few milliseconds) at the moment of islanding. This was presumably caused by the voltage angle jump. Hence, the Statcom did not influence on the measured behaviours during the islanding experiment, which simplifies the situation about analysis of the islanding experiment and validation of the wind turbine model.

The measurements and the description of measuring and estimation technique are originally described in [9], but some of the measured curves are drawn below for the purpose of comparing to the simulating results and the model validation only. The voltage and current measured in site B are shown in Fig. 2. The voltage maintained its level after islanding, but with some variations in the magnitude and the frequency. The current drops and shows the tendency to decay to zero.

The voltage angle in site B, which is estimated from the voltage measurements by the technique of Pedersen