Analysis and Research of Low Frequency Oscillation of Power Network Equipment Based on RIDS Test

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Abstract. Hybrid transmission of doubly-fed wind power plant and conventional power plant is the principal mode of large-scale wind power development and transmission in future, but overall stability of this transmission mode is possibly poor. The paper first analyzes low frequency oscillation of conventional power plant and wind power plant in hybrid transmission mode; then analyzes feasibility of wind power plant damping and conventional power plant low frequency oscillation, puts forward additional damping control technology and make experimental prototype which excavate wind turbines self transient active power regulation capacity to contribute to power network damping; and finally make real-time simulation modeling of system (including doubly-fed generator system model, synchronous generator system model and “wind fire banding” system model) with real-time digital simulator (RIDS) and make joint debugging together with experimental prototype.

Introduction

The paper makes research on damping regulation capacity of doubly-fed wind turbine generator, brings forward additional damping control technology and trial-produce testing apparatus. Test based on RIDS verifies that the device has significant damping effect on low frequency oscillation of power network. As new energy utilization pattern with most large scale development conditions, wind power generation enjoys a rapid expansion in the country [1]. To make wind power consumed in national market, large-scale wind power plant will make cross-region transmission after “binding” with thermal power[3]; since hybrid power transmission system has features of long distance and heavy loads, the power network structure and running status are easy to lead to weak (negative) damping low frequency oscillation[4]. Doubly-fed wind driven generator can achieve its active and reactive decoupling control[8], and can regulate its output active power through adjustment of wind turbine generator self active power control link in transient process; for large-scale wind power plant, it can regulate active power of whole wind field. With damping effect of wind power plant transient active power on synchronous motor in electric system, active stability of system can be achieved. Therefore, aimed to increase system damping, excavating wind turbines self transient active power regulation capacity to improve low frequency characteristic of power grid, which is of great importance in improvement of wind power integration technology and ensuring network security.

Low Frequency Oscillation of "Wind Fire Banding" Power Transmission System

Large-scale wind power bases of the country mainly lie in remote areas where generated power by large-scale wind power plant can not be wholly consumed and wind power cross-region transmission is necessary. However, wind power single remote transmission mode is of poor economical efficiency and wind power frequency fluctuates frequently and erratically which goes against safe and stable operation of power network and therefore "wind fire banding" type transmission mode [9] is mainly applied in electricity delivery of current large-scale wind power plant, as shown in Fig 1. Wind power is banded with neighboring conventional power plant and transmitted to distant large scale system through (ultra) high voltage line.

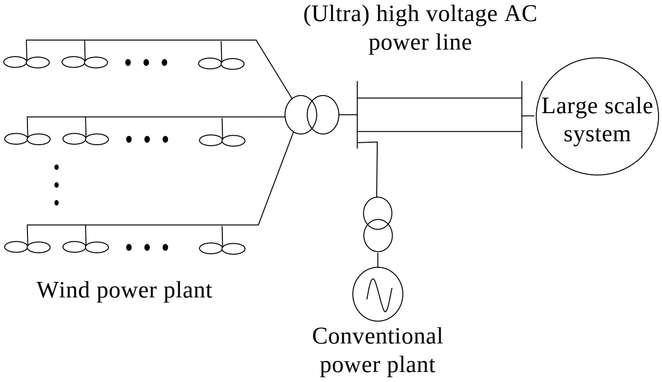


Fig.1. "Wind fire banding" type transmission mode

"Wind fire banding" hybrid transmission mode is the long distance power transmission mode. Since wind power utilization hours is far less than that of conventional power plant, wind power transmission channel capacity is not designed in accordance with maximum power but is smaller than maximum power. Hence, when the wind power is largely outputted, power transmission line is in heavy load and its closely banded conventional power plant is also in long distance and heavy load operating status, during which risk of low frequency oscillation is high. In addition, vector control applied in wind turbine will also influence its damping force characteristic[10]. Also note that thermal power generating unit banded with wind power plant assumes the task of stabilizing wind power fluctuation, thus thermal power generating unit is of frequent output adjustment which is easy lead to quitting of power system stabilizer (PSS) due to "reverse action"[11]. The damping force characteristic of thermal power generating unit will deteriorate further. It is thus clear that sufficient damping measures shall be taken for "wind fire banding" transmission system to ensure safe operation of this transmission mode.

Analysis of Single Wind Turbine Transient Active Rapidity

State equation of doubly-fed motor in d-q coordinate system with stator flux linkage () and rotor current () selected to be state variables can be expressed as

$$\begin{cases} p\psi_{ds} = -\dfrac{r_s}{L_s}\psi_{ds} + L''r_s i_{dr} + \omega_1\psi_{qs} \\ p\psi_{qs} = -\dfrac{r_s}{L_s}\psi_{qs} + L''r_s i_{qr} - \omega_1\psi_{ds} + u_{qs} \\ pL'i_{dr} = -r_r i_{dr} + u_{dr} + \omega_2 L' i_{qr} + \omega_2 L''\psi_{qs} - L''p\psi_{ds} \\ pL'i_{qr} = -r_r i_{qr} + u_{qr} - \omega_2 L' i_{dr} - \omega_2 L''\psi_{ds} - L''p\psi_{qs} \end{cases} \tag{1}$$

Thereinto:and are self-inductance and mutual inductance of stator and rotor respectively;are stator and rotor resistances respectively; and are synchronous speed and rotating speed difference respectively; are component of exciting voltage in ordinate axis and abscissa axis respectively; is stator voltage; *p* is differential operator.

When feedforward compensation is applied in rotor current state equation (1), relation between rotor current and control instruction (,) can obtained:

$$\begin{cases} pL'i_{dr} = -r_r i_{dr} + u_{dr}^* \\ pL'i_{qr} = -r_r i_{qr} + u_{qr}^* \end{cases} \tag{2}$$

Equation (2) indicates that response of rotor active current and reactive current to control instruction is a first-order inertial element; special attention needs to be paid to time constant of inertial element. Substitute typical parameter of doubly-fed motor in and it can get that τ is about 10ms. Analysis above shows that single wind turbine has active and reactive reaction capacity in millisecond under external control instruction.

Modeling and Prototype Testing Based on RTDS

To test effectiveness of damping control strategy and experimental prototype, “semi-physical test” based on real time digital simulator is needed for verification. Experimental prototype is material object to be verified, and “wind fire banding” power transmission system virtual controlled object which refers to the digital model based on RTDS.

Simulation model of “wind fire banding” power transmission system

Compared with conventional power plant, wind turbine generator is of small capacity and large number and it is unpractical to simulate each unit in details[14]. “Equal similarity ratio” simulation method is applied in the paper, i.e. to scale down the actual large-scale wind power system, to use one doubly-fed wind turbine for simulation of multiple units in close electrical connection with relationships among various parameters remaining unchanged. Hence, after a large-scale wind power plant is divided into several parts, dynamic behavior of the whole wind power plant can be simulated with a few doubly-fed wind turbines. The model established can simulate each unit’s electromagnetism and electromechanical transient in details and avoid aggregation, equivalence or simplification to make the simulation results more close to practical ones.

“Wind fire banding” power transmission system model established based on RTDS consists of 6 wind turbines and 1 synchronous generator and wind fire capacity ratio of whole system is 1:1.5. According to principle of “parameter per unit value is equal”, synchronous power station capacity is reduced to megawatt in accordance with ratio of similitude; thereinto: rated capacity of single doubly-fed wind turbine is 2.2MVA, rated frequency 50Hz, stator winding resistance value 0.00462p.u., stator leakage reactance 0.102p.u.; rated capacity of synchronous generator is 20MVA, rotor inertia time constant 4.7MWs, stator leakage reactance 0.2327p.u. and unsaturated reactance of d axis 1.7134 p.u..

Hardware requirements and computation task allocation of RTDS

Hardware requirements of RTDS is as follows: whole mode makes use of 2 RACK, 10 processors (GPC-PB5) in totaland 1 12-channel analog output card (GTAI) and 1 12-channle analog output card (GTAO). RTDS is the real-time simulation equipment and processor allocation needs to be considered during modeling; to improve simulation accuracy, RTDS/RSCAD small step (<2us) system is applied to establish doubly-fed generator system model; each model includes doubly-fed generator, PWM frequency converter and transformer, etc. Small step section needs to be established in VSC model of small step model library and each VSC model corresponds to the corresponding processor (GPC-PB5), so in 10 processors, 6 correspond to 6 doubly-fed generator system models respectively and the remaining 4 are used to calculate control segment, synchronous generator section and power network simulation section.

3.3 Experimental prototype and RTDS interface method

Wind power plant and electric system are simulated in real time by RTDS, public busbar frequency of wind power plant or synchronous motor speed and power angle are successive type state variables of real-time simulation model and are outputted by GATO of RTDS; these analog quantities are connected to data acquisition module of testing apparatus with signal cables. In order to simulate optical fiber channel actually applied in wind power plant, photovoltaic conversion module and 3km single mode fiber are installed in testing apparatus. The collection quantity from

RTDS passes data processing module and algorithm formation module and generates additional damping control signals. The additional damping control signals pass optical-electric module and fieldbus and are connected to GTAI interface of RTDS again to conduct system stabilization control. After being so connected, RTDS and testing apparatus constitute a closed loop control system among which testing apparatus is the controller and RTDS controlled object.

Testing Apparatus and RTDS On-Line Test

Closed loop test in semi-physical form can be carried out on the basis of Section 3 and the testing system structure is shown as Fig 3. The test procedure is as follows: adjust synchronous generator excitation parameter and active power output to make it take on weak damping working conditions; set three-phase short trouble in public busbar and activates system to have low frequency oscillation raised; supervise synchronous generator speed and wind turbine active power output, stator and rotor currents.

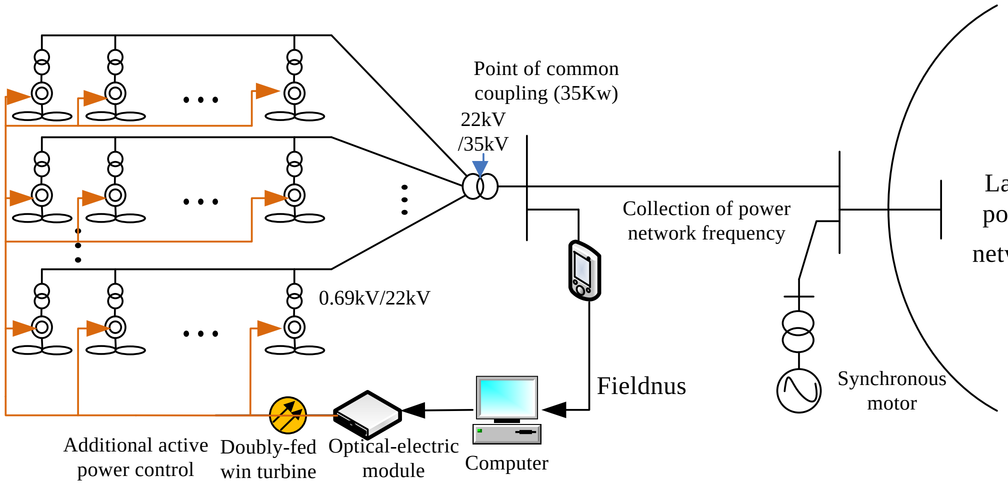
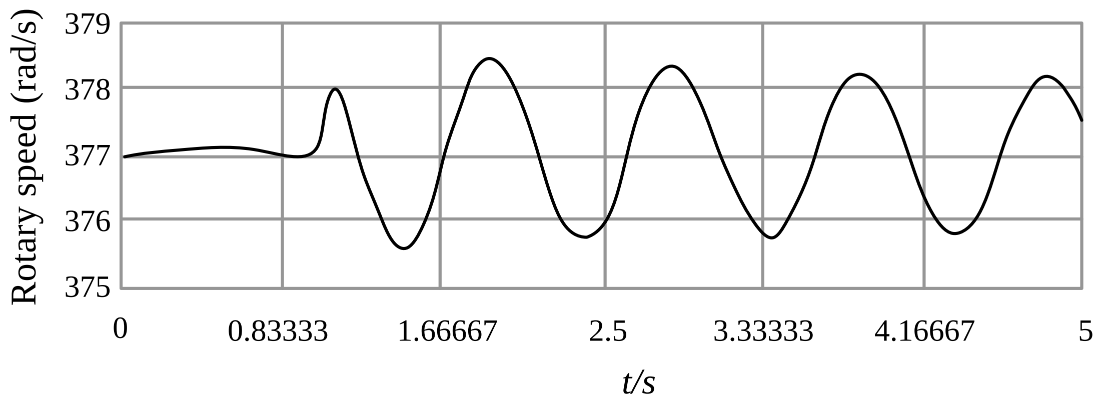
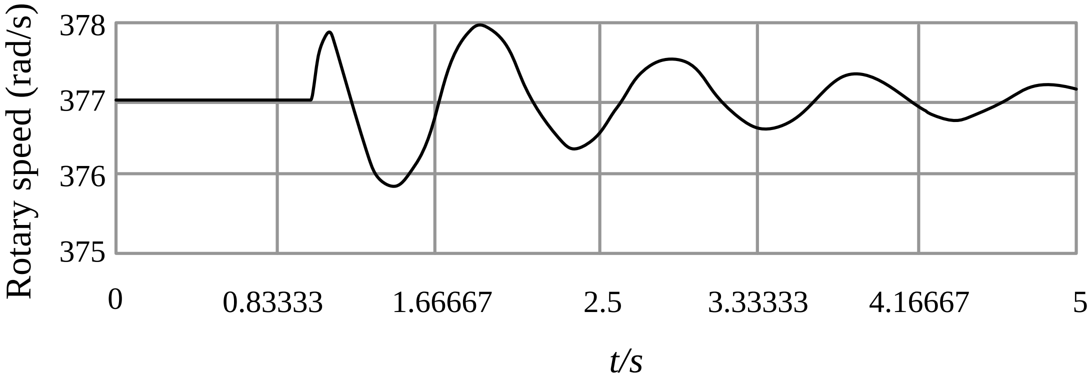


Fig.3. system structure drawing

(1) Supervise synchronous generator speed and observe additional damping control effect. For example, Fig 4(a) is synchronous motor speed rocking curve while testing apparatus is not connected; Fig. 4(b) synchronous motor speed change curve while testing apparatus is connected. The comparison between Fig 4(a) and Fig 4(b) shows that rotor rocking curve of synchronous motor after additional damping control is connected attenuates much quickly, showing a good damping force characteristic and explaining that damping force characteristic of additional damping control system is improved obviously.



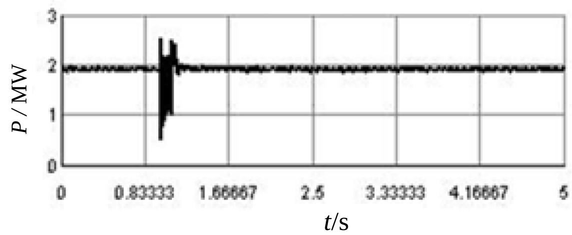
(a) Experimental prototype is not connected



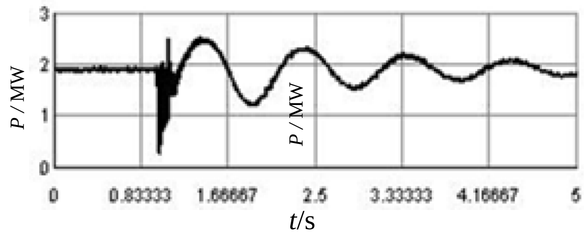
(b) Experimental prototype is connected

Fig.4. Synchronous generator speed

(2) Supervise active power output of doubly-fed wind turbine generator system and analyze that wind turbine self transient active power regulation capacity. Fig 5(a) is real-time active power output of doubly-fed wind turbine generator system in which damping control technology is not applied when there is a short trouble; Fig 5(b) is real-time active power output of doubly-fed wind turbine generator system in which damping control technology is applied. The comparison between the two figures shows that when low frequency oscillation occurs in the system, doubly-fed wind turbine adjusts its active power output to create additional damping control effect according to additional control signal generated by testing apparatus. But when testing apparatus is not connected, doubly-fed wind turbine operates in accordance with its constant active instruction and has no damping effect on synchronous generator in the power network.



(a) Experimental prototype is not connected



(b) Experimental prototype is connected

Fig.5. Doubly-fed generator active power output

On the basis of test results above, it can be seen that when system operates in weak (negative) damping, establishment of wind power plant centralized control platform and WAN communication network to control active power output of each doubly-fed wind turbine to create additional damping control can increase system damping and restrain low frequency oscillation occurring in the system and the control method would not have negative effect on wind turbine and system and is an enforceable technical proposal.

Conclusion

(1) Active power and reactive power of doubly-fed wind turbine have quick response ability and with support of WAN optical fiber communication network, doubly-fed wind power plant has quick adjustment ability of active power.

(2) Quick adjustability of doubly-fed wind power plant transient active power makes low

frequency oscillation of damping parallel operating thermal power generating unit possible and active power adjustment against wind power plant can produce damping against thermal power generating unit.

(3) On-line test is carried out for established experimental prototype and RTDS. The test shows that experimental prototype developed based on the proposed method can make the wind power plant have significant damping effect on thermal power plant, thus decreasing risk of occurrence of low frequency oscillation for power network.

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