Study on Small Signal Stability Improvement by PSS of the Large-Scale Wind Power Integration

Zi Lan Zhao, Wen Ying Liu, and Xu Bin Han

***Abstract*—With the increasing penetration of wind energy generation into power system, the impact of wind farms on power grids performance and stability control is of growing concern. Firstly there is a introduction of basic principles related to small signal stability analysis. Then a new method of improving small signal stability is proposed in this paper. The method, based on optimization adjustment of time constant of the phase shift link of PSS, is verified to be effective by an instance analysis of simulation in DIgSILENT/Power Factory. Three-machine Nine Nodes Model is used in this simulation.**

***Index Terms*—Small signal stability, PSS, wind farms.**

I. Introduction

An important aspect related to wind energy integration into the electrical power system is the fluctuation of the generated power due to the stochastic variations of the wind speed across the area where wind turbines are installed. The performance of power grid function is characteristic with weak damping. Simulation models are useful tools to evaluate the impact of the wind power on the power system stability and on the power quality.

Due to the intermittent nature of wind power, lower stabilization of power system operation can be incurred when wind penetration level increases. It is very decisive to accurately estimate the small signal stability of the power grid. Much more research on this field has been going with the intention of finding an effective approach to get the operation of power system improved in small signal stability.

Reference [1] have described the general asynchronous fan small signal stability study shows that fixed speed fan to of system has a little influence on the original oscillation mode, however, the wind farm related oscillation mode damping is performed better. Reference [2], [3] showed the small signal stability varied as the fan and the output of the wind farms changed. However, how the small signal stability can be improved by changing PSS parameters and installation points is not comprehensive [4].

In this paper, we analyze the effect of small signal stability when large-scale wind power is integrated firstly. Secondly, the power system small signal stability can be improved by PSS application and changing the PSS parameters, as well as by changing the installation locations. Finally, the Three-machine Nine Nodes Model is built by DIgSILENT/Power Factory software. PSS application and changing the PSS parameters, using frequency domain analysis and observation the system shock curve, get the conclusion of the wind Power generator application of PSS and rational changing the time constant of the phase shift link of PSS can improve the system small signal stability.

Manuscript received October 19, 2012; revised November 25, 2012 .

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II. Stability Problems of Small Signal Stability with Large-Scale Wind Power Integration

A. The Impacts of Large-Scale Wind Power Integration on the Small Signal Stability

In new wind power installations mostly variable-speed wind turbines with frequency converters are used, in contrast to the older constant-speed models with simple squirrel cage induction generators. Variable-speed operation of wind turbines offers certain advantages: mechanical stress is reduced, torque oscillations are not transmitted to the grid and, below rated wind speed, and the rotor speed is controlled to achieve maximum aerodynamic efficiency. With increasing wind power penetration in electric power systems, its effect on power system stability has become an important issue of concern [5].

Since the wind generation is replacing conventional power, its effect has to be assessed in two ways. First, the effect of reduced conventional generation is assessed by modeling the wind parks as negative loads, either constant admittance, or constant power. In all cases the reduction of conventional generation is represented first with a constantly loaded unit with reducing MVA, and the as reduced loading of a constant MVA unit. The first representation corresponds to the case of dis-connection of conventional units in order to accommodate wind generation, whereas in the second case conventional plants remain connected with reduced output, thus the system inertia remains intact.

B. Small Signal Stability Analysis

In general, we characterize a dynamic process of power system with nonlinear differential equations and algebraic equations as following.

$$\dot{x} = f(x,u)$$

$$\dot{y} = g(x,u) \tag{1}$$

where $x = [x_1, x_2, \ldots x_n]^T$ is state vector of the system; $[u_1, u_2, \ldots u_r]^T$ is input vector; $[y_1, y_2, \ldots y_m]^T$ is output vector; f, g are the nonlinear functions associated with x and u.

After linearizing transformation with the initial

DOI: 10.7763/IJCEE.2013.V5.704

point $x = x_0$, $y = y_0$, the system can be described as (2).

$$\Delta \dot{x} = A\Delta X_0 + B\Delta u_0$$

$$\Delta \dot{y} = C\Delta X_0 + D\Delta u_0 \tag{2}$$

where A is a $n \times n$ matrix; B is a $n \times r$ matrix of control variables; C is a $m \times n$ matrix of output; D is a $m \times r$ feedforward control variables matrix[6].

Assume that variable i is inject current vector of some dynamic component, and v is node voltage vector, we can get equations (3) according to Network equations.

$$i = Y_N v \tag{3}$$

where Y_N is admittance matrix. From (2) and (3),we can easily get the system 's augmented state equation like (4).

$$\Delta x = A' \Delta x \tag{4}$$

where $A' = A + B(Y_N - D)^{-1} C$ is an augmented state matrix, which includes all kinds of dynamic devices' characteristics and their connecting relationship in the system. And almost all of the information related to small signal stability can be obtained by calculating the eigenvalues of the matrix [7] .

There are two methods used in the process of small signal stability analysis. One is frequency domain analysis and the other is time domain analysis. Eigenvalue analysis is a classic study of power system dynamic stability of small interfering among the frequency-domain methods [8]. And it has been widely used in evaluating system small signal stability. In addition, the analysis of time domain simulations also called gradually integral method [9], which has the advantages that it can be used in various nonlinear equipment of the transient process, and neither concentrated parameter model or process parameter model can be used in the network components.

III. The Simulation Analysis of Improving the Small Signal Stability of Power System with Wind Integration by Using PSS

A. Basic Principles and the Model of the PSS

Power system stabilizer (PSS) is an automatic control device, which is designed to improve the stability of the synchronous motor. And it's control function is depending on the field winding of the excitation system.

PSS transfer function model is illustrated as Fig.1:

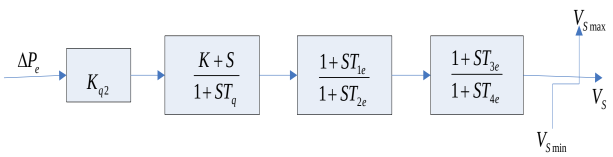

Fig.1. PSS transfer function model

In the Fig. 1, T_{1e} 、T_{2e} 、T_{3e} 、T_{4e} are the time constant of phase shift link [10].

The application of PSS can improve the damping characteristic of the system and then its static stability as well. Besides, the small single stability of the wind power integration can also be improved by changing the installation location and the parameters of PSS. In this paper, we take changing installation location for example, PSS is only installed in high magnification rapid response of excitation system of synchronous machine. So that the system low frequency oscillation should be inhibited efficiently. Therefore, PSS is not necessary in a small capacity power units or those which field system time constant is larger[4].

B. Instance Analysis of Simulation

In this paper, we use the model of the Three-machine Nine Nodes, containing DFIG, and it will be established in the DIgSILENT / Power Factory software. And then some simulation of the small signal stability on the power system is done. At last, the influence of PSS on small signal stability is concluded by analyzing the data used in the process, such as the locations, parameters and so on. Take DFIG as an example here and the model is pictured in Fig.2 as following.

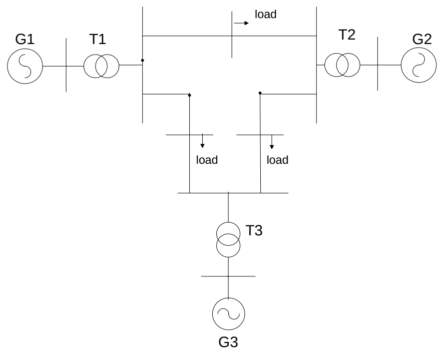

Fig. 2. With DFIG of Three-machine Nine Nodes Model

In order to find out how the small signal stability of the grid is going in this simulation, the first thing is calculating the initial value, and then figure out the eigenvalues of the three machine nine nodes. QR-algorithm method is used in this paper under the frequency domain analysis method, and calculating all the characteristic roots in the Five-Cycles Fault Mag-A-Stat case . Fig. 3 illustrates the eigenvalue calculation results.

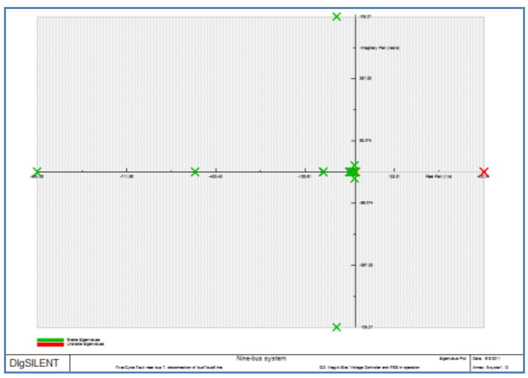

Fig. 3. the characteristic root calculation in Five-Cycles Fault Mag-A-Stat case

This case is the low-frequency oscillations in the electromechanical transient and in the mechanical mode have N-1 characteristic roots satisfy the oscillation frequency between 0.2Hz to 2Hz, so it should have two pairs (four) characteristic roots in the Three-machine Nine Node Model like that. The value of characteristic roots are as the following Table I:

TABLE I: THE VALUE OF CHARACTERISTIC ROOT IN FIVE-CYCLES FAULT MAG-A STAT CASE

Real Part (s^{-1})	Imaginary Part (s^{-1})	Damped Frequency (Hz)	Damping Ration
-1.826002	20.11498	1.801399	0.09040645
-1.826002	-20.11498	1.801399	0.09040645
1.157373	0.00000	0.7709918	0.222874
1.157373	0.00000	0.7709918	0.222874

The results show that there is an unstable characteristic roots. PSS is only added in the generator G1 and G3 in the system, so we can get G2 installed the PSS, and after simulation we can see that PSS application can make the system becomes stabilizer accordingly. The characteristic roots of simulation model are illustrated in Fig.4 as following.

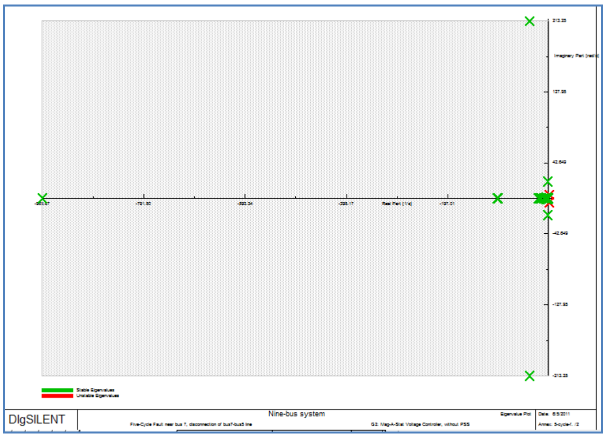

Fig. 4. the characteristic root calculation in Five-Cycles Fault Mag-A-Stat|PSS case

There are two pairs characteristic roots satisfying the oscillation frequency which ranged from 0.2Hz to 2Hz in electromechanical model, and the value of characteristic roots as follows in Table II:

TABLE II: THE VALUE OF CHARACTERISTIC ROOT IN FIVE-CYCLES FAULT MAG-A STAT|PSS CASE

Real Part (s^{-1})	Imaginary Part (s^{-1})	Damped Frequency (Hz)	Damping Ration
-1.826002	20.11498	1.801399	0.09040645
-1.826002	-20.11498	1.801399	0.09040645
-0.7403441	1.203119	0.1914824	-0.2323752
-0.7403441	1.203119	0.1914824	-0.2323752

As the Fig. 4 and Table II showing, after installing PSS to the power system, all characteristic roots are in the left half plane, and the system becomes stable. It is the reason that PSS can increase power system positive damping, and reduce the low-frequency oscillation of the system.

We can also adjust the parameters of the PSS to improve the power system small signal stability by the means like changing the parameters of the phase-shifting aspects of the time constant.

Fig. 3 is the initial state system, at that time $K_{q2}=30$, $K=30$, $V_{S\max}=0.1$, $V_{S\min}=-0.1$, $T_q=10$, $T_{1e}=T_{2e}=0.05$, $T_{2e}=T_{4e}=0.2$ and system small single is not stable. However, changing the parameters of PSS, time constant of the phase shift link adjust to $K_{q2}=30$, $K=30$, $V_{S\max}=0.1$, $V_{S\min}=-0.1$, $T_q=10$, $T_{1e}=T_{2e}=0.23$, $T_{2e}=T_{4e}=0.17$, it can also make the power angle curve of the system tends to stability, as shown in Fig. 5:

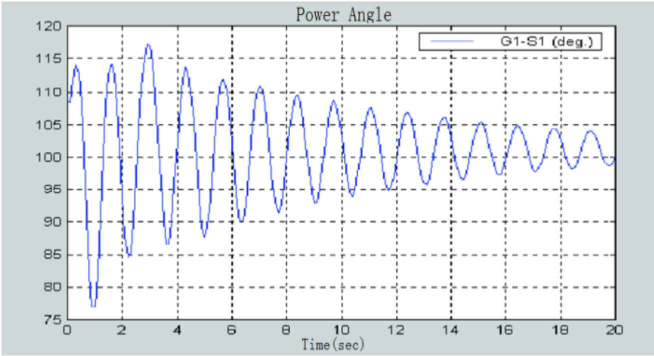

Fig. 5. Generator power angle oscillation curve after changing the PSS parameter

Fig. 5 indicates that the application of the PSS will have a good effect to ensure the small signal stability of power system.

IV. CONCLUSION

In this paper, Three-machine Nine Nodes Model is built in DIgSILENT/Power Factory software. The simulation calculation result shows that the wind farms integration will have adverse effect on small signal stability. Adding PSS and adjusting the phase shifting link time constant of PSS, according to the type of fan change, can improve the system of small signal stability. And the simulation results showed the same conclusion. It's hoped that the PPS with its proper parameters presented here would provide useful information in wind energy application.

ACKNOWLEDGMENT

Project Supported by State Grid Corporation of key project ([2012]327).

Project Name: The Research and demonstration of coordinated control and security defense system on AC/DC transmission at the base of shared transmission of wind power and thermal power.

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