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Investigation On Voltage Stability of Wind Integrated Power System

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Abstract: - In this paper the voltage stability of a wind integrated power system is analyzed using Hopf bifurcation. Voltage stability analysis of a power system is necessary during the planning and operation stages of the power system. In modern, stressed distribution system, voltage stability is a major concern from planning and operation perspectives. Remote wind farm connected to a weak distribution system through a long line could adversely affect the voltage stability of the respective distribution network. This paper investigates the steady-state voltage issues with a distant doubly fed induction generator (DFIG)-based wind farm. Bifurcation theory which holds good for Voltage stability analysis has been applied to the IEEE 14 test bus system with dynamic components and DFIG integrated with it. The Continuation Power Flow (CPF) and Eigen value analysis was carried out. The presence of Eigen values with negative complex conjugate values indicates the presence of Oscillatory instability. The study was carried out using PSAT tool box.

Key Words:— *Continuation Power Flow (CPF), Eigen value analysis, Hopf Bifurcation, PSAT, Saddle Node Bifurcation , Static Var Compensator.*

I. Introduction

The power systems are the world's largest and most complex nonlinear systems. The power system includes a large number of equipment's which interact with each other and thus exhibiting nonlinear dynamics with a wide range of time frame. When the power system is subjected to a disturbance, the stability of the power system will depend on the initial operating condition as well the nature of the disturbance.

Voltage instability occurs due to the inability of a power system to maintain acceptable voltages at all buses under normal conditions and during disturbances [1]. Especially large induction motors, as a form of distribution load, can consume a significant amount of reactive power upon network disturbances. Environmental concerns from fossil-fuel-based generation have propelled the integration of less-polluting energy sources in the generation portfolio and simultaneously have motivated increased energy conservation programs Renewable energy emerges from sources that are naturally inexhaustible, like hydro, the solar energy and the wind energy.

In the wind turbine (WT) technologies, WT with double-fed induction generator (DFIG) is becoming the dominant type due to its advantages of variable speed operation, four-quadrant active and reactive power capabilities, independent control of their active and reactive output power, high energy efficiency, and low size converters.

The integration and high penetration of renewable energy resources into a power system could introduce a number of key issues, including oscillatory stability which is also traditionally referred to as small signal stability. Voltage stability is the ability of the power system to maintain steady acceptable voltages at all the buses in the system under normal operating conditions and after being subjected to a disturbance. Voltage stability analysis can be done either online or offline, but offline study is preferred because it is less risky. Offline voltage stability analysis is normally conducted at the planning stage and is capable of giving early indication of the system load status. Thus necessary precaution and compensation techniques must be employed to avoid such incidents or occurrence of various undesirable faults within the system. Oscillatory instability may be caused by dynamic characteristics of distributed generators and improper tuning of the controllers.

As certain parameters in the system change slowly, allowing the system to recover quickly and maintain a stable operating point, the system eventually turns unstable, either due to one of the Eigen values becoming zero (saddle-node, transcritical, pitchfork bifurcations), or due to a pair of complex Eigen values crossing the imaginary axis of the complex plane (Hopf bifurcation). The instability of the system is reflected on the state variables, usually represented by frequency, angles and voltages, by an oscillatory behavior.

Local bifurcations are detected by monitoring the Eigen values of the current operating point. The stability of a linear system can be determined by studying Eigen values of the state matrix as follows. The system is stable if all real parts of Eigen values are negative. If any real part is positive the

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system is unstable. For the real part is zero we cannot say anything.

II. SMALL DISTURBANCE ANALYSIS METHOD

The dynamic characteristic of a high order power system can be described by a parameter depending differential algebraic equation shown in (1) and (2)

$$X = f(X, Y, p) \quad (1)$$

$$0 = g(X, Y, p) \quad (2)$$

where equation (1) represents the dynamic characteristic of the system components such as generators, exciter systems, load and other control systems. Equation (2) is the load flow equations. X represents the system state variables such as generator voltages (E′, E′q, E″q), rotor variables (ω, δ) excitation voltage Efd, speed governor variables, etc. Y in the equation 3 represents the algebraic variables such as magnitudes and angles of bus voltages. p is the system load power parameter. Given parameter p, the system equilibrium point X′ is the solution of the following equation.

$$\begin{cases} F\,(X', Y, p) \\ G\,(X', Y, p) \end{cases} = 0 \quad (3)$$

The system stability at equilibrium point X′ can be identified by solving the linearized (1) and (2) at the equilibrium point

$$\begin{bmatrix} \Delta x^{*} \\ 0 \end{bmatrix} = J \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \qquad J = \begin{bmatrix} fx & fy \\ gx & gy \end{bmatrix} \quad (4)$$

Assuming that gy is nonsingular, it is able to eliminate Δy from (4). As a result, the following equation is obtained.

$$\Delta' X = A\,\Delta X \quad (5)$$

$$A = fx - fg\;\; g^{-1}_{y}\, g_{x} \quad (6)$$

From (6), it is easy to analytically evaluate the stability by the state matrix A, which is often called the reduced Jacobin matrix compared with the unreduced one J. With the state matrix A, the system stability can be evaluated by the Eigen value analysis method, which is one of the stability analyzing method belonging to the Lyapunov stability theory. The analysis of equilibrium of the Differential Algebraic Equation (DAE) model often results in three major bifurcations, Saddle Node Bifurcation (SNB), Hopf Bifurcation and Singularity Induced (SI) bifurcations.

A saddle-node bifurcation is basically a local phenomenon and it is the disappearance of a system equilibrium as parameters change slowly. The point where a complex conjugate pair of Eigen values reach the imaginary axis with respect to the changes in (λ, p), say (x0, y0, p0, λ0), is known as a Hopf bifurcation point.

III. MODELING OF DFIG FOR VOLTAGE STABILITY STUDIES

The equivalent circuit diagram of DFIG is shown in figure 2.11. Stator voltage and current of DFIG are related to rotor voltage and current of the DFIG. So active power and reactive power of the stator side can be controlled by controlling the voltage and current of the rotor side.

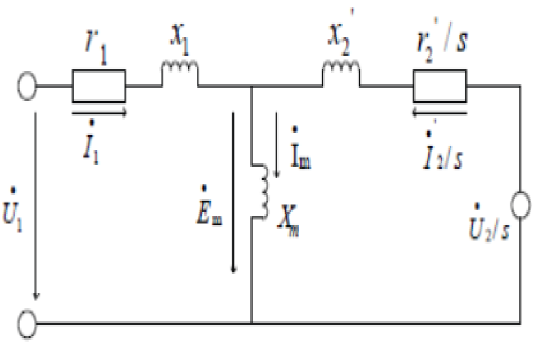

Fig.1. T-equivalent circuit of Doubly-fed induction generator

In modeling the DFIG, the variable speed wind turbine or even the whole wind farm is viewed as a PQ or PV node because of the decoupling control of DFIG active and reactive power, in the power flow calculation following the use of different operating modes.

In the constant power factor control mode, the power factor of variable speed wind turbine or wind farm is assumed to be constant and so the active power and reactive power have a linear relation, so it can be seen as a PQ node.

In the constant voltage control mode, the reactive power of the variable speed wind turbine can be regulated within a certain scope according to the variation between the terminal voltage and the set voltage, at this time it can be seen as a PV node.

When the required reactive power is more than the limit value, reactive power will be maintained within the acceptable limit, so the wind turbine is converted to a PQ node from the PV.

PSAT includes power flow, continuation power flow, optimal power flow, small-signal stability analysis, and time-domain simulation. The toolbox is also provided with a complete graphical interface and a Simulink-based one-line network editor. The features that are present in the PSAT includes the power flow (PF), the continuation power flow and/or voltage stability analysis (CPF-VS), the optimal power flow (OPF), the small-signal stability analysis (SSA), and the time-domain simulation (TD), along with “aesthetic” features such as the graphical user interface (GUI) and the graphical network editor (GNE).

IV. Simulations And Result Analysis

To investigate the voltage stability problems encountered due to the existence of bifurcation, and to select appropriate control equipment's the IEEE14 bus dynamic model was chosen.

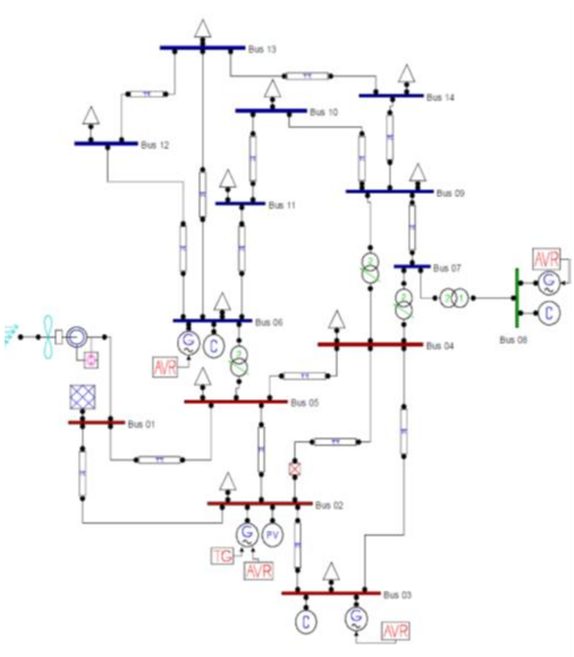

Fig.2. DFIG Integrated IEEE 14 Test Bus System

Initial power flow was run using Newton Raphson algorithm. The Continuation Power Flow program was executed using Power System Analysis Tool Box (PSAT). From the analysis of the power flow results it was observed that bus 14 was the weakest bus. The CPF was executed with bifurcation point as the stopping criteria. From the CPF it was determined that the voltage stability margin is 1.7188 pu.

Then the Eigen Analysis was carried out. The test results revealed the occurrence of the Hops bifurcation at 0.727 loading. The maximum loading limit is 1.7188 where the Jacobian matrix becomes singular. The Eigen value analysis plot is depicted in the figure.3. The absence of positive Eigen value indicates that the system is stable.

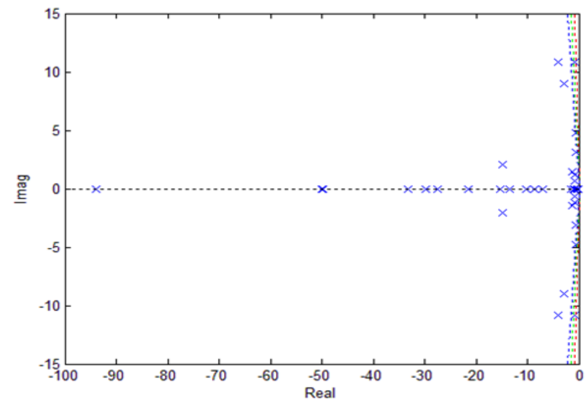

Fig.3. Eigen Value Plot of Ieee14 Test Bus System

The closer analysis of the Eigen values shows the existence of an Eigen value with zero, indicating the existence of Saddle Node Bifurcation.

The presence of a seven complex conjugate pair indicates the occurrence of Hops bifurcation. These are the pairs that may cause oscillatory instability.

Table.1: Complex Eigen Value Pairs

Eigen Number	Eigenvalue
Eig As #14,15	$-0.90866 \pm j\ 10.79441$
Eig As #16,17	$-3.95546 \pm j10.80121$
Eig As #18,19	$-14.9171 \pm j2.03359$
Eig As 22,23	$-2.95514 \pm j8.97055$
Eig As #27,28	$-0.61438 \pm j4.78412$
Eig As #29,30	$-0.68492 \pm j3.10934$
Eig As #31,32	$-1.15901 \pm j1.48117$

V. Conclusion

This paper investigates the dynamic voltage stability of a Wind Integrated IEEE14 test bus system. The simulation was carried out using CPF and Eigen value analysis which reveals the presence of complex conjugate pairs of Eigen values along with the presence of one Eigen value with zero, which is a clear indication about the existence of Hops bifurcation and Saddle Node bifurcation which lead the system to voltage instability. The absence of positive Eigen value indicate that the system is stable.

References

[1]. Abed, E. H., Wang, H. O., Alexander, J. C., Hamdan, A. M. A., Lee, H. C. (1993) Dynamic bifurcations in a power system model exhibiting voltage collapse.Int. J. of Bifur. Chaos, 3:1169–1176.

[2]. C. A. Cdeares, F. L. Alvarado, C. L. DeMarco, 1. Dobson,W. F. Long, “Point of Collapse Methods Applied to AC/DC Power Systems,” IEEE Trans. Power Systems, Vol. 7, No. 2, May 1992, pp. 673-683.

[3]. Ajjarapu and B. Lee, “Bifurcation Theory and its Appli- cation to NoillinearDynanical Phenomena in an Electrical Power System,” IEEE Trnas. Power Systems, Vol. 7, Febru- ary1992, pp, 424-431.

[4]. D.J. Hill and I.M.Y. Mareels, “Stability theory for Differential/Algebraic systems with application to power systems,” IEEE Trans. Circuits and Systems, vol. 37, no. 11, pp. 1416-1423. Nov. 1990.

[5]. Akhmatov and H. Knudsen, “An aggregate model of a grid-connected, large scale, offshore wind farm for power stability Investigations-Importance of windmill mechanical system,’’ Int. J. Elect. Power Energy Syst., vol. 24, pp. 709---717, Nov. 2002.

[6]. F. Zhou, G. Joos, and C. Abbey, “Voltage stability in weak connection wind farms,’’ in Power Engineering Society General Meeting, SanFrancisco, vol. 2, pp.1483---1488, Jun. 2005.

[7]. Abed, E. H., Varaiya, P. P. (1984) Nonlinear oscillations in power system. Int.J. of Electr. Power Energy Syst., 6:37–43.

[8]. Ajjarapu, V. A., Lee, B. (1992) The continuation power flow: A tool for steady state voltage stability analysis. IEEE Trans. Power Syst., 7:416–423.

[9]. Ajjarapu, V. A., Lee, B. (1992) Bifurcation theory and its application to nonlinear dynamical phenomena in an electric power system. IEEE Trans. PowerSyst., 7:424–431.

[10]. Budd, C. J., Wilson, J. P. (2002) Bogdanov-Takens bifurcation points andSil’nikovhomoclinicity in a simple power-system model of voltage collapse IEEE Trans. Circ. Syst.-I, 49:575–590.

[11]. Abed, E. H., Wang, H. O., Alexander, J. C., Hamdan, A. M. A., Lee, H. C. (1993) Dynamic bifurcations in a power system model exhibiting voltage collapse. Int. J. of Bifur. Chaos, 3:1169–1176.

[12]. Abed, E. H., Varaiya, P. P. (1984) Nonlinear oscillations in power system. Int. J. of Electr. Power Energy Syst., 6:37–43

[13]. Ajjarapu, V. A., Lee, B. (1992) The continuation power flow: A tool for steady state voltage stability analysis. IEEE Trans. Power Syst., 7:416–423

[14]. Ajjarapu, V. A., Lee, B. (1992) Bifurcation theory and its application to nonlinear dynamical phenomena in an electric power system. IEEE Trans. Power Syst., 7:424–431.

[15]. Budd, C. J., Wilson, J. P. (2002) Bogdanov-Takens bifurcation points andSil’nikovhomoclinicity in a simple power-system model of voltage collapse IEEE Trans.