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Effects of Generator's Under-Excited Operation on Power System Low-Frequency Oscillation

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I. Introduction

With the continuous expansion of the scale of power grids and the establishment of UHV along with long-distance power transmission network, the problem of higher voltage of power system in valley period becomes important increasingly. Research shows that generator's under-excited operation has been applied gradually as a means for adjusting voltage because of its special excellences, including simple executive, security, economy, adjust continuously, etc.

Generator's under-excited operation belongs to the normal low-excitation synchronous operation state. Generator's capability of absorbing the capacitive reactive power, namely the degree of generator's under-excited operation is restricted by many factors such as stator end fever, the decrease of bus voltage of auxiliary power system, steady-state stability limit, transient stability limit, etc. Therefore, generator's capability of the leading phase operation should be determined scientifically during generator's leading phase operation. Only in this way can power system be ensured to operate safety under the leading phase mode. Reference [2-4] analyses on leading phase operation capacity of huge hydro generator and turbo generator; Reference [5] analyses the influence of generator's und

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Excitation On Stability Of Zhejiang Power System; Reference [6] Analyses The Effects Of Generator's Under-Excitation Operation On Voltage And Reactive Power; Reference [7] Analyses The Effects Of Generator's Under-Excitation Operation On Power System Transient Stability; Reference [8] Offers A Set Of Effective On-Line Monitoring System Of The Leading Phase Of Generator. Reference [9] Analyses Effects Of Different Generator Excitation Modes On Generator's Under-Excitation Operator Stability, And Proposes The Improvement On Phase Lead Stability Of Generators For A Nonlinear Excitation Control System.

Study on effects of generator's under-excited operation on static stability of the electric power system was calculating the static stability reserve coefficient at some degree of generator's under-excited operation which couldn't present the effects of time-varying reactive power on oscillation frequency and damping ratio. The wavelet method is applied in this paper to identify the time-varying oscillation frequency and damping ratio based on the PMU recorded data during Pingwei generator's under-excited operation, and the relation of oscillation frequency and damping ratio with the variation of reactive power has been attained; Furthermore, the damping torque is used to analyze the effect on low-frequency oscillation damping during generator's leading phase operation with an OMIB system. The effects of tie-line's reactive power on inter-area oscillation damping have also been studied.

II. Pingwei Generator's Low-Frequency Oscillation Accidents

a) *Pingwei Generator's Low-frequency Oscillation Accidents*

With two 720MVA transformers, Generator1, 2 of Pingwei generator are upgraded to 500 kV. They are connected to the main grid of Shandong province through the 500kV transmission line. The connection between Pingwei generators and the system is shown in Fig.1.

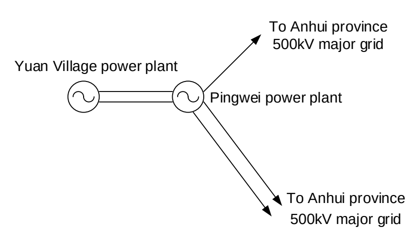

Figure 1: The diagram of Pingwei generators

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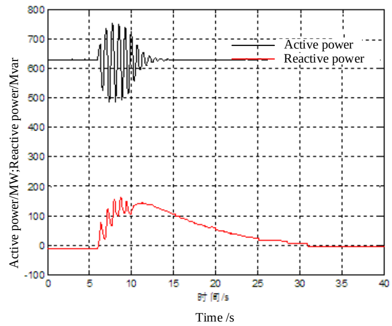
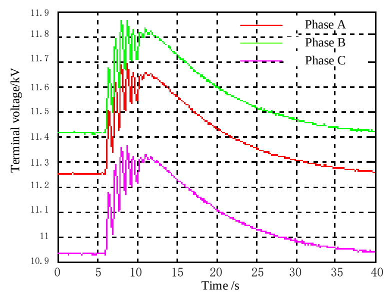
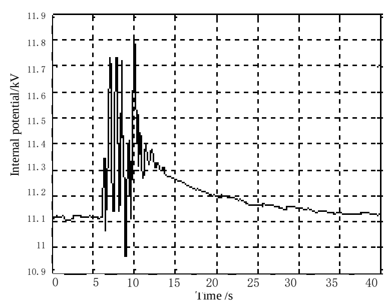
PMU recorded data such as active power, reactive power; terminal voltage magnitude, the internal voltage and power angle of generators are shown in Fig.2.



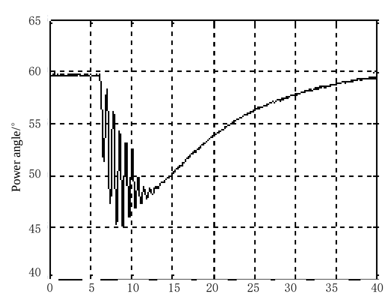
(a) active power and reactive power of generator



(b) terminal voltage magnitude of generator



(c) internal voltage of generator

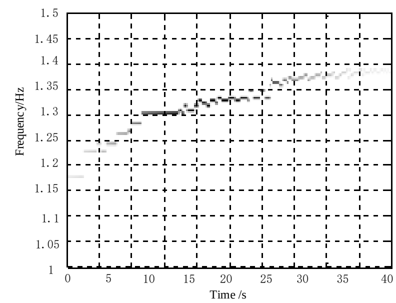


(d) power angle of generators

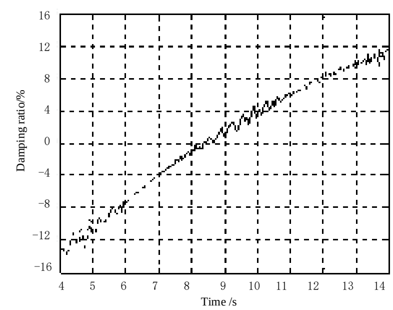
Figure 2: PMU data of oscillation accidents

Fig.2 (a) shows that during Pingwei generator's leading phase operation, the increasing amplitude oscillation accident of generators happens at 6s. With the increase of reactive power of generators, the vibration of the system decays to steady-state operation.

Fig.2 (b-d) shows that during the period when generator's under-excited operation varies into lagging phase operation again after 10s, the internal and terminal voltage of generators decrease continuously, while the power angle increases continuously. After that, there comes another low-frequency oscillation accident. Based on the active power oscillation trajectory of generator during 4-14s in Fig.2 (a), the continuous wavelet transform method is applied to identify the time-varying oscillation frequency and damping ratio. The results are shown in Fig.3.



(a) Identified frequency



(b) Identified damping ratio

Figure 3: Identified frequency and damping ratio based on wavelet method

Because of the ending effect, wavelet method has little influence on identified frequency error and has much influence on identified damping error. According to the method of area elimination of ending effect in reference [12], the effective damping ratio area can be seen in the solid line of Fig.3 (b).

From Fig.3, during generator's under-excited operation varies into lagging phase operation, with the increase of reactive power, the frequency of the low frequency oscillation increases and the oscillation damping increases from a negative to a positive accordingly. Therefore the system has turn to a system of small signal stability.

b) Damping Torque During Oscillation

To make it simple, the impact of generator's under-excited operation on oscillation damping torque is studied on an OMIB system.From Reference [13], electromagnetic torques variation ΔT_e consists of two parts： ΔT_{e1} and ΔT_{e2}. ΔT_{e1} is synchronizing torque equals with $k_1 \Delta\delta$; ΔT_{e2} includes two parts namely synchronizing torque $\Delta T_s \Delta\delta$ and damping torque $\Delta T_D \left(jh\Delta\delta \right)$. Where, ΔT_s and ΔT_D are additional synchronizing torque and damping torque coefficients respectively. $\Delta\delta$ represents the increment of generators' power angle. p represents differential operator, $p = jh$.

$$\Delta T_e = \Delta T_{e1} + \Delta T_{e2} = k_1 \Delta\delta + \Delta T_s \Delta\delta + \Delta T_D \left(jh\Delta\delta \right) \quad (1)$$

Suppose that the excitation system $G_e\left(s\right) = \dfrac{k_A}{1+T_A s}$ is in one-order inertia. Where, k_A and T_A are the gain and inertial time constant of the excitation system respectively. According to reference [13], ΔT_s and ΔT_D are shown as follows:

$$\Delta T_s = \frac{-k_2 k_5 k_A}{1/k_3 + k_6 k_A - T'_{d0} T_A h^2} \quad (2)$$

$$\Delta T_D = \frac{k_2 k_5 k_A \left(T_A/k_3 + T'_{d0} \right)}{\left(1/k_3 + k_6 k_A - T'_{d0} T_A h^2 \right)^2} \quad (3)$$

Where,

$$k_1 = \frac{E'_q U}{x'_{d\Sigma}} \cos\delta + U^2 \frac{x'_d - x_q}{x'_{d\Sigma} x_{q\Sigma}} \cos\left(2\delta\right) \quad (4)$$

$$k_2 = U \sin\delta / x'_{d\Sigma} \quad (5)$$

$$k_3 = x'_{d\Sigma} / x_{d\Sigma} \quad (6)$$

$$k_5 = \frac{U_{td0}}{U_{t0}} U \left(\frac{x_q}{x_{q\Sigma}} \cos\delta - \frac{x'_d}{x'_{d\Sigma}} \sin\delta \right) \quad (7)$$

$$k_6 = \frac{U_{tq0}}{U_{t0}} \frac{x_e}{x'_{d\Sigma}} \quad (8)$$

$$x'_{d\Sigma} = x'_d + x_e \quad (9)$$

$$x_{q\Sigma} = x_q + x_e \quad (10)$$

Where $E'_q, \delta, x'_d, x_q, x'_{d\Sigma}, x_{q\Sigma}, T'_{d0}$ are sub-transient voltage, power angle, direct-axis sub-transient reactance, quadrature-axis reactance, direct-axis sub-transient time constant of generators respectively; U_{t0}, U_{tq0}, U_{td0} are terminal voltage of generators, quadrature-axis and direct-axis component of terminal voltage of generators respectively, the suffix 0 means initial values; U is terminal voltage of infinite bus; x_e is Transformer and total line reactance between generators and infinite bus.

During the period of generator's under-excited operation varies into lagging phase operation, the internal and terminal voltages of generators decrease continuously, while power angle increases continuously. With power angle increasing gradually, k_5 decreases by degrees. When $k_5 < 0$, the damping torque $\Delta T_D < 0$, then increasing amplitude oscillation accident of generators occurs. That's the reason for easily oscillated during generator's leading phase operation.

III. Pingwei Generator's Low-Frequency Oscillation Accidents the Effects of Tie-Line's Reactive Power on Inter-area Oscillation Damping

Take the 4-machine 2-area system shown in Fig.4 as an example. Its network and generators possess the same parameters as those in reference [14]. In the case of two-axis generator model with power system stabilizer and constant impedance load model, the total active power load and total reactive power are 2734MW and 200MVar respectively.

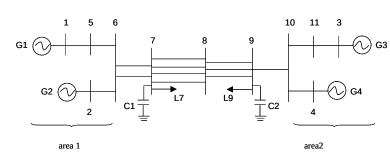


Figure 4: A two-area system

According to the results of power flow, the total power of tie-line 8-9 is $\tilde{S}_{8-9}$, where $\tilde{S}_{8-9} = 390.3 - j15.9$ MVA, namely the active power from bus 8 to bus 9 is 390.3MW and the reactive power from bus 8 to bus 9 is -15.9Mvar. By the use of the small signal analysis tool (SSAT), inter-area oscillation mode of the system is the oscillation between generating units G1, G2 and generating units G3, G4. The oscillation frequency of the mode is 0.7032Hz and damping ratio is 1.55%.

While active power from bus 8 to bus 9 is a constant, the reactive load of bus 7 and 9 varies. The change of inter-area oscillation damping with variation of the tie-line's reactive power is simulated and studied.

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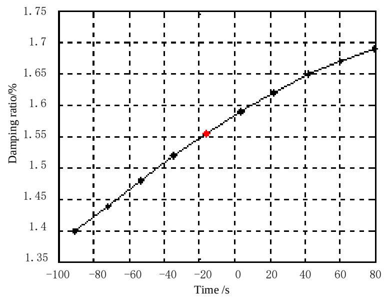

Figure 5: The change of inter-area oscillation damping with variation of the tie-line's reactive power

Fig.5 shows that oscillation damping is higher with the tie-line's positive reactive power's increase, and vice versa. When tie-line's reactive power is negative, which is in the reverse direction of active power, will give rise to inter-area oscillation negative damping/poor damping.

As generating units of area 1 and area 2 are coherent, therefore generating units of area 1 and area 2 can be aggregated into an equivalent, and bus 7 and 9 can be regarded as near zones of the equivalent. The original system is equivalent to a 2-machine system. So when tie-line's reactive power is in the reverse direction of active power, it can bear a resemblance to generator's under-excited operation. The increase of negative reactive power is not conducive to the damping of the system.

IV. Conclusion

The wavelet method is applied in this paper to identify the time-varying frequency and damping based on the PMU recorded data during Pingwei generator's under-excited operation, and the relation of oscillation frequency and damping ratio with the variation of reactive power has been attained; Furthermore, the damping torque is used to analyze the reason for easily oscillated during generator's leading phase operation.

When the active power is constant, the effects of tie-line's reactive power on inter-area oscillation damping have also been studied in this paper. When tie-line's reactive power is in the reverse direction of active power, it can give rise to negative damping/poor damping, which causes inter-area oscillation of power system.

References Références Referencias

1. Kekela J, Firestone L. "Under-excited operation of generators,". IEEE Trans on PAS. 1964, 83(8): 811-817.
2. Ming WANG. "Analysis on leading phase operation capacity of 1000MW hydro-generator,". Harbin University of Science and Technology, March 2010.
3. Wanqin XIANG. "The analysis and research for the character of large turbo-generator in leading phase operation," North China Electric Power University, Dec. 2005.
4. Wei YAN, Jun CHEN, Quanrong SHENG. "Discussion on large non-salient pole generator phase-advancement operation," Automation of Electric Power Systems, 2007, 31(2): 94-97.
5. Yuji CHEN. "The influence of generator under-excitation on stability of Zhejiang power system," Zhejiang University, April 2004.
6. Tao WANG, Dashan ZHOU, Zhi DU, et al. "Effects of generator in leading power factor operation under light flow on voltage and reactive power," Hubei Power, 2001, 25(1): 1-3.
7. Lian YAN, Jiayu HUANG, Xiaochuan LUO. "Transient stability study of east China power system during light load," Power System Technology, 1996, 20(10): 5-7.
8. Jiayan SHI, Yuansu SHI, Xiaomin ZHAO, et al. "The new method of determining the capability of leading phase of generator and realizing the online monitoring. Proceedings of the CESS," 2006, 26(11): 139-143.
9. Xuesong ZHOU, Youjie MA, Qiang LU, et al. "Experimental study on phase lead stability of a generator for a nonlinear excitation control system," Journal of Tsinghua University (Sci & Tech) , 1996, 36(9): 9-13.
10. Zhengfeng WANG, Shengsong LIU. "Analysis of low frequency oscillation of Anhui 500kV network," Relay, 2002, 30(10): 41-43.
11. Pengfei ZHANG, Yusheng XUE, Qiping ZHANG. "Power system time-varying oscillation analysis with wavelet ridge algorithm. Automation of Electric Power Systems," 2004, 28(16): 32-35,66. .
12. Kijewski T, Kareem A. "Wavelet transforms for system identification in civil engineering," Computer-aided civil and infrastructure engineering. 2003, 18: 339-355.
13. Daqiang. MA "Power system mechanical-electrical transient course," Hydraulic and Electric Power Press, Beijing, 1988.
14. Powertech Labs Inc. SSAT user manual. April 2004, Canada.
15. Yusheng XUE. "Quantitative study of general motion stability and an example of power system stability," Nanjing: Jiangsu Science and Technology Press, 1999.