Estimation of Inertia Constant of Iran Power Grid Using the Largest Simulation Model and PMU Data

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Abstract— **Inertia constant is an effective parameter for power system analysis and control such as the load frequency control, dynamic behavior study and for system operators to do decision making during contingency conditions. This paper uses the largest simulation model of Iran power grid (containing integrated transmission and sub-transmission network) and Phasor Measurement Units (PMU) data to analysis the outage of generator of Bushehr nuclear power plant as a very effective event to estimate the inertia constant of Iran power system. The approximate matching between simulation and measurement based calculation results supports the validity of resulted value.**

Keywords- Inertia constant; Phasor Measurement Unit (PMU); The Largest Simulation model of Iran Grid.

I. INTRODUCTION

Some parameters are very important for power system evaluation and control such as inertia constant which is especially used for load frequency control and dynamic behavior analysis of power network. On the Other hand, the inertia is a very effective parameter for system operators to do decision making during contingency conditions. Therefore, some papers such as [1]–[4] have presented discussions and methods for calculation and using this parameter in various issues.

In this paper, we use the largest simulation model of Iran containing transmission and sub-transmission network (with about 60000 busbar/terminal, detailed model of 500 generators, 4400 lines and 4000 transformers, etc.) which is developed and updated by workgroups of regional electric companies (RECs) with cooperation of Iran Grid Management Company(IGMC)[5]. Simulations are done using DIgSILENT PowerFactory[6].

On the other hand Wide Area Measurement System (WAMS) has been installed and operated in Iran network and used for system analysis and validation of simulation models[7], [8]. One of the main goals of WAMS is monitoring of system parameters in order to estimate the power system state such as stability margin and enhancement of system control. The main property of WAMS is synchronized measurement in Phasor Measurement Units (PMUs) which normally installed in some power system substations. In this paper, we use the PMU data at a very effective event in Iran network for estimation of Iran Grid inertia constant. Comparing the results of measurement and simulation based method show the validity of the calculations.

II. INERTIA OF POWER SYSTEM

Immediately following a disturbance, the missing/excess power is delivered from the kinetic energy stored in the rotating mass of the turbines. This leads to a deceleration/acceleration and thus to a decrease/increase in the system frequency. The contribution of each generator towards the total additional power required is proportional to its inertia. Individual contributions to the balance are proportional to the inertia/acceleration time constant of each generator. This relation can be mathematically described as follows:

$$\Delta P_i \triangleq P_i - P_i^{disp} = K_i . \Delta f \quad (1)$$

where,

P_i is the modified active power of generator i, P_i^{disp} is the initial active power dispatch of generator i and ΔP_i is the active power change in generator i. Δf is the total frequency deviation and K_i is the inertia gain parameter of generator i, which can be calculated as:

$$K_i = J_i . \omega_n . 2\pi \quad (2)$$

Where ω_n is the rated angular velocity of generator i and J_i as the moment of inertia of the generator can be calculated as:

$$J_i = P_{n_i} . \frac{Ta_i}{\omega n^2} = \frac{2H_i . Pn_i}{\omega n^2} \quad (3)$$

Where H_i is inertia time constant of generator i and $T_{a_i} = 2H$ is the acceleration time constant of the generator rated to its nominal active power (P_{n_i}). Where, having nominal apparent power (S_{n_i}) and nominal power factor ($\cos\theta_n$) of the generator, it is clear that:

$$P_{n_i} = S_{n_i} . \cos\theta_n \quad (4)$$

On the other hand, for all power network, swing equation states that[3]:

$$T_a = 2H = \frac{\Delta P / P_n}{\frac{df}{dt} / f_n} \qquad (5)$$

Figure 1 illustrates the different type of active power control based on frequency deviation after a system event containing a load-generation unbalance. The Rate of Change of Frequency (ROCOF) which is available using PMU can be used for calculation of the system inertia (H). Using equation (5) the value of H network is calculated for large-scale networks is usually between 2 and 9 seconds[1].

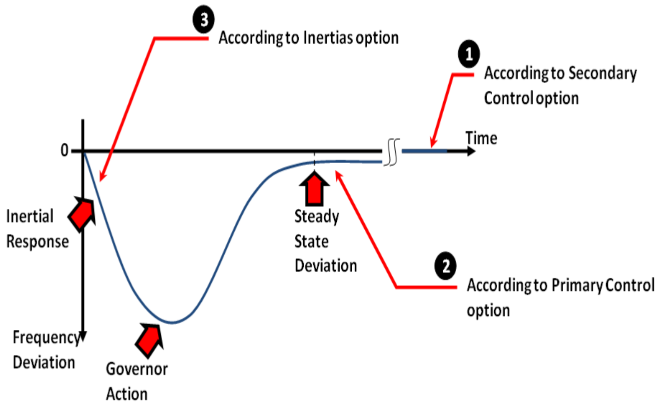

Figure 1: Typical frequency deviation following an unbalance in active Power

III. Estimation Using The Largest Simulation Model

Using the largest model of Iran transmission and sub-transmission network in DIgSILENT PowerFactory software which is taking the nominal active power of generating units of the interconnected network as the basis (P_n), the acceleration time constant of the power system is calculated, $T_a = 10.38$ sec, therefore the inertia constant of Iran network is calculated:

$$H_{IranGrid}^{*} = 5.19 \text{ sec.} \qquad (6)$$

Using the simulation model described above, outage of the generator of Bushehr nuclear power plant is simulated. Fig. 2 shows the impact of this event on the frequency at 400 kV bus of Choghadak near the Bushehr power plant in the south area of Iran and the frequency at 400 kV bus of Shahid Salimi (Neka) in the north area of the grid.

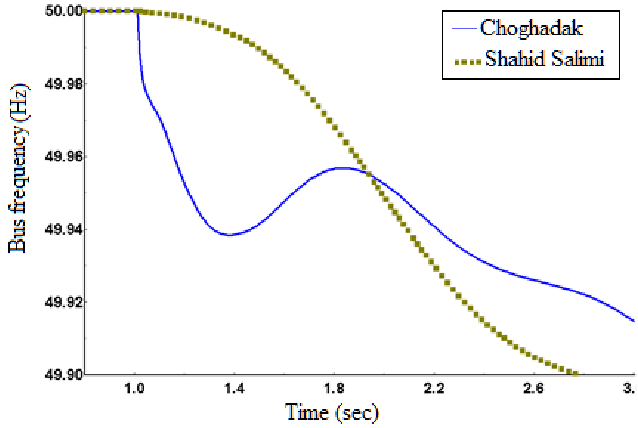

Figure 2: simulation results of bus frequency after event

IV. Estimation Using PMU Data

As mentioned according to scientific literature, the frequency measurements information after some events recorded by the phasor measurement unit (PMU) can be used to estimate the inertia constant of power system.

A. PMU Recorded Data

For this purpose, recorded frequency information after outage of the generator of Bushehr nuclear power plant on June 30, 2014 is evaluated. Fig. 3 shows the frequency measured by PMUs at 400 kV substations Choghadak and Shahid Salimi (Neka). In this way, there is little difference between two diagrams immediately after event.

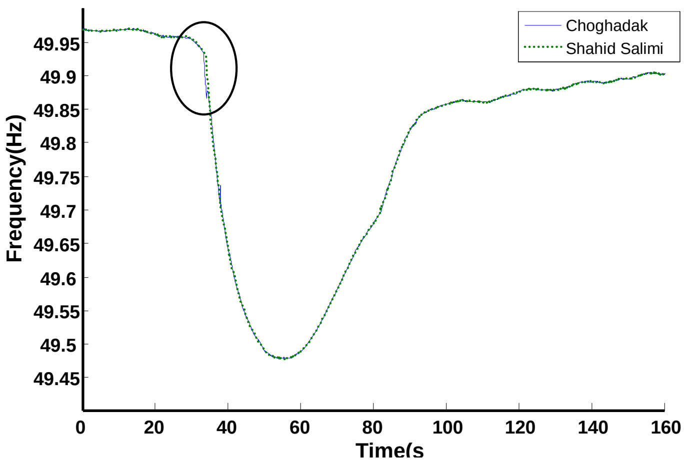

Figure 3: PMU recorded frequency after outage of the generator of Bushehr nuclear power plant

To calculate the equivalent H of Iran network, the frequency at the first moments after the event (sepecified in Fig. 3), should be considered. The frequency values with more distinction are shown in Fig. 4.

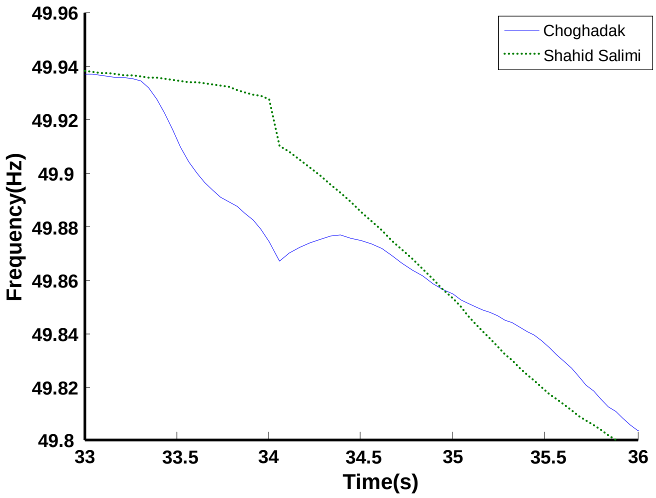

Figure 4: frequency data at first moments after the event

Comparison Fig. 2 and Fig. 4 shows the approximate matching between simulation model and the actual system behavior especially at a few seconds after event. It show the validation of the simulation model of Iran network and we can rely on the resulted value from simulation. However, the PMU data is used for calculation.

B. Inertia Calculation

At the time of the outage of nuclear power plant, a few generators of network had been out of service. The initial injected power from Bushehr generator to the grid before event was about 900MW and it is considered as ΔP in eq. (5). Changes of frequency can be represented in pu using nominal frequency f_n=50 Hz as the base value. In table 1. the rate of change of frequency (df/dt) called ROCOF in Choghadak substation (close to the nuclear power plant) is calculated. For elimination of unwanted oscillations from the data, the average of rate of change of the network frequency for 10 points in range of 400 ms after the event is considered.

Table 1: Measurement data of bus frequency recorded in PMU and ROCOF results

Sample Number	Time(sec)	Frequency (Hz)	df/dt (pu/sec)
1	33.522	49.90996	-
2	33.565	49.90446	0.002530
3	33.609	49.90025	0.001937
4	33.652	49.89681	0.001583
5	33.696	49.89375	0.001409
6	33.739	49.89117	0.001186
7	33.783	49.88947	0.000783
8	33.826	49.88764	0.000841
9	33.870	49.88525	0.001097
10	33.913	49.88264	0.001202
11	33.957	49.87912	0.001621
Average			0.001419

Using the resulted average of ROCOF in eq. (5) with considering P_n≈60000 MW as the nominal generation of Iran grid (according to IGMC dispatching center data at the event condition), inertia time constant of Iran grid is obtained as:

$$H_{IranGrid}^{\dagger} = 5.29 \text{ sec.} \quad (7)$$

The difference between resulted values for inertia from two approaches ($H_{IranGrid}^{*}$ and $H_{IranGrid}^{\dagger}$) is less than %2 which can be neglected according to large scale data in modeling and measuring procedure. Both approaches have obtained approximately same values for the important parameter of Iran network and it can be stated that:

$$H_{IranGrid} \approx 5.2 \text{ sec.} \quad (8)$$

V. CONCLUSION

In this paper, the inertia constant of Iran power grid has been obtained using two methods: simulation approach using the largest simulation model of Iran power grid and PMU based calculation. Outage of the generator of Bushehr nuclear power plant as an effective event has been studied for obtaining the inertia constant. Both approaches have obtained approximately same values for the important parameter of Iran network. On the other hand, comparison of the results of two methods can be useful for validation of the model because of approximate matching between simulation and actual measurement data.

REFERENCES

[1] P. Tielens and D. Van Hertem, “Grid Inertia and Frequency Control in Power Systems with High Penetration of Renewables,” no. 2, pp. 1–6.

[2] P. Wall, F. González-Longatt, and V. Terzija, “Demonstration of an inertia constant estimation method through simulation,” *Univ. Power Eng. Conf. (UPEC), 2010 45th Int.*, pp. 1–6, 2010.

[3] D. P. Chassin, Z. Huang, M. K. Donnelly, C. Hassler, E. Ramirez, and C. Ray, “Estimation of WECC system inertia using observed frequency transients,” *IEEE Trans. Power Syst.*, vol. 20, no. 2, pp. 1190–1192, 2005.

[4] T. Inoue, H. Taniguchi, Y. Ikeguchi, and K. Yoshida, “Estimation of power system inertia constant and capacity of spinning-reserve support generators using measured frequency transients,” *IEEE Trans. Power Syst.*, vol. 12, no. 1, pp. 136–143, 1997.

[5] Iran Grid Management Company and Regional Electric Companies of Iran, “Nationwide Transmission and Subtransmission Network Modeling,” 2015. [Online]. Available: http://igmc.ir/tabid/135/Default.aspx.

[6] DIgSILENT GmbH., “DIgSILENT PowerFactory (Version 15) User Manual.” DIgSILENT GmbH, Gomaringen, Germany, 2014.

[7] A. a. Hajnoroozi, F. Aminifar, and H. Ayoubzadeh, “Generating Unit Model Validation and Calibration Through Synchrophasor Measurements,” *IEEE Trans. Smart Grid*, vol. 6, no. 1, pp. 441–449, 2015.

[8] S. Rabiee, H. Ayoubzadeh, D. Farrokhzad, and F. Aminifar, “Practical aspects of phasor measurement unit (PMU) installation in power grids,” in *Smart Grid Conference (SGC), 2013*, 2013, pp. 20–25.