PMU BASED POWER OSCILLATION DETECTION SYSTEM AND ITS APPLICATION TO JAPANESE LONGITUDINAL POWER SYSTEM

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Abstract – This paper proposes a PMU (Phasor Measurement Unit) based power oscillation detection system. The phasor angles at domestic 100V power outlets are collected to the server PC through internet, and the power oscillations and their various parameters are detected from the phasor angles. PMUs and servers are installed to Japanese 60Hz system, which is a large-scale longitudinal power system, and the interarea power oscillations are actually evaluated in some generator dropping cases and a steady state case. Proposed system is applied to be an online observation system of transient and steady state stability.

Keywords: PMU, Power Outlet, Power Oscillation, Longitudinal Power System, Generator Dropping, Steady State Oscillation

1 INTRODUCTION

Japanese 60Hz system is a large-scale longitudinal power system, where six major power companies are interconnected with tie-lines. As the recent progress of electric deregulation, heavy power flow on the tie-line is expected. Therefore the interarea power oscillation would be remarkable, and the wide-area observation of the power oscillation is essential for the stable operation of interconnected system.

Recently, PMU (Phasor Measurement Unit) [(1), (2)] is in the spotlight as a wide-area measurement tool. Its sampling clock is synchronized to the GPS time signal, and the synchronized phasor angle is calculated from the instantaneous values of voltage. The authors have already installed PMUs at domestic 100V power outlets in some universities located in every power companies of Japanese 60Hz system [(3)]. The phasor angles are automatically collected to the server PC through the internet.

In this paper, a power oscillation detection method, which is aimed at real-time execution on PMU, is proposed. The power oscillations are extracted from the phasor angles by using digital filters. Then various parameters concerning power oscillations, such as oscillatory period, time difference, amplitude, and damping are calculated in order to evaluate the power oscillations.

The proposed method is applied to evaluate the power oscillation in Japanese 60Hz system. The features of the interarea power oscillation appeared on the longitudinal power system are confirmed and evaluated not only in some generator dropping cases but also in a steady state case.

2 POWER OSCILLATION DETECTION SYSTEM

2.1 Overview of system

Fig.1 shows the location of PMUs and servers on Japanese 60Hz system. Total eight PMUs are installed at Kyushu Institute of Technology (K.I.T), Kumamoto University, Miyazaki University, Hiroshima University, The University of Tokushima, Osaka University, University of Fukui, and Nagoya Institute of Technology (N.I.T). An aspect of PMU and server at N.I.T is shown in Fig.2, and specifications and measurement conditions of PMU are shown in Table.1. The employed PMU in this research is NCT2000 (Toshiba corporation) [(4)], which is oriented to an internet based multifunctional measurement terminal. The instantaneous values of power outlet voltage are measured with precise time-synchronization at the sampling frequency of 5760[Hz]. The phasor angle is calculated from the instantaneous values by the phasor computation based on DFT (Discrete Fourier Transform) in every period of 30[Hz].

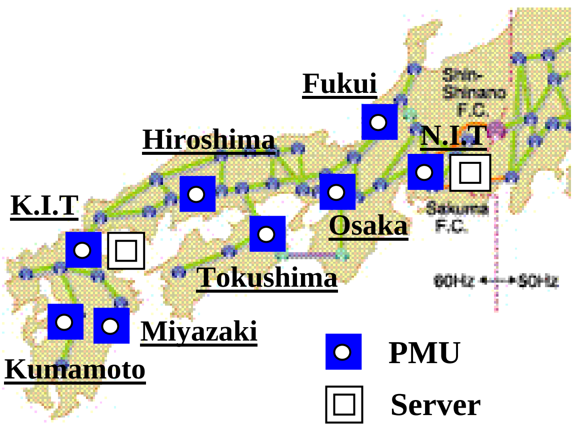


Figure 1: Location of PMUs and servers on Japanese 60Hz system.

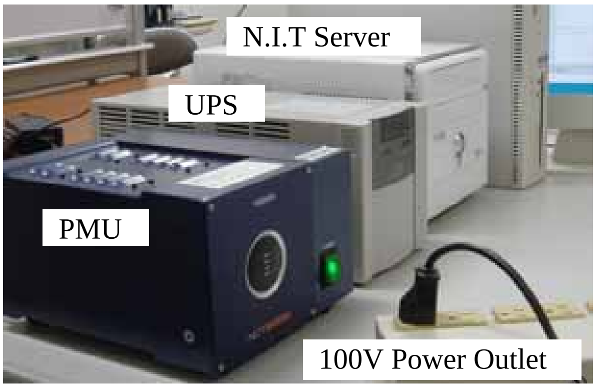


Figure 2: Aspect of PMU and server at N.I.T.

Hardware : Toshiba NCT2000 Type-A
Input : single phase voltage of power outlet
Output : effective value and phasor angle
Sampling : 5760[Hz]
Period of Phasor Computation : 30[Hz]
Measurement Period : 50-10 and 20-40[min]

Table 1: Specifications and measurement conditions of PMU

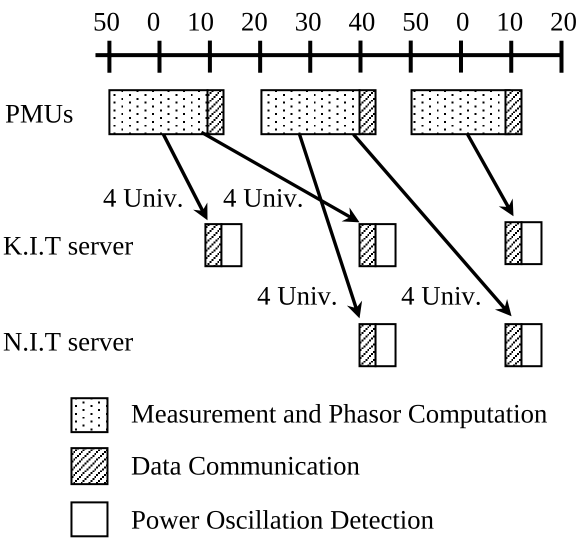


Figure 3: Task scheduling for data collection.

Of course, PMU have ability to measure three phase voltage phasors. If PMUs are installed to substations of the power system, PMUs deal with not symmetrical events but asymmetrical events.

The phasor angles during 50-10[min] and 20-40[min] are saved to respective files in every hour. The measurement period is totally 40[min] per hour. Fig.3 shows the task scheduling for data collection to servers. Firstly, phasor angles data during 50-10[min] (respect. 20-40[min]) at four universities are transmitted to K.I.T server (respect. N.I.T server), and the power oscillations and its parameters are detected on K.I.T server (respect. N.I.T server). Processing time of data communication and the power oscillation detection is within few minutes. In the next idle time of PMU, data files of remain four universities are collected and processed. In this way, 50-10[min] (respect. 20-40[min]) files are collected to K.I.T server (respect. N.I.T server) before the next 50-10[min] (respect. 20-40[min]) measurement start. The concrete procedure of the power oscillation detection is explained on the following section.

2.2 Power oscillation detection method

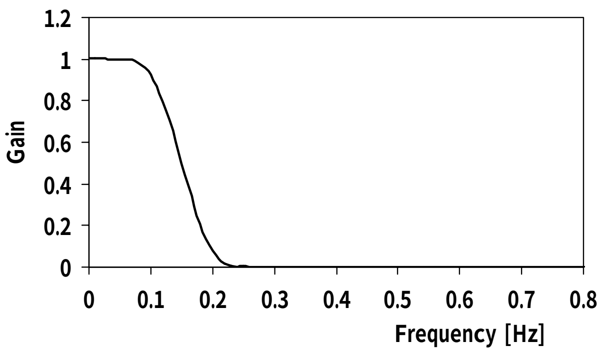
There are various frequency components other than the power oscillations on the phasor angles. The lower frequency component is caused by the frequency deviation from the fundamental frequency, which is common to the interconnected system. This frequency deviation component is extracted by using LPF (Low-Pass Filter), and is subtracted from the phasor angle after the compensation of phase delay caused by LPF. The higher frequency component is caused by the neighbor load fluctuation. Therefore, this load fluctuation component is removed by using BPF (Band-Pass Filter) from the phasor angle. In this way, the power oscillation component is extracted.

In Japanese 60Hz system, the interarea long period oscillations are dominant, especially in both ends of the longitudinal system. Their oscillatory frequency is around 0.4[Hz] varying in a day, week, and season [(4), (5)]. Therefore, the cutoff frequency of LPF is set as 0.15[Hz] not to influence on the interarea oscillations, and the center frequency of BPF is adaptively adjusted to the oscillatory period, which is calculated bellow. The local oscillations also occur just after the disturbance, but their amplitude is very small, and immediately converged. If there are plural modes on the phasor angles, the direct parametric estimation method such as the prony analysis [(6), (7)] should be used for separating the modes. The specifications and the frequency responses of LPF and BPF are shown in Table.2 and Fig.4, respectively.

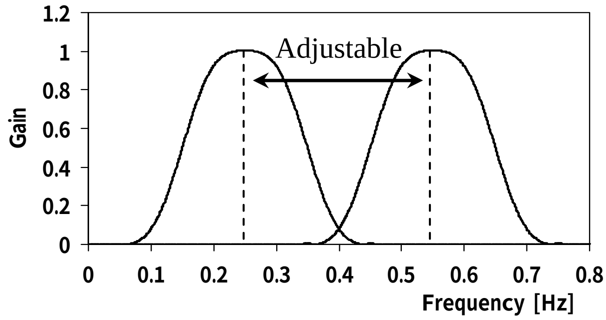
Once the power oscillation is extracted, the parameters concerning the power oscillation are quantified as shown in Fig.5. The oscillatory period is a time interval between the neighbor zero-crossing points, and the time difference is a time interval between the zero-crossing point and that of another location. The oscillatory amplitude is computed by root mean square value for half cycle of oscillation, and the oscillatory damping is executed by the logarithmic decrement of the oscillatory amplitude.

Type : FIR
Window function : Hamming Window
Width of filter : 20[s] (600 samples)
Cutoff frequency of LPF : 0.15[Hz]
Width of pass-band of BPF : 0.20[Hz]
Center frequency of BPF : Adjustable

Table 2: Specifications of LPF and BPF.



(a) Low-Pass Filter



(b) Band-Pass Filter

Figure 4: Frequency responces of LPF and BPF.

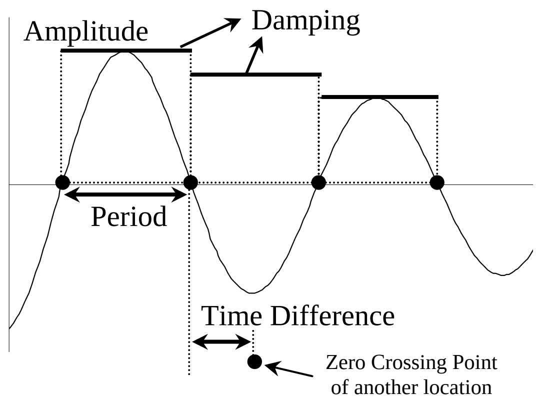


Figure 5: Parameters for evaluating power oscillation.

3 POWER OSCILLATION EVALUATION OF JAPANESE LONGITUDINAL POWER SYSTEM

3.1 Generator dropping case

Total fourteen disturbances have been observed by the proposed power oscillation detection system from 2002 to 2005. One case shown in this paper is that the generator whose rated output is 347[MW] in Kyushu Electric Power Company was accidentally dropped out of Japanese 60Hz system at 2003.8.24 19:02. The results are shown in Fig.6.

Fig.6 (a) indicates the phasor angle differences from N.I.T. An offset adjustment is done before the disturbance. The phase angle differences decreased from east to west after the disturbance at about 759[s] (19:02 39[s]). Therefore, it is estimated the active power flows from Chubu Electric Power Company to Kyushu Electric Power Company through the long interconnected line.

Fig.6 (b) shows the phasor angle difference of K.I.T and detected power oscillation by the proposed method. There is some error during first swing because of the transient responses of the digital filters. However, the accurate detection is realized after the second swing. Fig.6 (c) and Fig.6 (d) shows the detected power oscillations and their parameters. The oscillatory period and damping is computed by using the second swing of the phasor angle difference between K.I.T and N.I.T, and other parameters are computed by using the second swing of the phasor angle of each university. The reference of the oscillatory time difference is N.I.T.

The oscillation (oscillatory period is 2.467[s]) occurred after the disturbance converges with a damping factor 0.060. The time difference between K.I.T and N.I.T is nearly half cycle of the oscillation, that is, the oscillation between K.I.T and N.I.T is in opposite phase. The oscillatory amplitude is considerable in both end of Japanese 60Hz system.

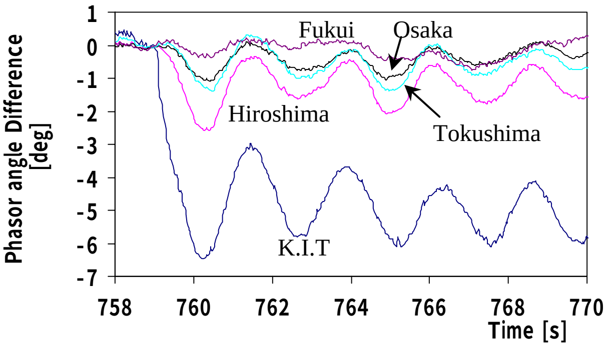
Another case is that the generator whose output is 1035[MW] in Chubu Electric Power Company was dropped out as a load rejection test at 2004.7.16 17:00. The results are shown in Fig.7. It is estimated the active power flows from Kyushu to Chubu, which is reverse direction against the previous case (2003.8.24). Concerning the power oscillations, the oscillatory period (2.733[s]) is longer, and the oscillatory amplitudes of each university are greater because the capacity of dropping is about three times. However, the oscillations are well converged with a damping factor 0.078.

The features of two cases show the characteristics of typical interarea power oscillation of the longitudinal power system. These oscillations are remarkable in both ends of the longitudinal power system, especially when the disturbances occur in both ends.

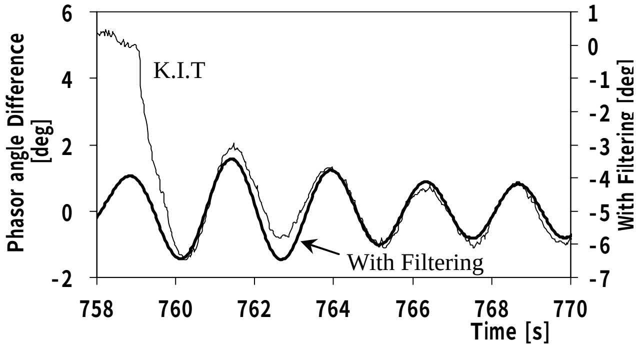
3.2 Steady state case

The proposed method is applied not only in the disturbance cases but also in the stable case. Fig.8 shows the results at 2003.10.10 14:20, when no disturbances have been reported.

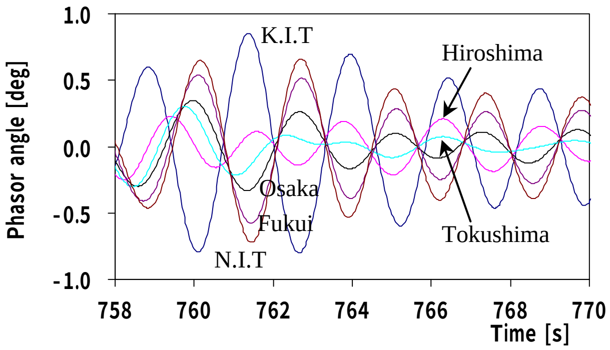
Fig.8 (a) indicates the phasor angles of Miyazaki and N.I.T. The frequency deviation components are dominant and the oscillations are not obviously appeared. However, the power oscillations are detected by using the proposed method as Fig.8 (b) (for 20[s]) and Fig.8 (c) (for 100[s]). In this case only oscillatory periods and amplitudes of these oscillations are detected. Then the averaging values of the parameters during 20[min] (14:20-40) is shown in Fig.8 (d). The interarea power oscillation is found to occur at the steady state because the tendency of parameters is similar to those at the disturbance cases (Fig.6 (d) and Fig.7 (d)).



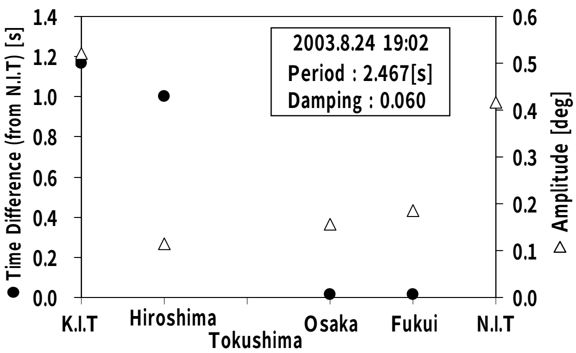
(a) Phasor angle differences from N.I.T



(b) Power oscillation detection by digital filters

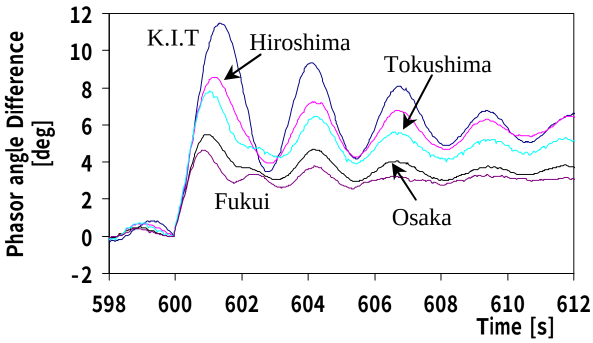


(c) Power oscillations

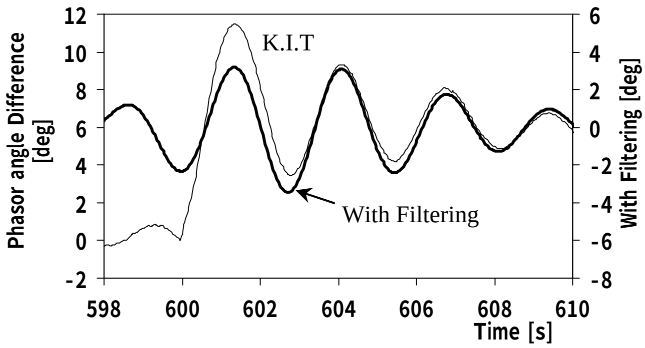


(d) Parameters concerning power oscillations

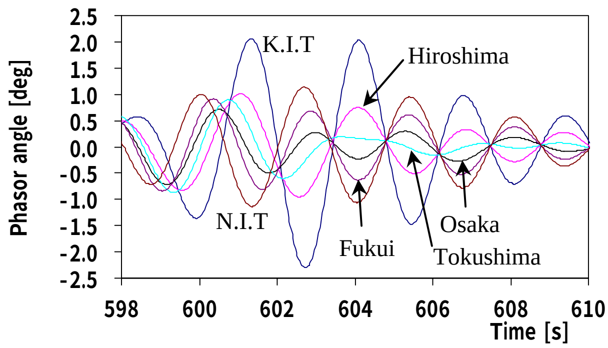
Figure 6: Power oscillation detection at generator dropping case (347[MW] in Kyushu)



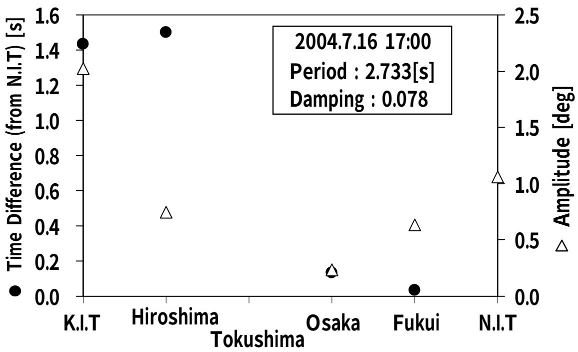
(a) Phasor angle differences from N.I.T



(b) Power oscillation detection by digital filters

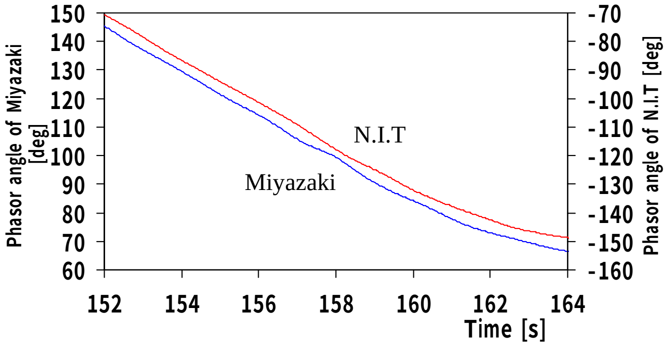


(c) Power oscillations

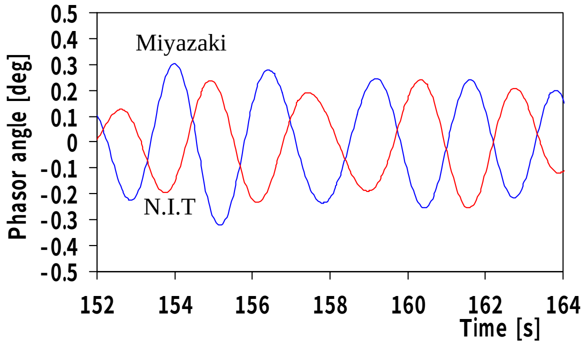


(d) Parameters concerning power oscillations

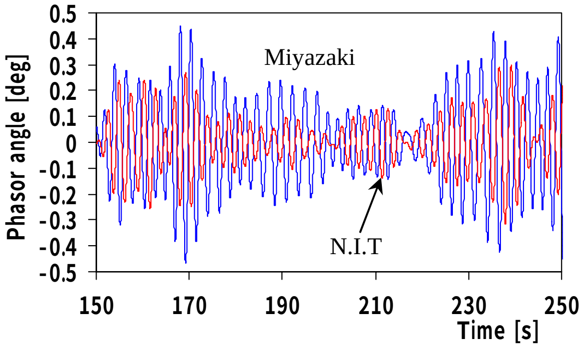
Figure 7: Power oscillation detection at generator dropping test case (1035[MW] in Chubu)



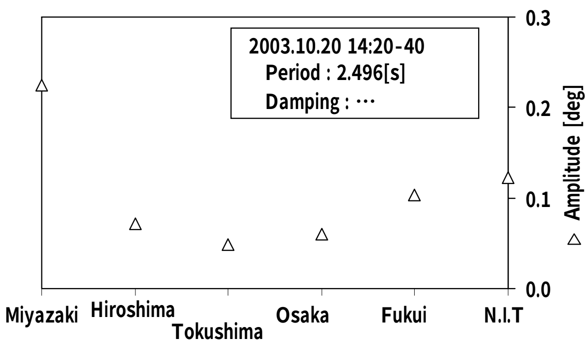
(a) Phasor angles of Miyazaki univ. and N.I.T



(b) Power oscillations (for 12[s])



(c) Power oscillations (for 100[s])



(d) Parameters concerning power oscillations (Averaging value during 14:20-40)

Figure 8: Power oscillation detection at steady state case

4 CONCLUSUONS

In this paper, a PMU based power oscillation detection system was proposed, and the overview of the system and the concrete procedure to detect the power oscillations and the related parameters were explained. Moreover, the proposed method was validated by evaluating the interarea long period oscillations on actual Japanese 60Hz system in two generator dropping cases and a steady state case.

As an application of the proposed system, the evaluation of the steady state characteristics and the power system modeling [(5), (8)] is expected by using the detected steady state oscillation information. Furthermore, a transient stability evaluation [(9)] is expected by using the power oscillation information under disturbance condition. Certainly recording the accidental disturbances, the continuous measurement at 50-10[min], 10-30[min], and 30-50[min] have been initiated since June 2005.

Since the proposed method is simple and fundamentally based on the local phasor angles, it can be achieved in real-time execution on PMUs, and hence the proposed method is applicable to the online observation system for both transient and steady state stability evaluations.

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