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Design and Evaluation of PMU Performance Measurement and GPS Monitoring System for Power Grid Stabilization

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ABSTRACT

Power grid techniques are distributed over general power systems ranging from power stations to power transmission, power distribution, and users. To monitor and control the elements and performance of a power system in real time in the extensive area of power generation, power transmission, wide-area monitoring (WAM) and control techniques are required (Sattinger et al. 2007). Also, to efficiently operate a power grid, integrated techniques of information and communication technology are required for the application of communication network and relevant equipment, computing, and system control software. WAM should make a precise power grid measurement of more than once per cycle by time synchronization using GPS. By collecting the measurement values of a power grid from substations located at faraway regions through remote communication, the current status of the entire power grid system can be examined. However, for GPS that is used in general national industries, unexpected dangerous situations have occurred due to its deterioration and jamming. Currently, the power grid is based on a synchronization system using GPS. Thus, interruption of the time synchronization system of the power system due to the failure or abnormal condition of GPS would have enormous effects on each field such as economy, security, and the lives of the public due to the destruction of the synchronization system of the national power grid. Developed countries have an emergency substitute system in preparation for this abnormal situation of GPS. Therefore, in Korea, a system that is used to prepare for the interruption of GPS reception should also be established on a long-term basis; but prior to this, it is required that an evaluation technique for the time synchronization performance of a GPS receiver using an atomic clock within the power grid. In this study, a monitoring system of time synchronization based on GPS at a power grid was implemented, and the results were presented.

Keywords: power grid, phasor, PMU, GPS, time synchronization

1. INTRODUCTION

With the advent of digital economy and knowledge/information society due to the recent development of information and communication technology, many countries around the globe have made efforts to improve national competitiveness through the promotion of IT technology. In the power system field in Korea, automation and power monitoring/control systems using IT technology have also been actively introduced. It is nearly impossible not to have only a power outage under the complicated power system of modern society. However, considering the damages to many aspects of the society caused by just a power outage, the purpose and important mission of electric power industry technology are to operate a power system so that power outage can be prevented, and to minimize the damage in case of power outage. Therefore, it is urgent to develop a technique that monitors and controls the power system in real time, and to apply the developed technique to the power system.

The real-time power system monitoring and control technique is a cutting-edge technology that monitors and controls a power system by obtaining the wide-area power system data of the phasors of current and voltage, 60 times per second, respectively, using the time synchronization performance of GPS through Phasor Measurement Unit (PMU) (NASPI 2007). PMU measures phase angles by generating precise frequency that has been synchronized

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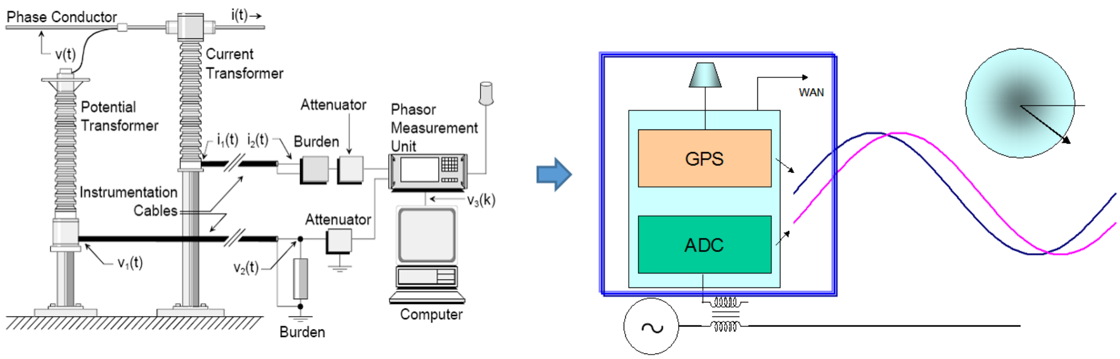

Fig. 1. Measurement concept of voltage and current by PMU: (a) block diagram of measurement system at substations, (b) phasor measurement by GPS and ADC.

with the reference signal of the GPS system, and thus can precisely measure the voltage phasor and current phasor for arbitrary measurement motion of a power system (Itagaki, Shirota, & Sekiguchi 2004). This is because a GPS receiver embedded in PMU provides accurate time and reference frequency traced by Coordinated Universal Time (UTC) (Rahman et al. 2013). However, signals transmitted from GPS satellites are vulnerable to jamming; and in particular, the failure frequency has recently increased due to the deterioration of the installed satellite clock (USNO 2015). The paralysis of the time synchronization system of the power system due to this GPS signal abnormality leads to the destruction of the synchronization system of the national power grid, which could have enormous effects on the society in general as well as the economy and the security. Also, for the last several years, jamming of GPS satellite signals by North Korea induced confusions for the operation of civilian aircraft and ships. Accordingly, several damages to communication networks, ships, and aircraft operation were reported in the west coast and the part of the Seoul Metropolitan region. Therefore, in Korea, to secure the stability of the power grid, a system that can monitor the GPS status of power system in real time needs to be established in preparation for various emergency situations (e.g., GPS satellite failure or jamming). Based on this, the failure or abnormal signal of GPS should be actively handled; and in case of emergency, an alternative power grid synchronization system should be maintained through linkage with another synchronization network. Also, a technique that is used to prepare for the black out of power by accurately measuring the phasor of electric power is required.

For this purpose, in this study, a system for monitoring the performance of PMU that is used as the reference device of power grid evaluation using GPS was designed, implemented, and evaluated.

2. IMPLEMENTATION AND EVALUATION OF THE PMU PERFORMANCE MEASUREMENT SYSTEM

2.1 Power Grid Synchronization by PMU

For the techniques of a power system, studies on the techniques for the wide-area monitoring of power have been actively performed. For this wide area monitoring system technique, a time control technique is essential for the wide-area monitoring of power, and this time synchronization technique has become a core issue. A time synchronization signal that synchronizes time is an essential signal source in PMU for synchronized phase monitoring. In general, a time synchronization signal is provided from GPS satellites. To receive 1 pulse per second (PPS), which is a signal for time synchronization, from GPS satellites, a GPS receiver receives the command signal generating 1 PPS from GPS satellites; generates 1 PPS signal and sends it to time synchronization devices.

For an Inter-Range Instrumentation Group-B (IRIG-B) signal, an IRIG-B generation part connected to a GPS receiver outputs an IRIG-B signal, and it includes the necessary data for time synchronization in GPS data. In this study, the accuracy of 1 PPS synchronization signal using the IRIG-B signal outputted from the GPS receiver of PMU was evaluated using an atomic clock. The PMU used for the measurement was PMU1133a which is capable of receiving the GPS signal of 12 channels and provides a synchronization accuracy of less than 1 us. It generates 1 PPS and embedded 10 MHz oscillator using GPS, and maintains the 1133a oscillation frequency at an accuracy of 10^{-10}.

In the case of PMU1133a for power grid synchronization, the optimal method for generating UTC reference time is to use GPS timing. GPS provides very accurate time

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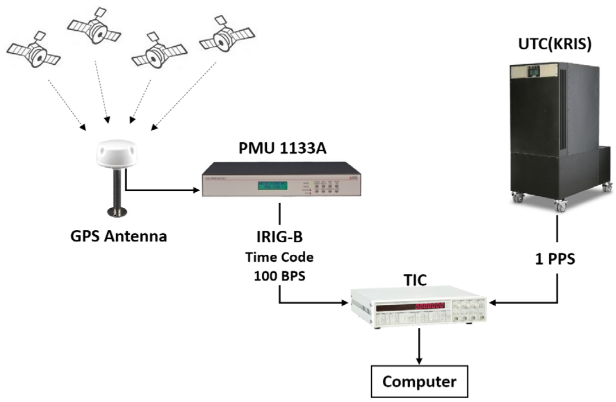

Fig. 2. Estimation of GPS synchronization signal of IRIG-B output of PMU_1133a.

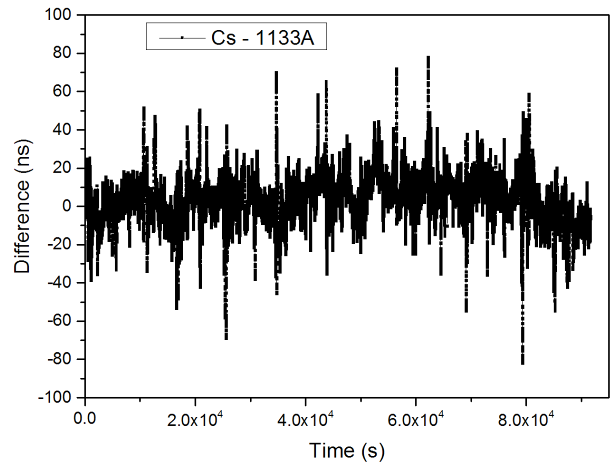

Fig. 3. Result of the phase comparison measurements.

and reference frequency information. However, signals transmitted from satellites could be temporarily unstable due to receiving environment, intentional jamming, and satellite abnormality; and thus a stable oscillator with outstanding performance that can constantly provide synchronization signals in case of holdover mode should be used. When a GPS receiver is not embedded, reference time signals for synchronization should be able to be externally entered in preparation for failure. For the external signal, the IRIG-B standard is generally used. Also, 1 PPS signal can be used from the clock signal that has been synchronized with UTC. Fig. 1 shows the method for the comparison of the phase of power by PMU. High-current and high-voltage phases are generated by ADC from the current transformer and potential transformer, and they are compared with the reference phase within PMU that has been made based on GPS. Therefore, the performance of reference signals generated by GPS is very important.

2.2 Implementation of the PMU Synchronization Performance Evaluation System

As explained in the earlier section, PMU for phasor measurement is installed at each substation of the power grid. By receiving GPS, PMU internally synchronizes the oscillator; and based on this, it externally outputs UTC information in an IRIG-B time code format. Also, there are voltage and current input terminals for the comparison of the phasor of power. As 60 Hz is used in Korea, this phase is compared with the internal reference signal that has been synchronized with GPS. Therefore, the performance of PMU can be examined through comparison with the IRIG-B code which is an output signal generated by the internal reference signal. A conversion device that generates standard time and outputs 1 PPS by receiving the IRIG-B code outputted from PMU has also been commercialized. However, this test was to measure the degree of the stabilization of output signals. Thus, one of the 100 BPS time code pulses generated by the IRIG-B code was selected and compared with UTC (KRIS), which is the coordinated universal time maintained at Korea Research Institute of Standards and Science. Fig. 2 shows the diagram for the implementation of measurement.

2.3 Performance Measurement and Evaluation Results of PMU

Based on the method shown in Fig. 2, the phase difference between the 1 PPS output of atomic clock and the reference output of PMU was measured using a time interval counter (TIC) in a laboratory where constant temperature and humidity are maintained. PMU1133a does not output second pulses, and thus an optimal trigger level was found by performing an experiment that establishes the trigger level to get an optimal point for IRIG-B output (5V) in advance. IRIG-B output is general digital code data, rather than a pulse type that has an abrupt rising edge for timing. Thus, finding a stable trigger point is important for precise measurement. For this purpose, comparisons were made at 2V, 3V, and 3.5V, which are middle levels with relatively small noise and signal distortion. In the case of the 2V setting, outliers occurred, but the most stable data could be obtained. Fig. 3 shows the data measured at a trigger level of 2V. As shown in the measurement result, outliers occurred intermittently, but the signal level was less than 100 ns. The average of the measured data was 3.7 ns, and the standard deviation was 11.9 ns, which showed substantially outstanding performance. Figs. 4 and 5 show the stability and the maximum time interval error (MTIE), respectively.

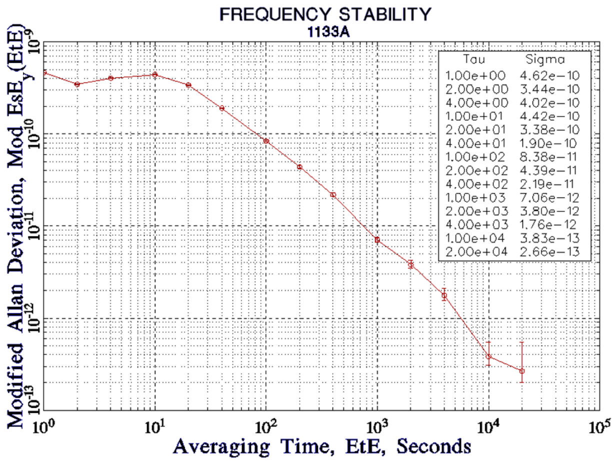

Fig. 4. MVAR of the phase comparison measurements.

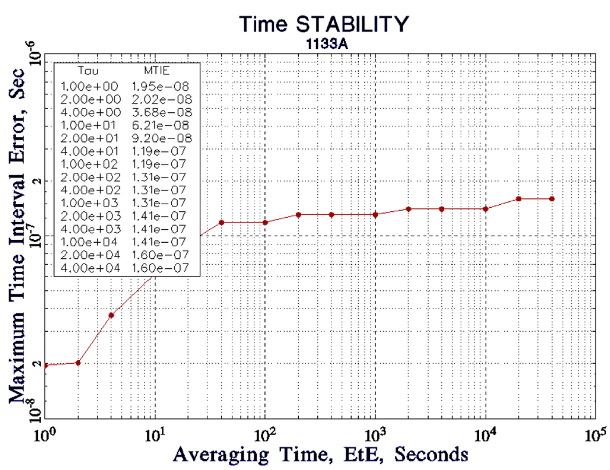

Fig. 5. MTIE of the phase comparison measurements.

As shown in the figure, for the 10-second average interval, the frequency stability was about 10^{-10}; and for the entire measurement period, the MTIE value was less than 200 ns. It is thought that this performance is sufficient for a power measurement system.

3. DESIGN OF A REMOTE MEASUREMENT SYSTEM FOR THE PMU OF POWER GRID AND THE EVALUATION OF A GPS TIME TRNASFER RECEIVER

Using the method shown in Fig. 2, institutions that maintain a time standard can directly measure PMU, but general power stations and substations cannot make a direct measurement by using this method. Thus, a method shown in Fig. 6 was suggested. Except for UTC, even an atomic clock shows a drift, and the variation is dozens of

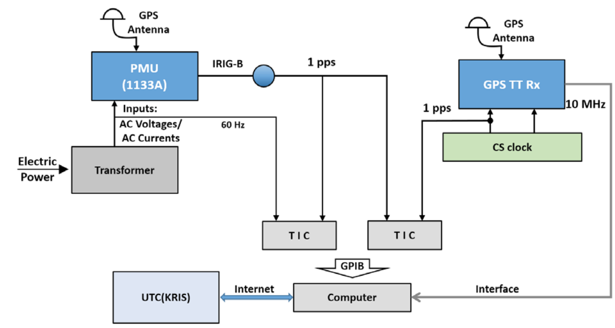

Fig. 6. Remote monitoring and calibration system for the measurement of timing accuracy of a GPS receiver and a PMU.

nano-seconds ~ hundreds of nano-seconds per day. This induces a large error in a system that should measure nano-second level. Therefore, a process of measuring and compensating the variation of a clock is required. For this purpose, the remote measurement system of reference phase of power grid that can measure the drift of an atomic clock using a time transfer GPS receiver and can make a measurement with low uncertainty through the post-processing of GPS time comparison data was implemented as shown in Fig. 6.

The remote measurement system of reference phase of power grid is a system for the remote evaluation of the synchronization signal of a power grid of GPS based PMU system. In this study, a PMU reference phase remote measurement monitoring system that can monitor normal operation by measuring the status of 1 PPS by the GPS signal reference IRIG-B signal outputted from PMU was designed. In an actual substation, the levels of voltage and current of a power system for measurement are changed to the input range of PMU by lowering the voltage using a potential transformer or by lowering the current using a current transformer, and are then inputted to the installed PMU. PMU measures the phases of the voltage and the current of a power system based on the 1 PPS signal provided by GPS (an accuracy of less than hundreds of ns), and transmits them to a data collector of phasor. In this regard, for the same measurement, an accurate synchronizing signal based on reference time needs to be used; and in most cases, PMU measures the phase angles of voltage and current by applying a synchronizing signal that provides a reference signal (e.g., GPS). The IEEE 37.118 standard states that the phase angle of power needs to be measured and calculated using 1 PPS of UTC as the synchronizing signal (IEEE 2011). For synchronization with UTC using GPS time information, PMU based on the synchronizing signal using GPS needs to be used at each measurement point. When PMU is used as mentioned above, the phase differences of voltage and

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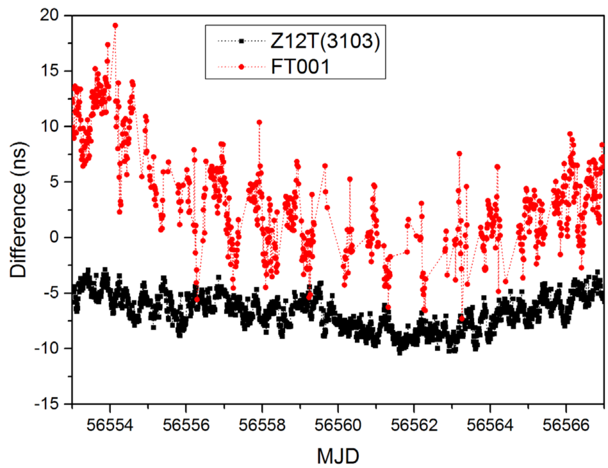

Fig. 7. Comparison of the phase performance between a reference receiver (Z12T) and a remote one (FT-001).

current at the measurement location of a transmission line can be measured through the measurement of the transmission line. Based on the real-time measurement of these measurement values, the effects of system load and the change in the power phase of the entire substation line can be monitored.

Fig. 7 shows the measurement data of the performance of the GPS time transfer receiver for remote monitoring. This is a relatively inexpensive receiver that performs time comparison that makes a measurement based on C/A code. Using the CCTF Group on GNSS Time Transfer Standard (CGGTTS) file stored in the receiver, the applicability to the power grid was tested through comparison with the CGGTTS file of the Z12T receiver which is a P3 code time transfer receiver. For the measurement period, 15-day data were used for the comparison; and as shown in the result, the difference between the two receivers was less than 30 ns. It is thought that this performance is sufficient for monitoring the change in the phase of PMU.

4. CONCLUSIONS

In this study, we designed and implemented that a remote measurement monitoring system of reference phase of PMU that can monitor the performance of GPS which serves as the reference of time and frequency of PMU and can measure the phasor of a power grid at the same time by measuring the 1 PPS output of the IRIG-B signal outputted from PMU. Through this system, 1 PPS phases of PMU in power grid can be monitored by the simultaneous time comparison of the 1 PPS for the remote PMU and the synchronization measurement data of GPS for remote monitoring by using a high-performance atomic clock. When this system is installed at substations and the measurements that have compared the reference phase of PMU by GPS at faraway locations with a Cs atomic clock are collected in real time through a remote communication channel, it can be monitored and evaluated that the phases of power grid as well as the synchronization status of the reference signal of the power grid system for the entire smart grid.

REFERENCES

IEEE Power Engineering Society 2011, IEEE Standard for Synchrophasors for Power System, IEEE Std C37.118.1-2011

Itagaki, D., Shirota, Y., & Sekiguchi, K. 2004, Field experiences and assessment of GPS synchronizing signal receiving for power system protection, control and monitoring, 2004 Technical Meeting on Power Protective Relay IEE Japan.

North American Synchrophasor Initiative (NASPI) 2007, A Guide for PMU Installation, Commissioning and Maintenance Part II PMU Installation Procedures.

Rahman, W. U., Ali, M., Mehmood, C. A., & Khan, A. 2013, Design and Implementation for Wide Area Power System Monitoring and Protection using Phasor Measuring Units, WSEAS TRANSACTIONS on POWER SYSTEMS, 8, 57-64.

Sattinger, W., Baumann, R., & Rothermann, P. 2007, A new dimension in grid monitoring, Transmission & Distribution World Magazine, Feb 1, 2007. http://tdworld.com/overhead-transmission/new-dimension-grid-monitoring

UNITED STATES NAVAL OBSERVATORY (USNO) 2015, Block II Satellite Information, cited 2015 Feb 24, available from: ftp://tycho.usno.navy.mil/pub/gps/

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