Web-based Wide Area Measurement System
- System Architecture and Experiences

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Abstract

Fault and disturbance recording systems using the latest communication and information technology allow for innovative solutions to a wide range of power system problems. This paper describes a Web-based wide area measurement system for fault and disturbance recording. When the proposed "Network" devices, server and browser in this system communicate, they can share information which can enhance the overall fault and disturbance analysis. The paper includes: overview of network devices, key technologies, applications, issues and conclusion.

1. INTRODUCTION

Various services using a network have been proposed and their practical use has been enabled by the spread of the Internet. The authors have so far proposed various application systems based on wide-area synchronized measurement systems using power system multiple point data [1-3]. In addition, improvements in processor throughput in recent years are enabling it to collect two or more services at one server. We have developed a Web-based wide area measurement system to realize a fault location function and a fault and disturbance analysis function using one server. Introduction of this system has progressed in Japan, and this system has been applied as a standard system.

In this paper, while describing the basic configuration, the features, and the component technology of the proposed system, the function and actual result are in the main explained with regard to fault location and disturbance analysis as an application system. Furthermore, the features of power quality monitoring, phasor measurement, and the agent system that are currently being considered for introduction to this system are also reported.

2. BASIC CONFIGURATION

The basic configuration of the proposed system is shown in Fig. 1. A Network Computing Terminal or a protection and control device with network computing unit board is applied as a terminal device. The details of the terminal device are described in the following chapter. The terminal device collects information, including voltage, current, relay operation, etc.. Terminal devices are installed in throughout the power system. The terminal device has real-time processing capability and a Web-server function. Moreover, it has the GPS (Global Positioning System) time synchronization function, the Ethernet LAN interface, etc. and power system information is accumulated and processed and a transmission output is executed. It is connected to the communication network via communication network interface apparatus, such as a router, a modem, and HUB; the power system information, which is tagged with GPS time, is transmitted to a maintenance base. The server installed in the maintenance base uses the transmitted power system information, and carries out the fault location and measurement analysis of a fault or disturbance. Moreover, since the Web function is mounted in a terminal device and a server, the state of a terminal device, and the record and operation result of each application can be easily perused through a network using a general-purpose browser. The capability for the server to be able to collect and analyze the information from 200 terminals at the maximum is required.

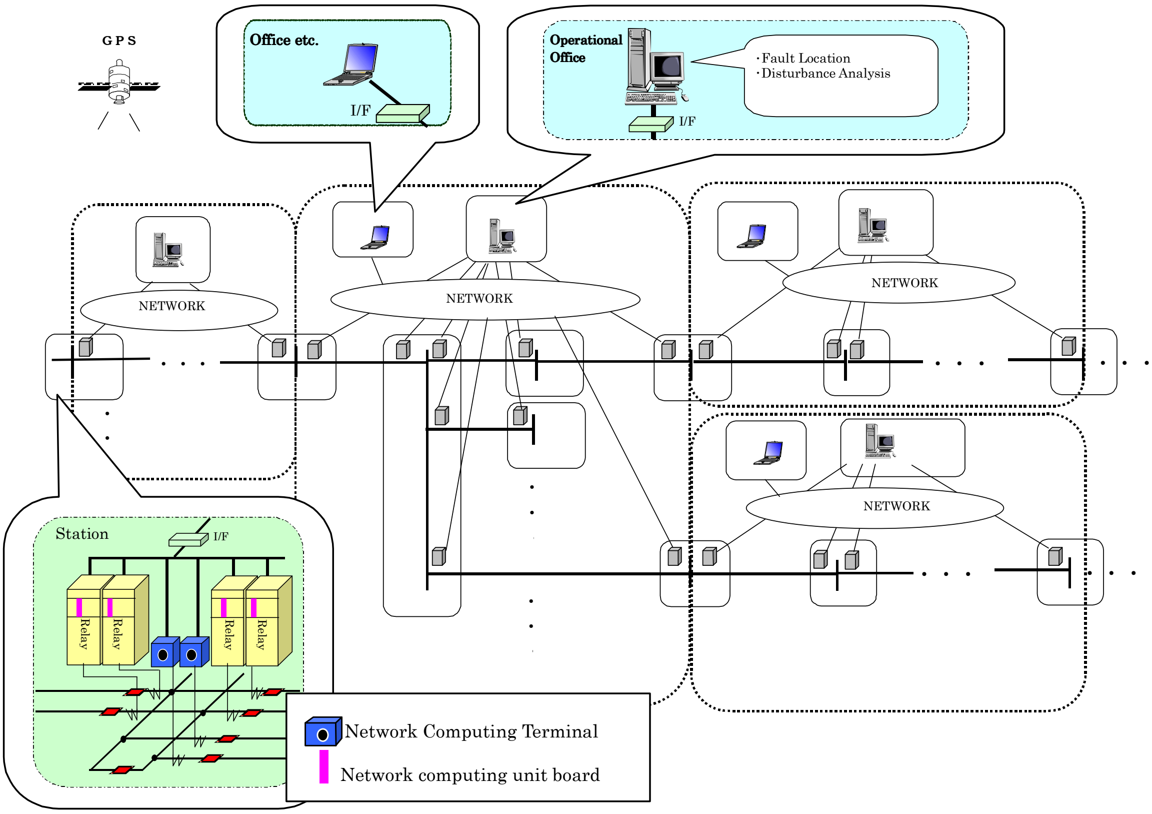


Fig. 1. Web-based wide-area measurement system

3. KEY TECHNOLOGY

The relationship between the needs of the system proposed by the authors and the key technology developed to solve this is shown in Fig.2. Details of each key technology are described in the following section.

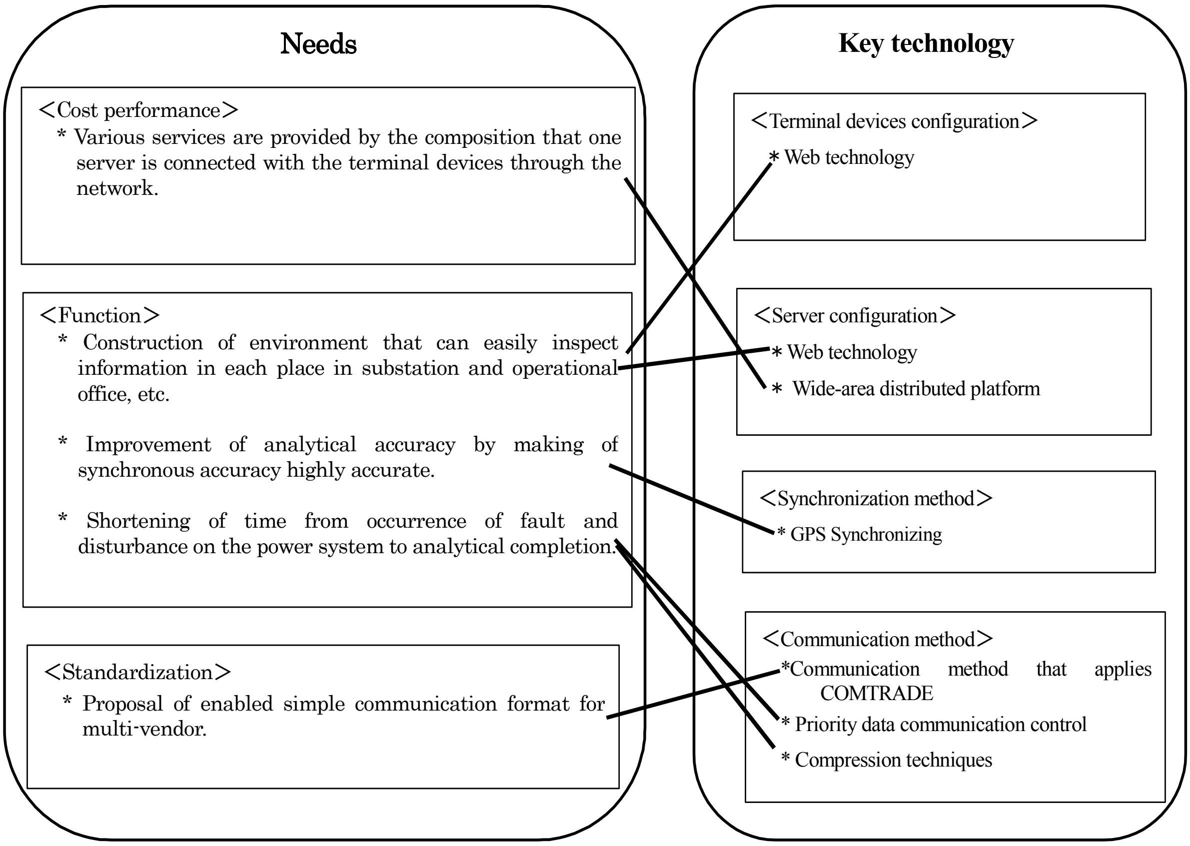


Fig.2. The relationship between the needs of the system proposed by the authors and the key technologies

3.1 Terminal devices configuration

The basic configuration of the terminal device is shown in Fig.3. A terminal device includes a core area and Web area.

In the core area, a real-time operating system is desirable for real-time processing; μITRON (Industrial The Real-Time Operating system Nuclears) was used. Protection and Control operations written in C language are executed as tasks managed at microsecond order, and the acquired data is supplied with absolute time stamps received via GPS.

In the Web area, Java^{TM} applications are operated on a JVM^{TM} (Java Virtual Machine). Java^{TM} is an object-oriented language developed in the Internet world. It is an appropriate option for terminal devices as it possesses the qualities of reusability, safety, and network compatibility. A compact data database (data management system) is provided for easy acquisition from Java^{TM} applications. The Web area is provided with an Internet-like communications and information processing mechanism, thus assuring free data exchange with the server and browsers. So as to assure better reliability, the Web area is also furnished with a tracing mechanism for Java^{TM} threads operations, and with self-diagnosis functions corresponding to computer relays.

To realize the system in the minimum installation space, the authors developed a compact terminal device (Network Computing Terminal) and a Network computing unit board that can be inserted in a protection and control device. Fig. 4 shows the Network Computing Terminal device. Fig. 5 shows the Network computing unit board.

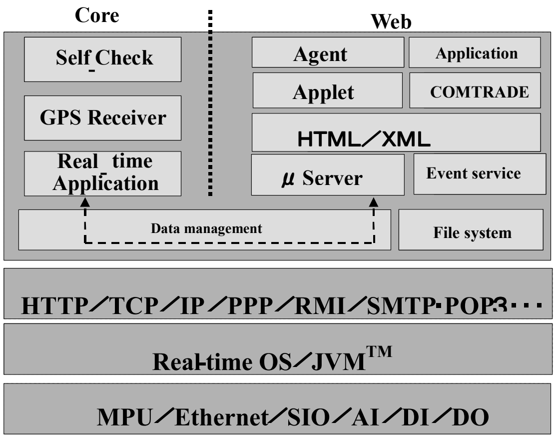


Fig.3. Configuration of Network device

Fig.4. Network Computing Terminal

Fig.5. Network computing unit board

3.2 Server configuration

In the system proposed by the authors, it is a requirement to achieve various services with one server in consideration of economy. Therefore, the wide-area distributed platform has been developed as the core middleware for this configuration. Fig. 6 shows the configuration of the server. The API (Application Programming Interface) of the platform supports unified handling of data received from all terminal devices. Examples of the API are shown in Table 1. This API simplifies the programming of fault locator, disturbance analysis, and other application systems. These applications are written in Java™. In addition, because the Web function is installed in this server, the monitoring and analysis results of each application can be easily inspected by a browser through the network.

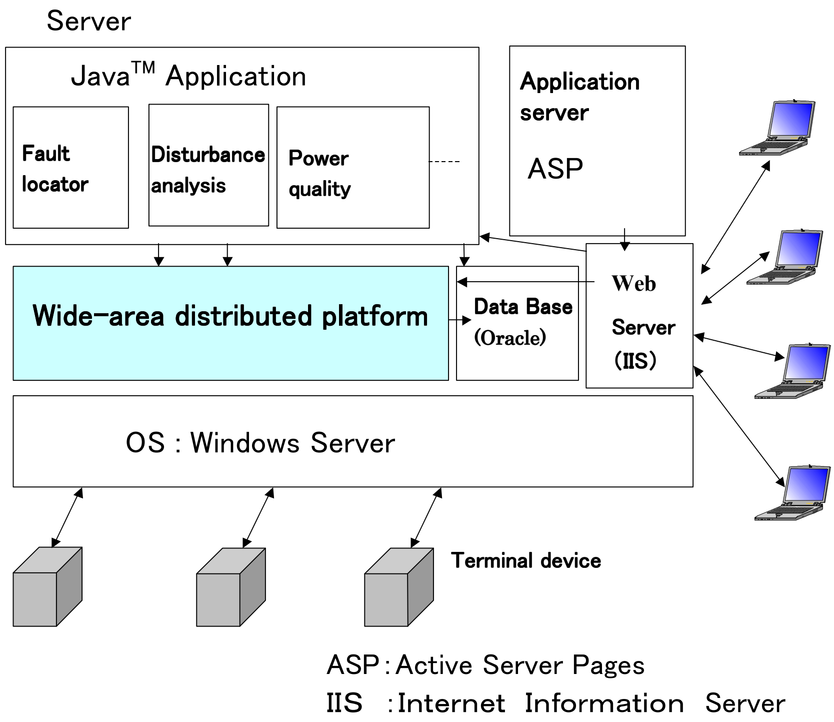


Fig.6. Configuration of the server

Table 1. Examples of API in the wide-area distributed platform

Packages	
nc.common	Provides the standard interfaces for accessing network devices. (e.g. CbCheck, GetComTrade, ExclusiveIP, Http)
nc.exception	Contains SystemException class and TimeoutException class.
nc.wave.api.control	Contains APIs for the system control. (e.g. MainControl, FaultGrouping)
nc.db.common	Defines common APIs to access the data base.
nc.db.table	Defines APIs to access the data base tables. (e.g. Comtrade, Device, PowerStation・・)
nc.debug	Provides the APIs to test the system

3.3 GPS Synchronizing

In this system, GPS time is applied as the method used to synchronize power system information data. At present, IRIG-B time code, which carries out amplitude modulation of the carrier of 1 kHz by a time signal, is widely used for time synchronization for substation equipment. Because the waveform of the electrical signal is prone to being degraded by the frequency characteristics of the transmission line and is also sensitive to electromagnetic fields and filter propagation delay, it is difficult to achieve synchronization with the precision required in some practical cases. Fig.7 shows the new synchronized signal distribution system [4]. The terminal devices synchronize data sampling timing only when the timing code is received. Therefore, incorrect timing edge detection caused by signal noise or optical device deterioration is avoided. In addition, serial data containing data and time information from the receiver is superimposed with the timing code. Hence, only a single optical fiber is needed to distribute the data. Serial data in asynchronous communication format is suitable for microprocessor based equipment in substations and there is no need for special decoding circuitry.

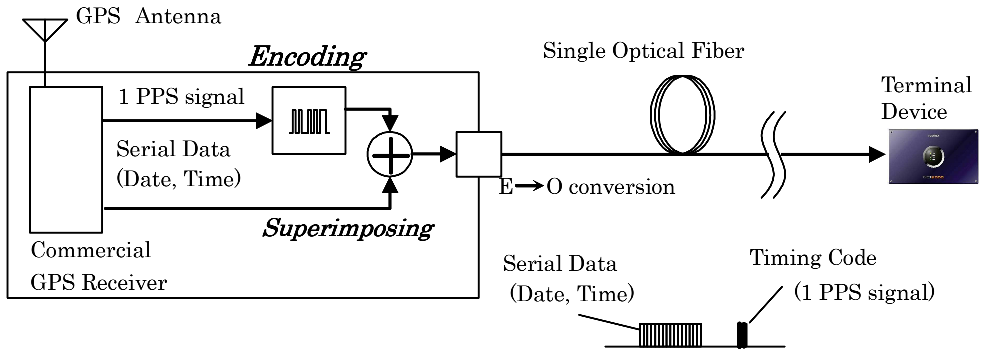
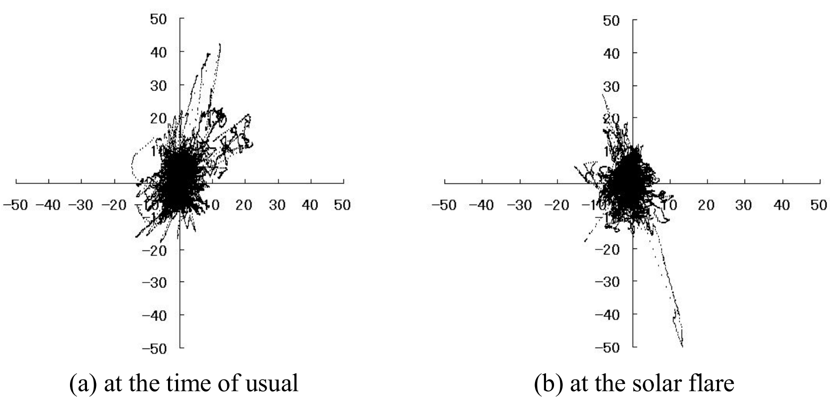


Fig.7. GPS synchronizing signal distributing technique

Moreover, the result of having investigated the influence of the weather on GPS synchronization is described. There was no influence from rain or snow. Furthermore, with respect to severe conditions, a change of the positioning result was observed from October 29 to 31 in 2003 in the period when a magnetic storm had occurred under the influence of a solar flare. The result is shown in Fig.8. The standard deviation in the level of position accuracy over 24 hours is 5.3m, and the result was no different when compared with a change in position of 6.2m at the time the usual data was obtained. It has been confirmed that sufficient reliability could be obtained from this result when using GPS time as a means to synchronize the system.



(a) at the time of usual
(24 hours from 2001/3/10 0:00)

(b) at the solar flare
(24 hours from 2003/10/30 12:15)

Fig.8. Example of reception monitoring result

3.4 Communication method

1) Communication method that applies COMTRADE

For the purpose of easy system design, HTTP is used as the protocol for communications between terminal devices and the server. File formats are based on COMTRADE (IEEE C37.111). Being a popular standard to record system transient phenomena, COMTRADE is also suitable for data exchange between terminal devices and the server. COMTRADE includes four types of files, namely, DAT, CFG, HEAD, and INFO. The explanation of each file is shown as follows.

- DAT : data file
  The data collected is described by the binary form etc.
- CFG : configuration file
  The configuration of the data collected is described.
- HEAD : optional text file
  An explanation of the device is provided if necessary.
- INFO : information file
  Information to display waveforms is described.

These files are sent to the server in the sequence shown in Fig.9. Communication between terminal devices and the server is made easy by using the HTTP POST/GET method. In the COMTRADE standard, substation and device names are represented in ASCII code. In addition, the numerical format (endian) is also fixed as little endian. In this study, the standard is extended so that Japanese characters can be handled using Unicode, and endian information (big or little endian) can be specified in CFG files. A number of manufactures in Japan are open to the public in this communication method.

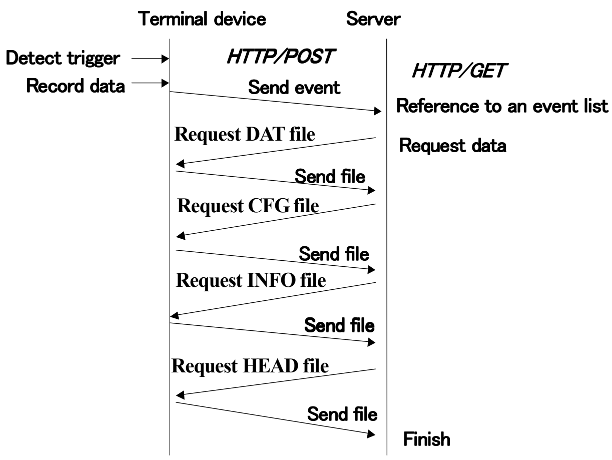


Fig.9. Interaction between server and terminal device

2) Priority data communication control

In general, after a power system fault occurs, operators usually immediately require the result of fault location analysis. The network load increases if the data needed for two applications of fault location and disturbance analysis are collected from the terminal devices at the same time, and the time to complete fault location analysis is delayed. As a counter measure, "Priority data communication control " has been developed, and installed in the server.

Fig. 10 shows the explanation chart for the priority data communication control. If collection data for fault location is given priority and transmitted, fault location analysis output, in the shortest time becomes possible. This control was achieved as one function of the wide-area distributed platform installed in the server.

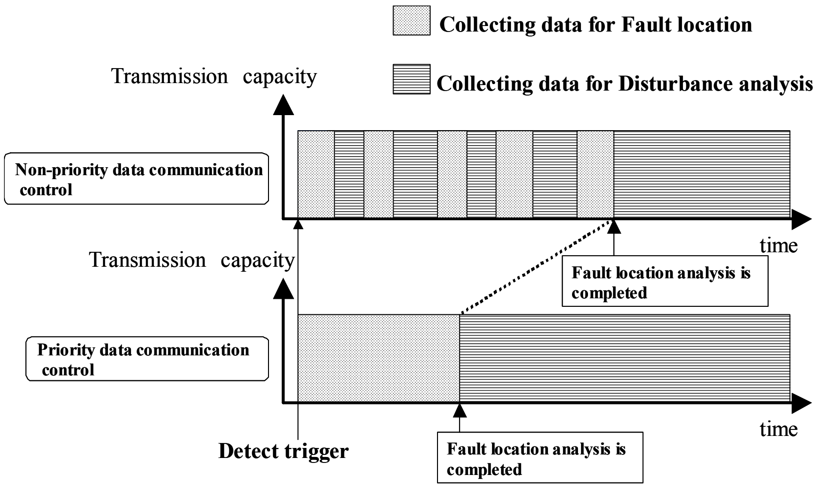


Fig. 10. The explanation chart of the priority data communication control

3) Compression techniques

System fault data and much other information are stored in the terminal devices. The importance of such information depends on how rapidly and easily it can be retrieved from remote locations.

If the network bandwidth is large enough, transmission delays do not matter even though great volumes of data are collected in the core areas. However, many existing networks offer only a narrow bandwidth, and here compression techniques come in handy. Image compression has proven efficient on the Internet. A variety of algorithms are available for data compression, but when temporal features such as sharp signal fall patterns (power system fault waveforms) must be rendered accurately, special compression techniques are required, different from those used for compression of text files or Web images.

In particular, wavelet shrinkage is drawing attention as a signal compression technique. In this study, a data compression mechanism based on wavelet shrinkage was employed in terminal devices, and proved appropriate for high –speed data transfer. Specifically, the wavelet expansion coefficients $w(j,i)$ are found as in Eq.(1), and then the signal is reconstructed so that these coefficients are replaced with zeroes if their absolute values are smaller than some threshold (wavelet shrinkage). In addition, encoding is performed using the fact that the nonzero expansion coefficients are distributed unevenly.

$$s(j,i) = \Sigma_k p_k s(j\text{-}1,2i+k)$$
$$w(j,i) = \Sigma_k q_k s(j\text{-}1,2i+k) \quad \text{......................} \ (1)$$

Here j is the level, and i is the sequential sample number.

Considering the input signal in Eq.(1) as a 0-level sequence $s(0,i)$,the coefficients $s(j,i)$,$w(j,i)$ can be found recursively. The constant sequences $\{p_k\}\{q_k\}$ correspond to the mother wavelet. Since j is a frequency component, time resolution can be applied here.

Fig.11 presents the transient response waveform of the zero-sequence current of a power electronics device in case of a ground fault (The file size is 2 MB, sampled rate is 28.8kHz.), and the same waveform compressed by the algorithm described above. The algorithm was implemented in the Web area of terminal devices, and data decompression was executed on the server. It was confirmed that the main features of waveforms were reproduced accurately at a compression rate of 1/30. The proposed algorithm achieves powerful data compression while retaining local features [5].

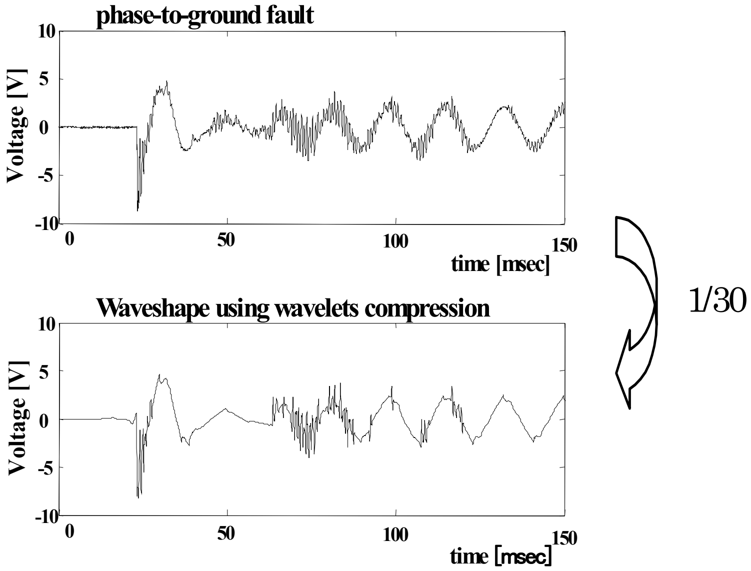


Fig. 11. Data compression for power system

4. APPLICATION SYSTEMS

4.1 Web-based Fault Location and Disturbance Analysis System

1) Features

By applying the above-mentioned wide-area distributed platform as a server structure, as realized in one server, and since this system does not need a dedicated device for every function as in the past, it contributes greatly in respect to economic efficiency and installation space. The features of each function are explained below.

a) Web-based fault location function

This is an impedance-based fault locating system which performs fault location automatically using the voltage and the current information from both-terminals of a power transmission line which uses highly precise time synchronization using GPS. Generally, impedance-based fault location functions are integrated into protection relays using one-terminal methods. However, it is difficult for one-terminal methods to take the effect of the fault resistance and remote terminal current into consideration. Therefore, the highly precise two-terminal fault locating system was developed and put into practical use using the fault location algorithms which use the positive-sequence component and are not influenced by fault resistance and remote terminal current. The positive-sequence component has the advantage that faulted phase selection is unnecessary, and there is little positive mutual coupling between parallel lines. Also, the positive-sequence component is a mode exhibiting high propagation velocity, and it is not influenced by the grounding return path which exhibits slow propagation velocity. Therefore, it has the advantage of giving a steady result immediately after the fault. Moreover, it uses a transverse difference component of parallel lines for high precision in parallel transmission lines [6].

b) Web-based disturbance analysis function

Since the data based on GPS was able to take the synchronization with high precision is collected automatically and can be specified from a required terminal, a display and analysis of the information of a power system at the time of the fault and the disturbance can easily be made. Moreover, since the quantity-of-electricity data which a terminal device acquires is data from the same transformer (VT, CT) as the data used for protection relay operation, it can conduct fault analysis by linking directly to the operation of the protection relay.

2) Data storage and transmission

The preservation timing of the data is shown in Fig.12. The fault detection relay built into the terminal device operates when a fault occurs, and the pre-fault data and post-fault data are saved. A disturbance analysis needs all of the data saved at a sampling rate of 4800Hz from fault occurrence to the fault clearance. On the other hand, fault location does not need all the saved data. A fault location operation is possible, if the data of five cycles before the fault occurred and eight cycles during the fault are obtained at a sampling rate of 1200Hz.

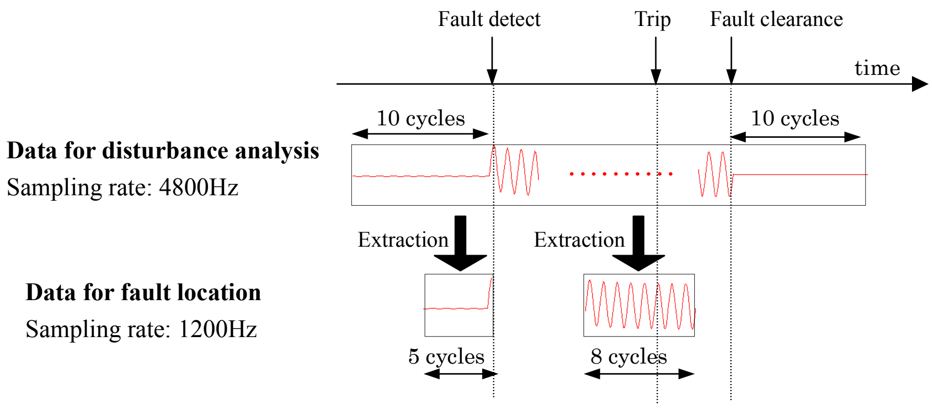


Fig.12. The preservation timing of the data

An example of the procedure for data acquisition in case of a transmission line fault is shown in Fig. 13. As a procedure for data transmission to a server, by priority data communication control, the data required for a fault location is extracted first, and it transmits to a server (First STEP). The data for disturbance measurement is transmitted from the equipment which carried out the trip output after fault location completion according to the demand from the server side (Second STEP). So far, fault occurrence is automatically performed as a trigger. Henceforth, if needed, the data for disturbance analysis of the circuit of the adjacent line etc. is collected, and the range of analysis can be extended (Third STEP). Fault location is performed in the shortest time, without being dependent on transmission of the data for disturbance measurement by carrying out such priority attachment and performing data transmission. Moreover, the information on the most important trip terminal at the time of analysis is quickly collected including the data for disturbance analysis.

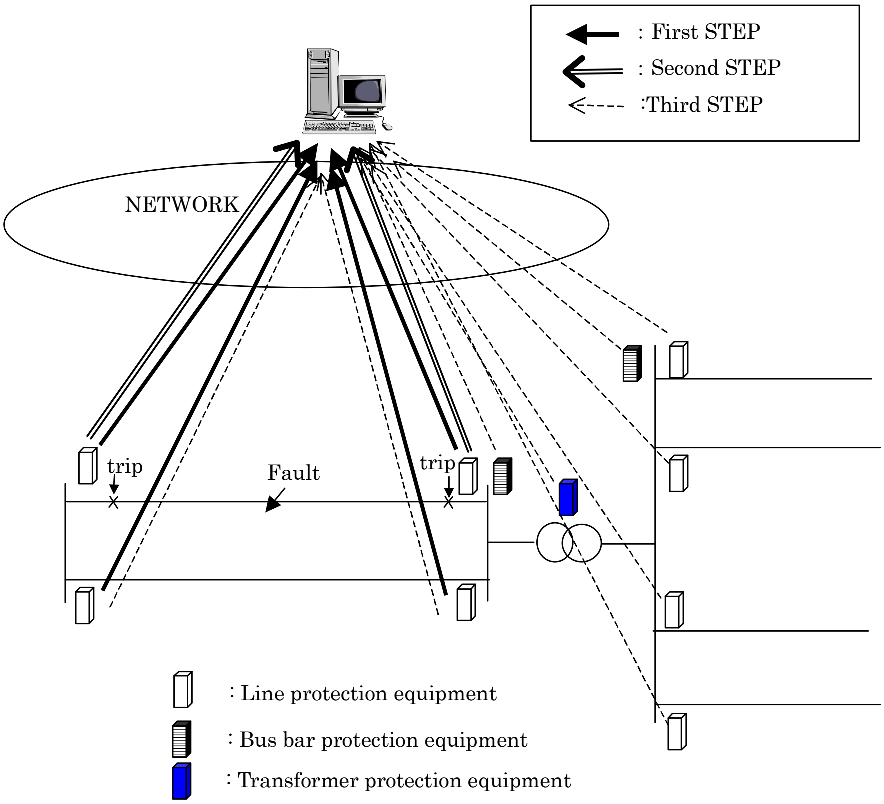


Fig.13. Example of a procedure for data acquisition

3) Actual results

Here, the actual results of a web-based fault location and disturbance analysis system are described.

a) Web-based fault location function

i) Fault location accuracy

In Japan, the fault locating system has been applied in many transmission systems on single and parallel lines and already many fault location results have been obtained. The results (Table 2) show good performance with measured errors within 1% of line length for solidly grounded systems.

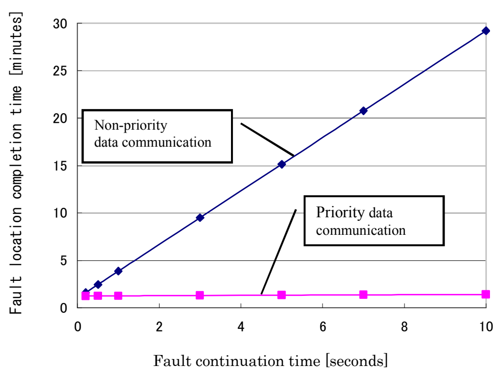
Table 2. Actual measured results in solidly grounded systems in Japan

Voltage	Line	Fault type	|Error| [%]
275kV	parallel lines	1L-a 2L-ab	0.02
187kV	parallel lines	1L-bc	0.12
187kV	parallel lines	12L-b	0.41
187kV	parallel lines	21L-a	0.67
187kV	parallel lines	2L-a	0.64
		Average	**0.37**

Otherwise, the fault locating system has also been applied in many resistance grounded systems. In resistance grounded systems, the grounding impedance allows for a current of 200A or 300A in the case of an earth fault. For that reason, it is difficult to obtain high location accuracy, but we were able to obtain good location results [7].

ii) Time concerning a fault location

The fault location completion time is shortened by carrying out priority control to data transmission. The time concerning the fault location for a fault in a parallel transmission line is shown in Fig. 14. The time concerning a fault location is always fixed time (1 minute and less than 30 seconds), independently on fault continuation time.



<Conditions>

- Transmission line: parallel lines
- The number of terminal devices: four devices
- The data size

    Data for fault location: about 16 kbyte/one line at one terminal (un-depending to fault continuation time)

    Data for disturbance analysis: about 2 Mbyte/one line at one Terminal (In the case of fault continuation time: 10 seconds)

- Data rate : 9600bps

Fig. 14. Time concerning a fault location

b) Web-based disturbance analysis function

The disturbance analysis function mounts the analog waveform analysis (Fig. 15), the vector analysis (Fig. 16), the basic display of a relay operation, and the harmonic analysis (Fig. 17). Since it is the data which was able to take the synchronization with high precision by GPS, the comparison analysis of the data acquired from the different points can be carried out on the same screen. When the data compression technique by Wavelet is applied, if a network band is narrow, the start to quick analysis will be attained.

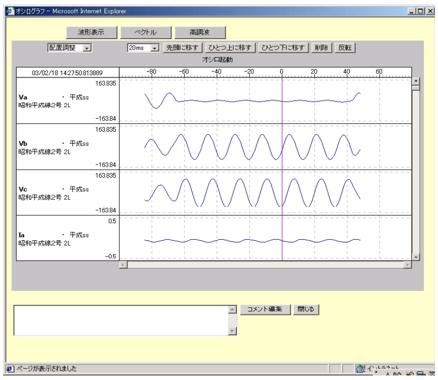


Fig. 15. An analog waveform indication

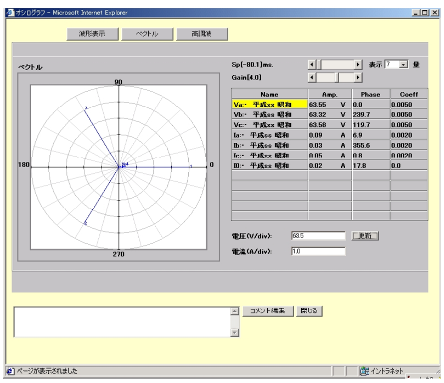


Fig. 16. A vector indication

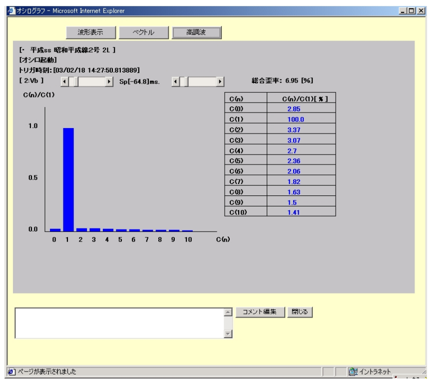


Fig. 17. A harmonics analysis indication

4.2 Other application systems

Application systems described in this chapter individually construct the server and have been achieved. In the future, the aim is to consolidate these applications in one server by applying the wide-area distributed platform technology.

1) Power quality monitoring

The fact that system voltage and current values are contained in protective relays was utilized for the measurement of PQVF, voltage sag, and harmonics. Since all line currents concentrate at a bus protective relay with a network computing unit board, providing the relay makes possible the implementation of the PQVF function and remote data collection without using any dedicated devices. An example of such system is shown in Fig.18. Here protective relays are used as information sources and information servers, which is helpful in power system operation.

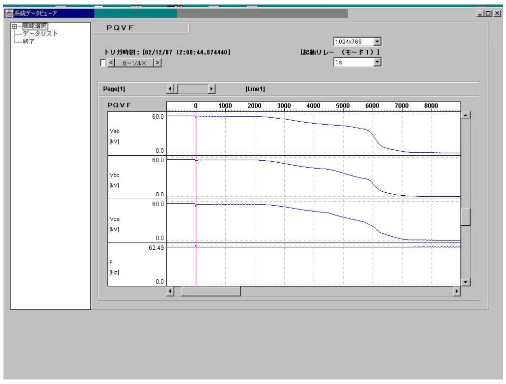


Fig. 18. Power Quality Monitoring System.

2) Phasor Measurement System

To monitor dynamic characteristics, in particular the transient stability of a power system on a real-time basis, a phasor measurement system is useful, which collects data including the amplitude and phase angle of the voltage, and active power flow from multiple locations on the power system, and extracts the dynamic characteristics of the system from the data easily and with a high degree of accuracy.

Fig.19 shows the architecture of the Phasor Measurement System. The Network Computing Terminal performs A/D-conversion of the input voltage with 16bit, sampling frequency of 4800Hz or 5760Hz, and calculates the amplitude and phase of the input voltage by the phasor operation with the one-second pulsed signal received from the GPS satellite for reference, and save the results. Phasor Measurement Systems have been installed in several universities in Japan and have been utilized for the analysis of the power fluctuation between different locations [8].

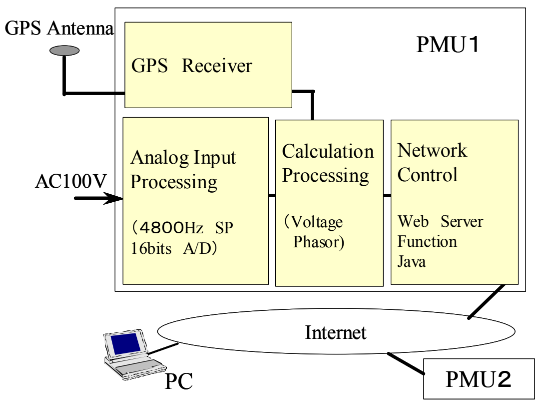


Fig.19 Architecture of the Phasor Measurement System

3) Agents

Agents are a notable modern technology. The authors developed reliable architecture with compact mobile agents. Three mobile agents [9] have been developed that can move between the server, browser, and protection and control equipment with a network computing unit board to further enhance operation and maintenance functions:

- Patrol agent, which can gather information about the condition of the equipment.
- Setting agent, which can be used to set one or a number of devices; can also reside in one device to monitor power system conditions such that, if they change, it can alter protection and control settings, which enables adaptive protection.
- Analyzing agent, which moves between devices and collects and analyzes data in the event that a power system fault should occur; following data collection, it prepares a report.

An example of an analyzing agent system is shown in Fig.20. An analysis agent is started by the equipment operation information at the time of the occurrence of the system fault registered into operation-DB. The traveling path and the data to be collected are planned with reference to the system-DB and the analysis-KB. After the analyzing agent has returned to the agent server it reports the collected equipment operation information. Collection information is analyzed using the verification-KB, and it's validity is evaluated.

We confirmed that the analyzing agent performed efficient data collection for power system fault analysis by autonomous traveling path generation and the decision for agent work based on system configuration data, analysis-KB, and verification-KB.

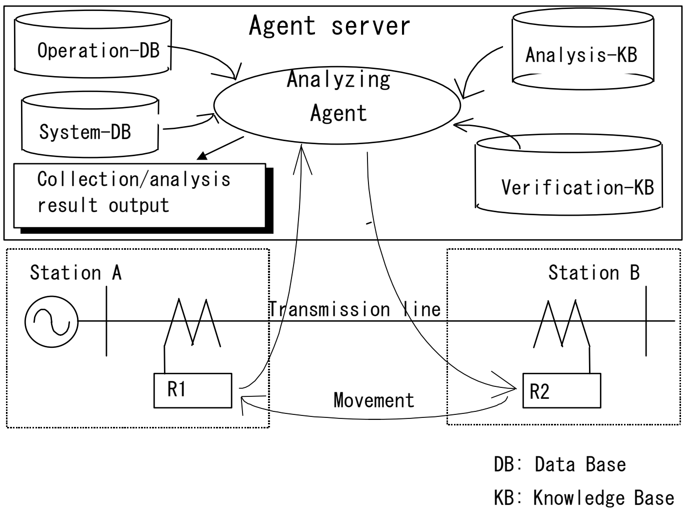


Fig.20. Analyzing agent

5. CONCULUSIONS

In this paper, the basic configuration of a Web-based wide area measurement system and its key technology were proposed. In addition, some fault location and disturbance analysis systems have already been introduced in Japan, and they are applied as a standard system in some electric power companies. In the future, improvements in the service quality are expected by adding various applications (Power quality monitoring, Phasor Measurement, Agents, and etc.) that can be installed in this system without an increase in the hardware requirement.

REFERENCES

[1] K. Sekiguchi, S. Takenaka, Y. Shirota, “Power System Protection and Control System applying Intranet Technology”, TOSHIBA Review,1999; Vol.54, No.6, pp.34-37 (in Japanese)

[2] R. Tsukui, P. Beaumont , T. Tanaka, K. Sekiguchi, “Intranet-Based Protection and Control”, IEEE Computer Applications in Power, pp14-17, 2001

[3] K. Sekiguchi, Y. Shirota, M. Shimoo, H. Sugiura, T. Kagami, “Network Centric Approach to Protection,Control, and Monitoring for Power System”, Electrical Engineering in Japan,Vol.149,No.4, pp31-41,2004

[4] D. Itagaki, K. Ohashi, M. Saga, I.Shuto, ”Development of High Resolution and High Reliability Time Synchronizing Signal Distribution Technique for Substation Systems”, IEE-DPSP’04, pp.714-717, 2004

[5] D.Murayama, T.Kagami, W.Shinohara, K.Mitsumoto, and Y.Tone : ”Development of Wavelet Signal Compression function on Network Computing Terminal”, National Convention, IEE of Japan, pp.402, 4-252 (2002) (in Japanese)

[6] S.Imai, K.Kihara, T.Inoue, M.Inukai, H.Takani, and T.Kagami, "A Newly Developed Web-based Fault Locating Technology for Transmission Lines and Its Experience in the Field." IEEE/PES Transmission and Distribution Conference Proceedings Vol.1, October 2002, pp.136-141.

[7] H. Takani, Y. Kurosawa, S. Imai, M. Inukai, "Analysis and Evaluation of Multi-terminal Fault Location using Actual Fault Data," IEE DPSP2004 Conference Proceedings Vol.1, 2004, pp.208-211.

[8] T. Hashiguchi, M. Yoshimoto, Y. Mitani, O. Saeki, K. Tsuji, H. Ukai, M.Hojo, ”Observation of Power System Oscillation Characteristics by Using Measurement Data Obtained from Demand Side Outlets”, IEEE Bologna PowerTech Conference’03

[9] T. Shono, K. Sekiguchi, T. Tanaka, S. Katayama,” A Remote Supervisory System for A Power system Protection and Control Unit Applying Mobile Agent Technology”,IEEE/PES Transmission and Distribution Conference and Exhibition 2002 : Asia Pacific,Vol.1,OR4-7,pp.148-153,2002

BIOGRAPHIES

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