Distributed Real-time Monitoring and Controlling System Specialized Japanese Power Grid

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Abstract— According to a liberalization process of power market in Japan, significant higher congestion on Japanese power grid is expected. Furthermore, we have to cut down peak loads to reduce oil import from Middle East which is facing political instability. Thus a sophisticated IT based system which is specialized for Japanese power grid, is required. We propose KNIVES system; Keio university Network Integrated Versatile Energy saving System. KNIVES system has the functions of optimal control and flat power supply. In addition, this system allows making good scalability, reliability, and dynamic adaptability. The prototype of KNIVES system is now evaluated.

I. INTRODUCTION

Currently, cutting the peak load is critical issue for electrical power company because of the cost problem. The base price of the electric power is decided by the peak load even if the electric energy use is same amount. Flat power supply has the advantage that there is no need to construct big generating plant only for the peak load. The utility will get cheaper, because power companies allow reducing their investment in facilities.

With the process of the liberalization of power market, the number of small-scale generators will increase. It may cause congestion on the power grid, which will invoke serious power shortage or black out. And the small-scale

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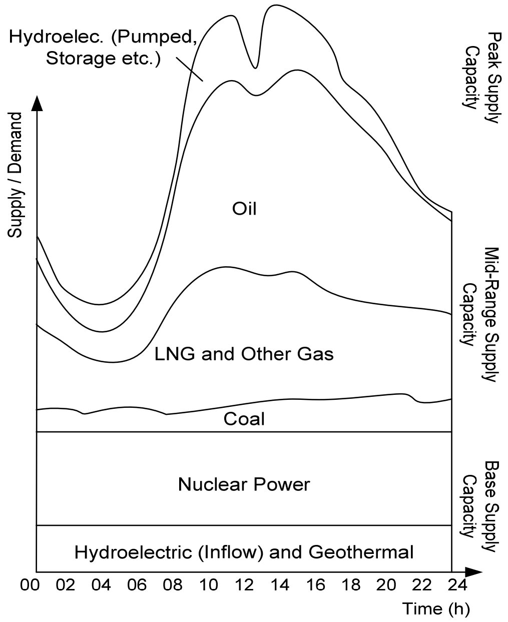

Fig. 1 daily change of the power demand

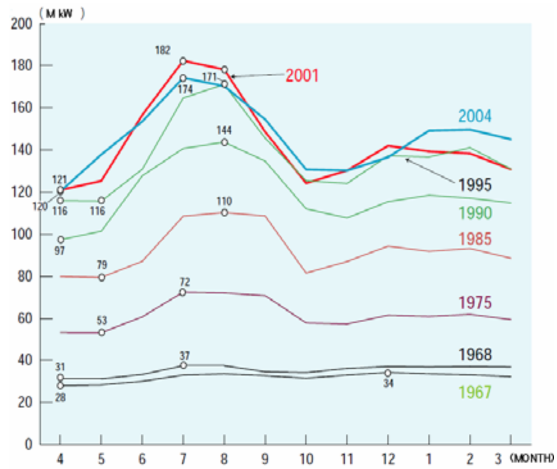

Fig. 2 yearly change of the power demand generator needs to provide proper coverage of electricity in a smaller area. In this situation, the variation in the use of electric power of a house will have a profound effect on production of electricity. The supply-demand control system is required, too.

In addition, Japan is lack of energy resources, 96% of energy resource is from foreign countries. Especially as for oil, we have to import oil from Middle East where is politically-insecure countries. In fact, oil is needed for meeting daily and yearly electrical power demand movement (エラー! 参照元が見つかりません。). The power demands increase daytime or summer and winter when we use air conditioner frequency (Fig. 2). Besides, load factor of the generation will be a serious problem, too. Load factor is the ratio between average and maximum electrical power generation. Daily and yearly change of power demands are result in highly oil use and inefficiency of power generation. Consequently, flat power supply and demand control is required in current state of affairs based in these stand points, too. These have effects on reducing emission of CO2 is important for electrical power generation. Japan adopted Kyoto protocol and needs to reduce 6% CO2 emission. In power sector, thermal power generation has a considerable impact on CO2. Therefore cut the peak load is highly desirable benefit to environmental protection as well as energy security.

II. THE ELECTRICAL POWER SYSTEM CIRCUMSTANCE IN JAPAN

Japan has a population of about 130 million, and most of people install electricity in home. Now the production of electricity grows year by year, because of advancement of information society and the penetration of air conditioner. More and more people require welfare and use of the internet.

The liberalization process of power market has started since 1995, and now, the liberalization of the electric power industry goes into those who get above 50 kW telegram, for example, large factories and department stores etc. From next year, 2007, consideration of power market liberalization will be start. High-cost structure of power generation in Japan was seen as a problem for a long time, whereas the process of liberalization was expanded in the whole world. Heretofore, there were only 10 electrical power companies in Japan. They are government-affiliated public corporation, which inaugurated in1951. And Since 1995, the liberalization of power market has started in Japan. World planetary trend toward free market of electrical power leaded Japan to admit new entry of Independent Power Producer (IPP). IPP provides electrical power to the electrical power companies.

Actually, in the U.S. and EU countries, which started liberalization earlier, have some problems now; black out and congestion on power grid, for example, the meltdown of California's electricity market and the huge Northeast blackout in August 2003. Response to that, various strategies for the congestion is developed. In the U.S., micro grid system, which operates independently parallel with the power grid, has become very popular to reduce the congestion. The U.S. consults on the high predicting performance system architecture. And EU countries develop the system, which meets the canonicalization of different range of clients, OSGi; Open Services Gateway initiatives, and DLMS; Device Language Message Specification, which is the standard system in EU countries. In DLMS system, the energy flow is managed via internet and power line. Thus, people can get stable power supply with high security and low cost. But the power grid system in Japan is different from theirs, so we cannot apply the same system to the Japanese one. New system befitted Japanese power grid is required.

III. PROPOSED SYSTEM: KNIVES

KNIVES (Keio university Network Integrated Versatile Energy saving System) is under development as a joint project among Keio University, Tokyo Gas Ltd, and Energy Management Group Inc. KNIVES system provides an automatic control concept for local supervision of end-use energy devices. This system has two control method; standalone mode, and shared mode. These enable to realize demand and supply control in local and global area.

KNIVES system also allows load optimization, demand control, and flat power supply. And this system also has performance of scalability, reliability, and dynamic adaptability. KNIVES system observes the relationship of environment and power consumption. The system makes it possible to predict optimal generation and control the user demand. It also cuts peak value and effects flat power supply. When the power demand exceeds peak value, it can shut down the devises to realize flat power supply based on the priority, which is settled by users.

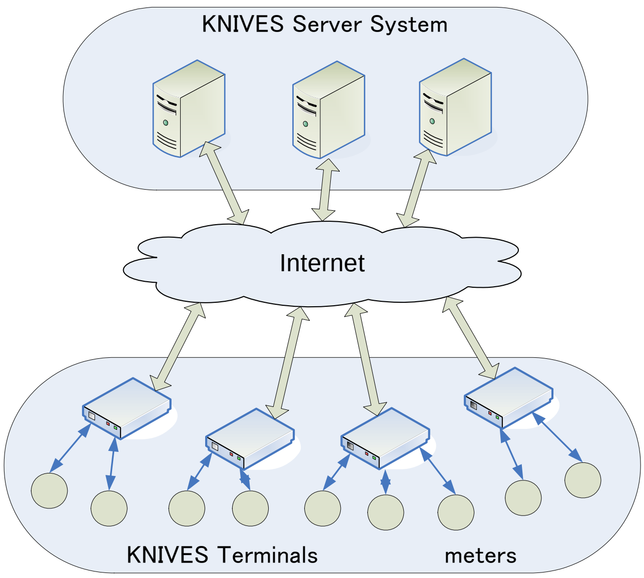

Fig. 3 outline drawing of KNIVES system

A. The Construction of KNIVES

KNIVES system consists of KNIVES server and KNIVES terminals. KNIVES server achieves a tree-based distributed and load balancing system. It achieves enhancing scalability and reducing the network congestion (Fig. 3). The servers control their child terminals and make generating schedule for optimal control. The terminal observes and control user's devices. KNIVES terminals send data to their parent server, and the servers send data to upper servers. Finally, all data is gathered to KNIVES root server, which communicates with electric power plant, through the internet. This structure meets scalability, and avoidance of network congestion. It is good for sharing data, too. This hierarchy structure is easy to reconstitute, so it can incorporate new clients. The initial server manages the allocation of the whole system and allows flexible participation and withdrawal of clients.

In this system, the servers and the terminals communicate with TCP/IP protocol to ensure security and SSL (Secure Socket Layer) connection. SSH (Secure Shell) are also applied for login service and temporally VPN (Virtual Path Network). In particular, KNIVES server leverage a general UNIX TCP/IP based application programmed C language and thread library. Each server and terminal has TCP socket interface and it is responsible for internet security.

In addition, this hierarchy structure can reduce communication load of the servers so that it can avoid the congestion in the network. And also, this system is good for barraging and sharing the data, too. (上に同じような記載があるのでカット？)

In next section, the detail of each server and terminal are described.

B. KNIVES Server

In KNVES system, there are 4 types of servers: initial server, root server, branch servers, and leaf server (エラー! 参照元が見つかりません。). The initial server assumes the role of maintaining the tree structure and reconfiguration of the servers and terminals after reboot of a server or terminal. It provides the necessary

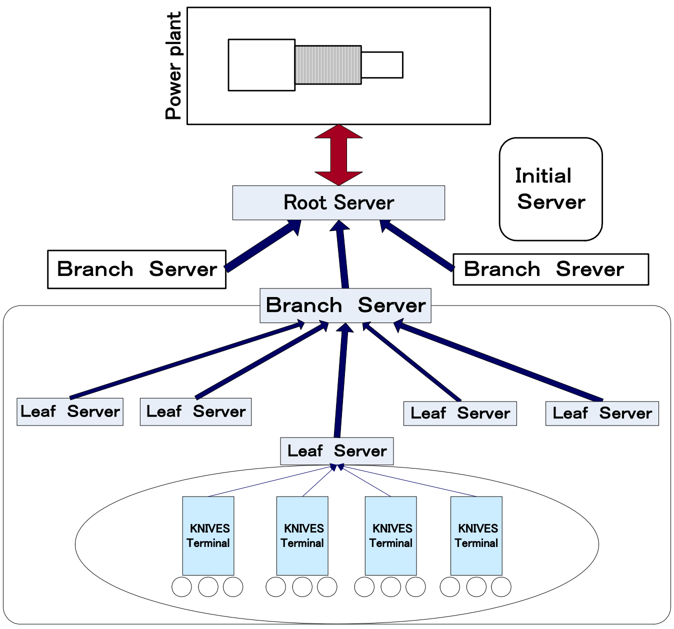

Fig. 4 KNIVES server structure

information for integrating server and terminals into the KNIVES architecture. This initial server suggests a new server where it should connect. Initial server manages the location and system load. This server also contributes to the load balancing of KNIVES system. It can suggest the location to be connected according to the load of servers. When a large black out is happen, traffic congestion will be occurred because all server accesses the Initial server first. In order to prevent this congestion, CSMA/CA based congestion control. If the Initial server is busy, the retry of the connection will be made after randomized time.

The root server is the top of the tree structure, and it gathers up the data from the leaf server and communicates with an electric power plant. This root server does not manage all individual data of terminals and other servers. It only manages the sum-upped data.

The branch and leaf servers make a tree structure (Fig. 4). This structure allows the reduction of communication load per sever and supports flexible expansion. The leaf servers gather up the environmental data from their child terminals and send the data to their parent branch servers. The environmental data is temperature, humidity, and luminosity. The branch servers share the data and analyze the relation between environmental data and consumption of electrical power. And they make schedule table to forecast the power demands. The table is dynamically reconfigured for optimal control. The prediction of power demand will support optimal generation and the terminals control the power usage of their child device with the schedule table.

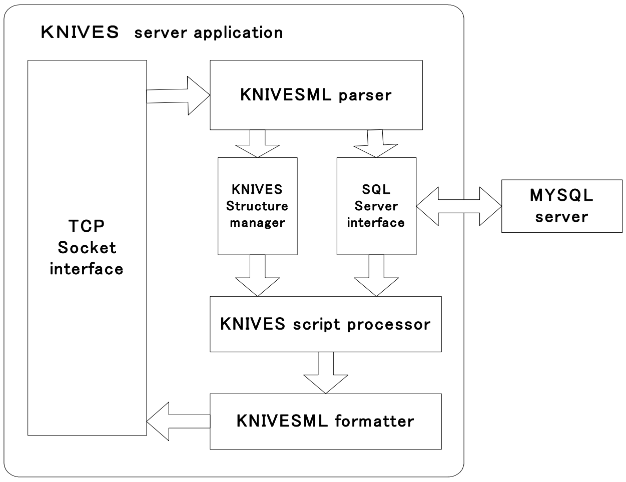

Fig. 5 structure of server application

The server program consist of the following functional blocks: TCP socket interface, KNIVESML parser, KNIVES structure manager, SQL server interface, KNIVESML formatter, and a KNIVES script processor (Fig. 5).

TCP socket interface is responsible for Internet communication. In order to improve security, SSL (Secure Socket Layer) connection and SSH (Secure Shell) port forwarding and shell service are also supported. All transactions are described in

KNIVESML; the enhanced mark-up language, which based on XML. KNIVESML contains sensor data, control commands, and location of terminal, etc. KNIVESML parser parses the input contents of input TCP connection and it makes commands to KNIVES structure manager or SQL server interface. Each KNIVES terminal and server own a separate account using a private key.

KNIVES structure manager consist of a simple data base to manage hierarchy storing the network address and configuration data of its parent and child server. KNIVES script processor executes scripts defined by user or system administrators as an external process. It sets up the curtailment of the total power consumption of all child servers connected to this server and contains all necessary information derived from the MYSQL query of a server containing location, environmental data, power consumption, which has been defined or collected from sensors and meters. In case a parent server issues commands for load reduction, e.g. to limit the consumption up to 1MW/h, the script will dispatch the individual reduction to each child server by using operation schedules and controlling algorithms. Moreover, the script can be utilized to regulate the tree structure by means of determined policy of maximum hierarchy. KNIVESML formatter assembles necessary information in KNIVESML for transfer to parent or child servers. If the transferred script contains errors, the current control will break off, but frequent updates of script allows continuing control within seconds. The SQL server interface handles communication with the local MYSQL database, which keeping essential system data, such as script language, history of summarized sensor data of all children and necessary parameters for maintaining the server operation.

C. *KNIVES Terminal*

The terminals are connected to leaf servers on the lowest hierarchy level. The terminals are local control structure; they observe and control users dynamically. They monitor the energy consumption and environment data, and send the data to their parent servers.

Each terminal has 6 sensors and 15 channels to observe environmental data and to control devices. The sensors are two light sensors, humidity sensors, and thermo sensors. The thermo sensor is DS18B20 (DALLAS SEMICONDUCTOR) and consists of two-coins-sized small Linux platform, PIC controller, photo MOS switches, sensors, and a sense amplifier. It can measure from - 10 to + 85 at -/+ 0.5 degree centigrade error. The digital interface named 1-Wire uses one signal line for communication. Brightness sensor is a cadmium cell sensor and the resolution it contains about -/+ 10% error.

15 channels are connected to every device. Each channel has the priority and the terminal can shut down the device on its priority, in the case of electric power shortage. The priority of these electric devices will be defined dynamically by a priority list calculated based on environmental data collected by the local sensor networks. E.g. in case of a hot sunny day the shut down of additional lights is preferable, whereas at night-time, air-conditions can be interrupted more easily without facing any loss of quality of service.

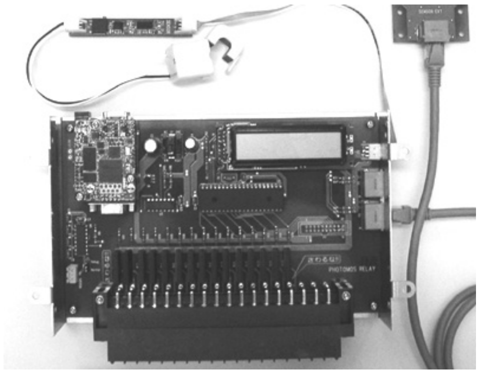

Fig. 7 prototype of KNIVES terminal

Electrical power consumption is measured by counting pulses generated from electric meter of TEPCO (Tokyo Electric Power Company). A simple sensor is used, which consists of a current transformer, comparator and pulse hold circuit. The level of sampled signal is very low and this sampler has to be fixed within one-meter wire. The length between this sampler and the main body of KNIVES terminal can be extended over 500m.

Sensors and I/O controller are implemented on the PIC16F877 (PIC) microprocessor by means of software programmed in assembler language. The controller operates based on event driven interruption. When an interruption occurs, PIC prohibits further (multiple) interruptions and processes further operation depending on the device, which caused the interrupt:

- *Power pulse sensor*: The power counter will be incremented.

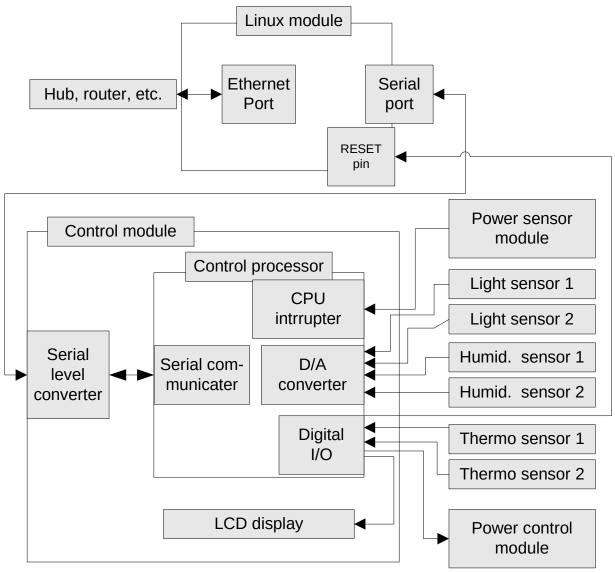

Fig. 6 Hardware structure of controller

- *Serial module*: PIC checks received commands of Ethernet Terminal, responding the requested value, such as temperature, humidity etc. or relay port settings.
- *Timer module*: PIC checks 1 s before previous interruption. Then PIC updates values of temperature, humidity, and brightness sensors. In case the data displayed on LCD has been changed, LCD will be refreshed.

Ethernet terminal program derives the communication to KNIVES servers. The operating system is based on Linux using a C program. During booting of a KNIVES terminal the program reads the configuration file of the costumer containing ID number and address of KNIVES initial server. According to the information the KNIVES terminal connects automatically to the initialization server to receive the initialization information containing data server address for future control.

In fact, KNIVES system has two control algorisms: standalone mode and shared mode, which are referred follows. Each terminal has a schedule table which is from its parent server. They calculate the rest of usable amount of electric power per every 5 second to control the device with the schedule table and the power consumption. With the schedule table, KNIVES system can totally manage power generation and can realize effective demand control.

IV. THE FUNCTION OF KNIVES

KNIVES system is a Demand Response System (DRS), which allows energy management by means of curtailing loads and realizes flat power supply and optimal control. As above, KNIVES system provides high reliability, and scalability, too.

KNIVES system also brings in new control method, hybrid demand control. Hybrid demand control consists of standalone mode and shared mode. With the use of this method, KNIVES system enables local and global demand control.

A. Optimal control and flat power supply

It is impossible to impound electricity power, so generating optimal amount of electricity is very important. KNIVES system employs optimal generating control. In particular, terminal gathers environmental data and power consumption dynamically. Terminals send data to their parent server. Each server shares the data and makes a database with stored historical data. And the servers use it to analyze the relation with environmental data and power consumption for each season. They predict the accurate electricity consumption seasonally and area by area. They make timetable for each terminal and generate schedule for the generator. The timetable is sectionalized by season, week, and hour of a day. According to the time table, terminals control their devices not to exceed the thresholds. Terminal allows shutting down its devices when the total power usage surpasses the usable amount based on the priority. The priority is settled on each channel. In addition, the root server communicates with electrical generator and passes on the optimal amount to the generator.

The main theme of this investigation is cutting down the peak load and actualizing flat power supply to curtail oil consumption. The KNIVES system allows cutting the peak load like a knife. In particular, the terminal observes and controls the client's devices with 15 channels in real time. Each channel is connected to a device and has own threshold. The terminal can shut the device down when the peak load surpasses the threshold.

Flat power supply and optimal control have effect to reducing CO_2. High ratio of load factor leads to inefficient use of generation system and produce excessive CO_2.

B. Hybrid demand control

KNIVES system adapts hybrid demand control mechanism, which provides two types of control: standalone mode and shared mode. The standalone mode is used in offline, and each terminal controls the clients individually. The shared mode is used in on-line, and terminals communicate with server to cooperate with whole KNIVES system.

In the standalone mode, each terminal works alone and keeps the power consumption assigned. Terminals control their child devices by the limit of the value. This standalone mode is workable when network is not installed or the internet is down. In case the predicted power consumption PP_i of consumer i might exceed the pre-defined limit value of consumption DM_i, KNIVES terminal has to shut down electric equipment in order to remain bellow the DM_i. The calculation for prediction is derived every 5 seconds. If the predicted consumption PP_i does not exceed DM_i, KNIVES terminal will execute no operation.

In shared mode, terminals share the margin of demand and controlling command. KNIVES system observes the predicted demand of devices (1-i) not to exceed the predefined shared limit value DM of the group in real time. DM is the sum of individually defined KNIVES system observes the shared limit value of the demand in real time. And KNIVES server recognizes where and when the consumption is exceeded. Thus, they can totally effectuate the optimal control with whole system. If the shortage of power supply is detected, KNIVES system announces the shutdown to the devices which have lower priority to prevent a blackout.

$$\Sigma DM_i > DM \quad \text{[W]} \qquad (1)$$

(i) $\Sigma PP_i \geqq DM$ and $PP_i \geqq DM_i$
KNIVES terminal shut down gradually electric equipment in order to fall bellow the individually given consumption limits DM_i. This process is done identically as in case (i) of standalone mode.

(ii) $\Sigma PP_i \geqq DM$ and $PP_i < DM_i$
The temporary reduction of DM because of shortage in supply can entail that the predicted overall power

consumption ΣPPi exceeds DM, although the limit value of individual consumption does not exceed ($PPi < DMi$). In this case equation (2) will be used for control:

$$DMi(temp.) = DM - \delta \quad (2)$$

The given limit DM*i* will be reduced temporarily at a calculated level, in order to reduce overall consumption although each consumer does not exceed its own pre-defined consumption limit.

New time dependent tariff models taking hybrid demand control into account provide remuneration for load scheduling to reduce temporarily the congestion of the power grid. These and other auxiliary services can be provided by means of using the extended scripts of KNIVES infrastructure. All scripts can make use of the collected system data, namely values of consumption rate, date, time, brightness, temperature, but also business data such as maximum cost, emission of CO_2, wholesale prices, business type, etc. This script presents the core of active control to achieve system objectives of energy saving, sustainability and reliability. The script has to be configured to the individual needs of each customer to guarantee optimal operation. Due to requirements in dynamic adaptability and minimization of manual reconfiguration pre-defined default schemas can be used. Furthermore system can detect the errors by checking the discrepancy between temperature and amount of power demand. Further error detection, e.g. using a pressure sensor of compressor is also available by means of unused D/A channels.

V. EVALUATION

KNIVES system allows deriving automatic curtailing and rescheduling of loads based on dynamically generated hierarchy updated environmental data. KNIVES can provide a high scalability and dynamic adaptability by means of automatic configuration processes. The prototype of KNIVES which contain local control hardware, local sensor and server system and control software has been built. Evaluation test showed that the prototype is capable to control up to 1,000 end users with one KNIVES server. Now operation evaluation is started and environmental durability, heating and cooling systems, is also tested in cooperation with Tokyo Gas Ltd.

The evaluation system uses real KNIVES root server and virtual KNIVES terminals. The virtual terminal is implemented as a process, which emulates all actions of real KNIVES terminal and it can execute the controlling script and also exchange KNIVESML. Two workstations are installed via 1-Gbps Ether network with one router. The workstation has two XEON processors and 2-Gbytes memory. One workstation is used for KNIVES server. Beside the KNIVES server the performance monitor of KNIVES server or the evaluation runs on this machine. This performance monitor is used exclusively for evaluation, and it is needless in normal operation. In evaluation which is described below, the load of this performance monitor is included, but this load is comparatively small and can be ignored. The other workstation represents the virtual KNIVES terminals and its initiator. A KNIVES server has designed to support up to 1,000 end-users (terminals). The evaluation is done with up to 1,500 simulated terminals. Connection between server and client terminal is reestablished in every connection, i.e. every 5 seconds. In server software, every connection makes MYSQL query to the KNIVES database and this query contains the amount of power consumption in all other clients.

Fig. 8 shows the network traffic of KNIVES server as

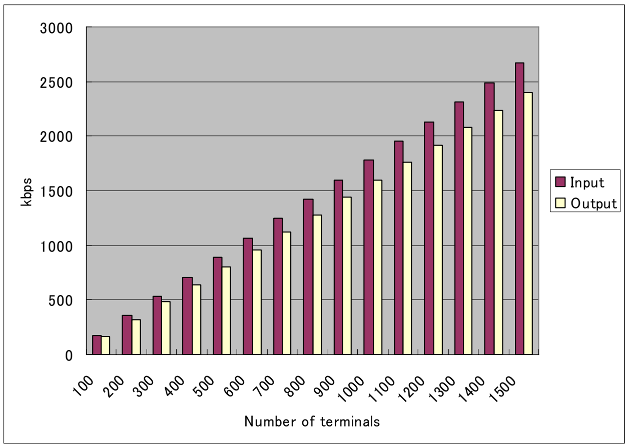

Fig. 8 Network traffic of KNIVES server

a result of the evaluation. According to the evaluation, one KNIVES terminal produces about 1.5kbps traffic. The traffic load rises linearly, which means that, in case of 1000 clients, KINVES sever has to cope with processing 1500kbps. To run scripts every 5 seconds mean that there has to be about more than 7,500 kbit have to be processed on KNIVES server to refresh the current operation state of the microgrid.

Fig. 9 shows the percentage of average CPU load. The load average was increased according to the number of terminal. As a result, this KNIVES server and MYSQL server has enough performance to manage about 1,000 clients.

The performance monitor also monitors the processing

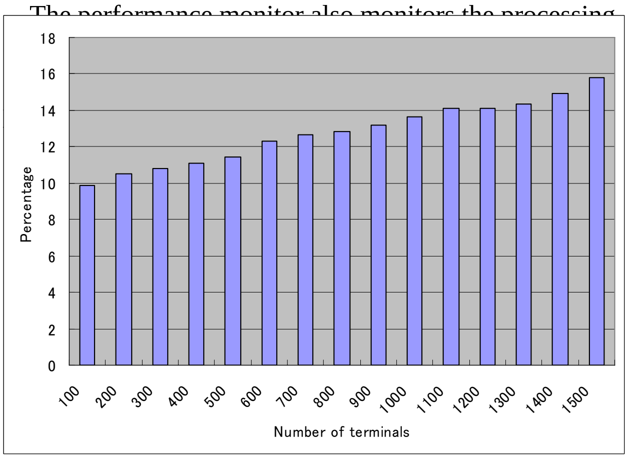

Fig. 9 Average CPU load of KNIVES server

of KNIVES. In this case, total processing delay can be suppressed up to five seconds with a time to spare, which is the data acquisition interval of KNIVES. This application enables to control the power plant and keep balance between total amount of power consumption in demand area and that in supply area. This balancing control can also contribute to the suppression of energy exhaust and the emission of CO2.

Fig. 10 shows the summarized memory size of KNIVES server and MYSQL server. The memory usage remains almost constant on 175Mbytes. KNIVES system also has memory scalability.

A real KNIVES system, which consists of one KNIVES server and three KNIVES terminals were developed and demonstrated in an exhibition of Keio University. In this demonstration system, the effectiveness of shared control was proved. However, the quantitative assessments have to be made by a future real field experiment. In this demonstration, shutdown and reboot process of KNIVES terminal are also confirmed.

VI. CONCLUSION

KNIVES system is the high sophisticated IT based system for Japanese power grid. The system provides optimal demand and supply control for cost optimization, environmental problem, and reduction of the congestion on power grid.

The hierarchy and real-time processing makes it easy to gather large amount of user information and predict the power demand dynamically. The volume of information and dynamic adaptability provides correct prediction of the user demand.

In the future, the liberalization of power market will increase the number of small generator. It will cause the significant congestion on the power grid and the shortage of power demands because of inability of optimal generation. Optimal control is requisite for covering the small area by a small size generator.

KNIVES system is need for the future Japanese power market which advanced in the liberalization of power market.

VII. ACKNOWLEDGEMENT

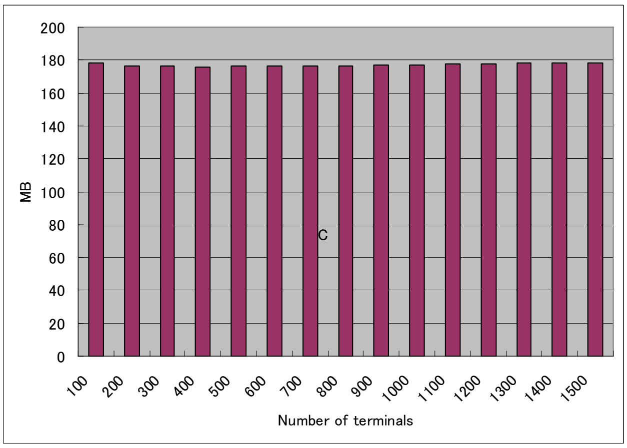

Fig. 10 emory sizze of KNIVES server

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