Development of Electronic Power Monitoring System
전력 모니터링 시스템의 개발

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Key Words : Electronic Power(전력), Monitoring(감시), Microprocessor(마이크로프로세서), Power Shedding(배전)

요약 : 최근의 배전반 설비의 고성능, 안정성, 신뢰성은 전기에너지의 사회적 욕구로 요구되고 있다. 본 논문에서는 전력품질에 관한 정보를 수집하고 통합 모니터링과 설비의 보호, 그리고 다양한 장치들을 제어할 수 있는 전력 모니터링 시스템의 개발에 대하여 고려하고자 한다. 전력품질 모니터링을 통하여 수집된 정보는 시스템의 효과적인 운용과 사용상의 신뢰성을 개선시킨다. 본 시스템은 크게 하드웨어부와 소프트웨어부로 구성된다. 하드웨어부는 원칩 마이크로 프로세서(Intel 80C196KC)를 사용한 측정과 제어, 통신 그리고 입/출력을 담당하는 다기능 인디케이터와 컨트롤러로 구성된다. 다양한 기능의 모니터링, 데이터베이스와 제어를 PC상에서 구현하기 위한 소프트웨어부는 사용자 그래픽 인터페이스(GUI) 기반의 비주얼 프로그래밍을 사용하여 개발되었다.

1. Introduction

The basic concepts of integrated monitoring, protection, and control systems are described along with the various functions that can be provided in integrated systems. It is shown that the integrated systems are very flexible and can be expanded easily.

The electric power system environment is in a state of constant flux. Customer loads have evolved from simple linear devices, such as motors and incandescent lighting to more sophisticated power electronics based on loads such as computers, compact fluorescent lighting etc. The nature of these new loads has created the needs to close examine the existing electrical infrastructure. In addition to this new state, traditional facilities are managing business and manufacturing operations through sophisticated power electronics based on device for continuous performance[1).

Besides the load change, the types of customer facilities have also been changed. The emergence of 24 hours per day, 7 days per week operations are commonplace and required to meet a new competitive marketplace. Today, a clear example of this technological growth is the global emergence of Internet data centers. The level of reliability demanded / needed / required is now changing with the type of facility and its needs. To ensure continual productivity and growth, the electrical environment needs to be pure and clean. Power quality can now be used as a metric for solving the reliability concerns associated with the sensitive nature of a customer facility.

The philosophy of power quality monitoring has evolved from the strict troubleshooting objective to multitude of purposes. These purposes include: assuring compliance to a contractual or legal standard; determining preventive practices; and establishing a predictive baseline. In conjunction with the shifts in objective, monitoring equipment has incorporated numerous technological advancements in the areas of communication, data capture, physical size and cost. As data is being made available quicker, the desire to use that information to meet defined objectives is only natural. With the

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increased emphasis on reliability, the needs for ensuring both the accuracy and the depth of measurements have become paramount[2].

In this paper, integrated monitoring system is designed with microprocessor, 80C196KC and visual programing for electronic power monitoring, protection and control. Integrated monitoring system can improve the efficiency of operating the power shedding system and the reliability of customer operation.

2. Electronic Power Monitoring System

The architecture of integrated systems makes it possible to configure the system for one or more purposes. The architecture makes it possible to be easy to expand the system after it has been installed to add more of the same functions or to add additional functions. For example, it may be desirable to do monitoring at first and then add control later[4].

The basic purpose of the integrated system is to provide more comprehensive monitoring, improve protection, and reduce cost. It also provides for centralized monitoring and control. Integrated system consists of a number of devices connected to a computer through a local area network (LAN). The computer periodically sends digital messages, requested information from the devices connect to the network. The computer also sends commands to operate switches or change set points on automatic controls. Each device has an address, so the computer may talk to one device at a time. The devices connected to the network perform one or more of the following functions:

Provide circuit protection;
Supply metering data of V, I, watts, vars;
Supply status readings for various on off devices;
Respond to commands to activate output contacts.

Fig. 1 shows integrated system to be developed. The functions may be combined in multifunction devices to reduce panel space and cost, but that may involve some performance compromises. For example, meters generally measure harmonics while protective relays may not. The devices are normally placed close to the input/output sources to minimize wiring which reduces the installation cost. Also, the computer human machine interface may be used for control in lieu of manual control switches to provide further savings in space and cost.

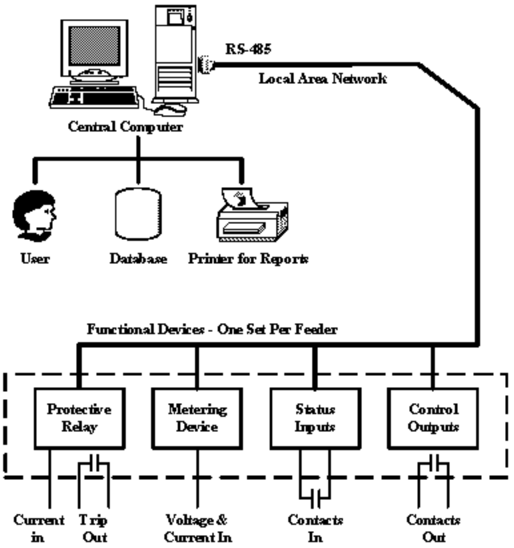

Fig. 1 The function diagram of the developed integrated system

These capabilities, integrated into a system, provide the means to report problems and control the power system more efficiently. The actual means of report and control are achieved through the central computer software.

3. Development of Electronics Power Monitoring System

Power quality instrumentation has made incredible advances over times. Advanced power quality monitors are designed to accept voltage and current quantities. Typical instrument input limits are around 600V RMS for voltage and 5 A RMS for current. To obtain usable voltage and current signal levels, voltage transducers (PTs) and current transformers (CTs) are used. Digital monitoring instruments also utilizes A/D converters for convert the analogue signals from the signal conditioning circuits into numeric values to process in the instrument. To get the good resolution the A/D converter should have a high order of bits, somewhere between 16 and 20. After the signals have been digitized, the processor operates on the fundamental measurements of time, voltage and current to derive many power quality parameters.

The following drawings, Fig. 2 and Fig. 3 are the basic concept diagram of power monitoring system in switchboard facility.

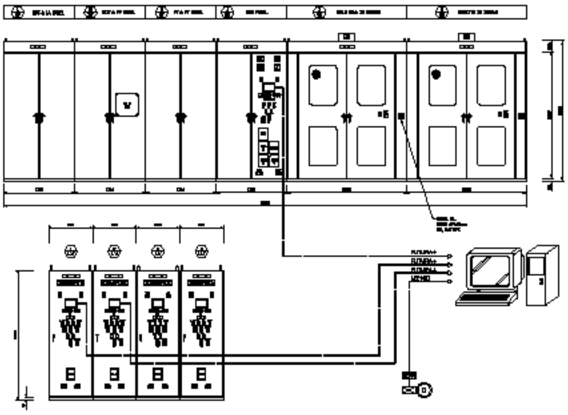

Fig. 2 Basic concept diagram of power monitoring system in switchboard facility

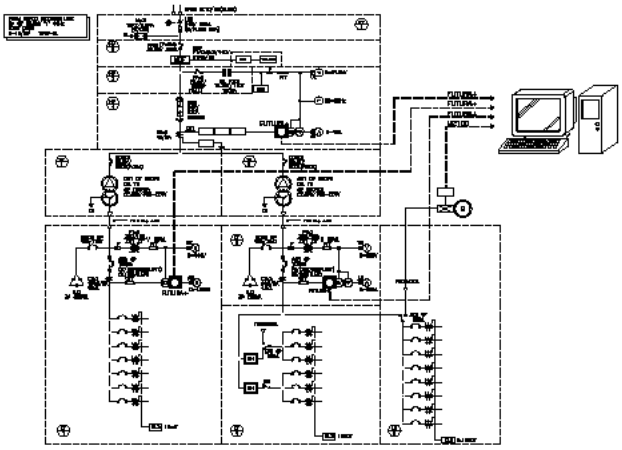

Fig. 3 One line diagram of power monitoring system

For users, the most important item to consider is not running out of memory while monitoring but capturing the power quality event. A common method for triggering RMS variations is to set manual thresholds. Typical settings are +10% of nominal voltage.

An alternative method is to provide full disclosure monitoring with adaptive thresholds. If the RMS value changes by more than 2% of the RMS value of the previous cycle, the wave shape change is triggered and stored. Each of the RMS cycle values is stored and when the wave shape stabilizes for two cycles, the end of the event is designated. A maximum number of 128 individual wave shape cycles can be stored and displayed. If RMS has not been stabilized after two seconds, the wave shape information is discarded and then the RMS values are used to display the event. RMS events are also graded by calculating the product of the square of the RMS deviation and the duration. The periods during which the RMS values value to a new value defined as transition.

This system consists of hardware and software part mostly. The hardware part is composed of measurement part, communication part, controller, and display part, which manage measurement, communication, control and input / output device using one chip microprocessor (Intel80C196KC). Multifunction indicator and / or controller execute these functions.

The software has various monitoring, database, and control in PC using visual programming by graphic user interface (GUI).

3.1 Hardware

Some of the issues to consider when looking at power quality hardware are:

Backup of data: collected even when the power fails;

Enclosure: depends on portable or permanent application;

Sampling rate: is it fast enough for RMS, transients, energy and harmonics measurements?

Ease of use, set up and programming;

Processing power: how much data is reduced by instrument?

Communications: current state of the art uses Ethernet, TCP/IP.

Many communication devices are already developed. These devices also have multifunction and high performance. For example, it is available to control baud rate of input and output transmission, to treat various protocols and multidrop data, and to function as ethernet gateway and concentrator.

3.1.1 Measurement part

We measure the data of electric power. The economics of electric power distribution networking dictate several configurations of AC power transmission. The number of phases and voltage levels characterize these configurations.

A single phase system is a basic two wire system used in low power distribution applications, such as residential communities or offices. Typically, the voltage is 120V AC. For higher power requirements, such as small commercial facilities, the typical power configuration is two lines of 120V AC opposite in phase. This system produces 120 volts from line to neutral for lighting and small appliance use. The line to line voltage is 240V AC, used for higher loads such as water heaters, electric dryers, ranges and machinery.

The power(W) in a single phase system is:

$$W = E \cdot I \cdot \cos\theta$$

E electric potential, I current and $\cos\theta$ phase difference between the electric potential and the current.

Power in a 120/240V AC system is:

$$W = (E_{Line1} \cdot I_{Line1} \cdot \cos\theta) + (E_{Line2} \cdot I_{Line2} \cdot \cos\theta)$$

Phase difference between the potential and the current are resulted from a non resistive load, either reactive or capacitive.

Reactive power (VAR): The additional power consumed that dose not produce any work but must be delivered to the load; $VAR = E \cdot I \cdot \sin\theta$. This is a measure of the inefficiency of the electrical system.

Apparent power (VA): The total power delivered to the load, and the vector sum of real power and reactive power.

Power factor (PF): The ratio between real power and apparent power:

$$PF = \frac{W}{VA} = \frac{W}{\sqrt{W^2 + VAR^2}}$$

Ideal power distribution should have a PF of 1. This condition can be met only if no reactive power loads exist. In real life applications, many loads are inductive loads. Often, corrective capacitors are installed to correct poor power factor.

A three phase system delivers higher levels of power for industrial and commercial applications; the three phases correspond to tree potential line. A 120°phase shift exists between the three potential lines. A typical configuration has either a delta connection or a wye connection. In a three phase system, the voltage levels between the phases and the neutral are uniform and defined by:

$$E_{an} = E_{bn} = E_{cn} = \frac{E_{ab}}{\sqrt{3}} = \frac{E_{bc}}{\sqrt{3}} = \frac{E_{ac}}{\sqrt{3}}$$

Voltages between the phases could vary according to loading factors and quality of distribution transformers. The three phase system is governed by Blondels Theorem. Blondels theorem sates that in a power distribution network which has N conductors, the number of measurement elements required to determine power is N 1. A typical configuration of poly phase system has either a delta connection or a wye connection.

And we require the measurement of consumption, demands and poor power factors.

Power consumption:

$$WH = W \times T$$

W instantaneous power, T time in hours.

The total electric energy usage over times period is the consumption of WH. Typically, the unit in which power consumption is specified is the kilowatt hour(KWH): one thousand watts consumed over one hour. Utilities use the WH equation to determine the overall consumption in a billing period.

Demand: Average energy consumed over a specified time interval is determined by the utility, typically 15 or 30 minutes. The utility measures the maximum demand over a billing period. This measurement exhibits from average consumption causing the utility to provide generating capacity to satisfy a high maximum consumption demand. The highest average demand is retained in the metering system until the demand level is reset.

Poor power factor: Results in reactive power consumption. Transferring reactive power over a monitoring reactive power consumption and penalize the user for poor power factor.

Ideal power distribution has sinusoidal waveforms on voltages and currents. In real life applications, where inverters, computers, and motor controls are used, and distorted waveforms are generated. These distortions consists of harmonics of the fundamental frequency.

Sinusoidal: $A \cdot \sin(\omega \cdot t)$

Distorted waveform:

$$A \cdot \sin(\omega \cdot t) + A_1 \cdot \sin(\omega_1 \cdot t) + A_2 \cdot \sin(\omega_2 \cdot t) + \cdots$$

Total harmonic distortion (THD):

$$\%\text{ of THD} = \frac{\text{RMS of total harmonic distortion signal}}{\text{RMS of the fundamental signal}} \times 100$$

Harmonic distortion: A destructive force in power distribution systems. It creates the safety problems, shortens the life span of distribution transformers, and interferes with the operation of electronic devices. A recent device monitors the harmonic distortion to the 31st harmonic. The capturing distorted waveform is also possible.

3.1.2 Communication part

The device of communication part is the interface converter. Generally it converts signal of RS 232 or RS 422/485. It is the needs of compact size, lightweight, multi protocol support, and various communication mode support.

RS 232 communication is used for linking a single instrument with a computer or device such as RTU or PLC. The link is capable for a distance up 100 ft (about 30 m). A standard 9 pin female serial port allows direct connection to a computer with a 9 pin cable.

RS 422/485 parallels multiple instruments are on the same link like RS 232. Its operation capability is up to 4000 ft (about 1220 m). When using only 2 wires, the link can include up to 15 instruments. When using 4 wires, the link can include up to 31 instruments. Each instrument has a unique address up to four digits length. It allows for the user to communicate with up to 10,000 instruments. Available standard baud rate are 1200, 2400, 4800, 9600, 19200 and 38400 bps. To select the proper baud rate, apply the following rules:

The top port should always be operated at 9600 baud max;

Maximum baud rate is 38400 for the main port;

For a smaller number of instruments over a long distance, use a lower baud rate;

Optimal recommended baud rate is 1200 baud if noisy conditions exist.

Fig. 4 shows the developed RS 232 to RS 422/485, RS 422/485 to RS 232 converter. This converter is able to support various communication modes, for instance, full duplex, single half duplex (Fig. 5), twin half duplex, and repeater mode.

3.1.3 Controller

80C196KC is able to control each input/output ports with five 8 bit I/O ports and 8 or 10 bit A/D converter. Main board of controller using 80C196KC has two output ports, three input ports and one A/D port. Input ports are used to receive the signal of each node, that is ACB, VCB, and relay etc. Where as output ports are used to send the signal of switch on/off and other device control. A/D port is used to transduce the signal of devices condition to the signal of data for monitoring or measurement.

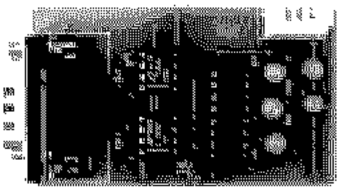

Fig. 4 RS 232 to 422/485 converter

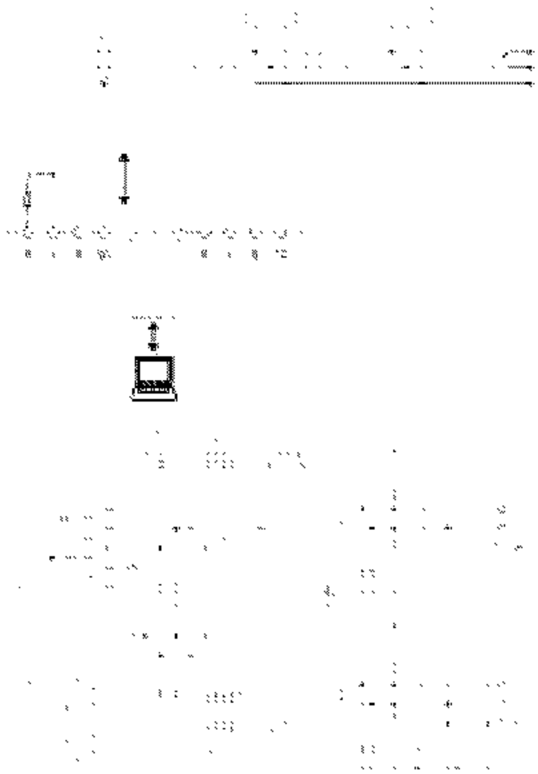

Fig. 5 Example of 232/485 single half duplex

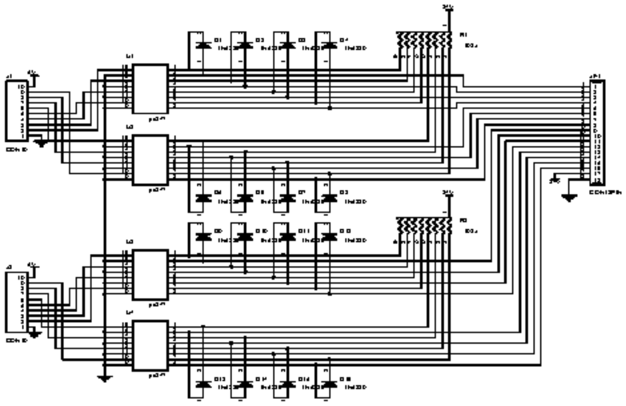

Fig. 6 Gate circuit of input

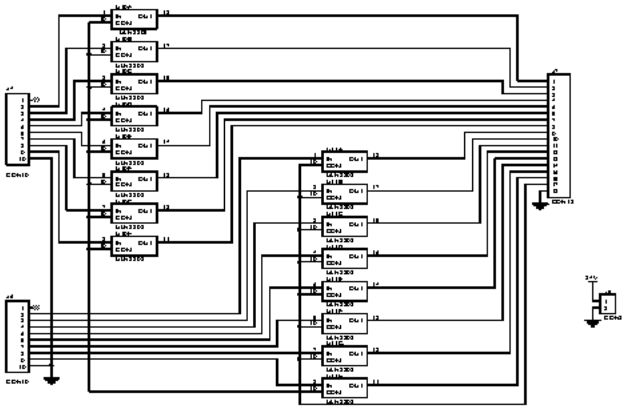

Fig. 7 Gate circuit of output

And Gate circuit is added on board because signal level of I/O port is TTL. Fig. 6 and 7 show the designed gate circuit. Controllers firmware is programmed by assembly language and A96 compiler.

Fig. 8 shows 80C196KC board in switchboard for controller and relay board for node.

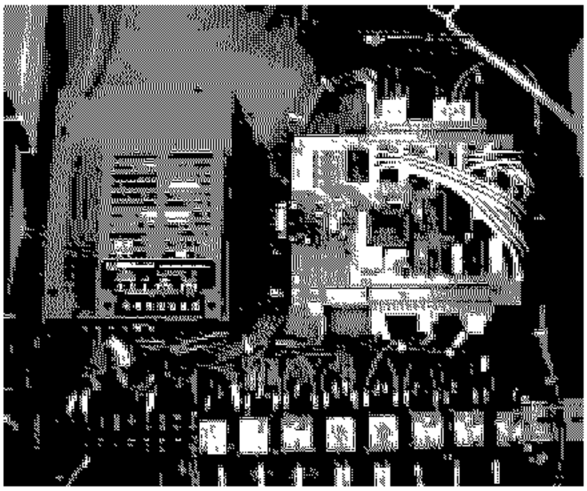

Fig. 8 80C196KC board in switchboard

3.1.4 Display part

The display part consists of LCD, VFD, or 7 segment LED etc and monitors various useful values, kilowatt, kilowatt demand, kilowatt hour readings, reactive power and so on. Displayer is the unique part that is visual in front panel of switchboard or instrumentation device. So it is the needs of smart design and good looking for users convenience. And it must be the needs of representation for various values. Fig. 9 is the digital LCD panel of analog type displayed for user.

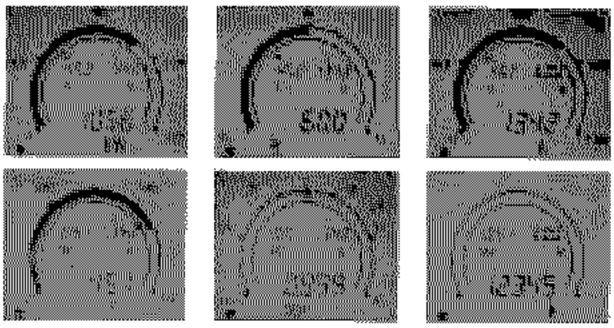

Fig. 9 Digital LCD panel of analog type displaying for user

3.2 Software

The evolution of the computer industry has enabled sophisticated tools to emerge that facilitate the data collection and analysis the process. Advanced monitoring software tools require the following capabilities:

An open database architecture (ODBC);

Automation of data collection and report / alarm generation;

Text and graphic export into other application (i.e. Microsoft Excel and Word);

Report writer capability.

One of the most important of the above item is to use an ODBC compliant software tool. Depending on the power quality monitoring objective, different instruments may be used for differing monitoring situations. As a result, having the capability to extract information from different databases for comparison into another non proprietary database structure is essential for correlation purposes.

With the available advanced tools, continuous monitoring is possible. This data is needed to determine how and where events were caused, leading to the understandings of how they may be avoided in the future, and how the effects may be mitigated. Other benefits of continuous monitoring are:

Harmonics must be monitored on a continuous basis to ensure that, over times, the incremental addition of loads does not cause excessive heating that can lead to the premature failure of transformers, conductors and circuit breakers;

Continuous tracking of power consumption and RMS quantities provide useful data for planning future plant expansion and for ensuring that existing and future utility feeder and substation capacities are adequate. It is also useful for planning the addition of new discrete loads or new back up power systems. The data is also useful in determining whether an adequate level of investment in the infrastructure is being made and if the money is being spent in the most appropriate areas;

Archiving power survey reports containing all detailed aspects of power in a database provides the ability to compare the existing conditions with the historical conditions and to predict when a failure will occur. This concept is called as predictive maintenance. Advanced warning of a deteriorating power situation provides the ability to correct the situation before disaster strikes. The mission of critical operations, data canters and financially vulnerable applications, prevention is to yield enormous economic benefits by ensuring continuous system reliability and full availability. Predictive techniques provide the information required to achieve 100% up time;

Key personal can be alerted immediately when a power problem is detected by issuing alarms or by sending messages to pagers or PC screens. Immediate notification allows the action to be taken to isolate a problem and prevent a domino effect that would jeopardize the entire facility;

Sophisticated software tools also allow the useful comparisons of various parameters. Software tools are available for data analysis after monitoring and then it provide the capability to overlay different quantities on top of each other for the correlation of parameters with known events.

The advanced technology has enabled to the significant improvements in the collection and sharing of data across all media; the latest being the Internet. The possibilities in the new medium are extraordinary. Mission critical facilities are now able to deliver the information to concerned individuals by simply sending a web address via e mail, pager or fax. This link allows for investigator to determine immediately and remotely the information required to apply predictive, preventive and maintenance measures.

Fig. 10～16 show monitoring program. Various screens can be used to monitor and analysis data of devices condition and measuring value. Fig. 10 is a main screen in monitoring program. The monitoring system classifies as main and subsystems. Fig. 11 is a screen of annunciator that helps to move quickly other subsystem for needs. Fig. 12 is a screen of switchboard condition, which is similar to real facility so that it provides users benefit. Fig. 13 is a screen of system one line diagram that helps to understand system conceptually. Fig. 14 and 15 describe data analysis and demand control of electronic power. And Fig 16 shows the report from monitoring data including database for printing or management. The monitoring system carries out functions like following screens. As windows program support multitasking each screens, it may always be activated by user commands.

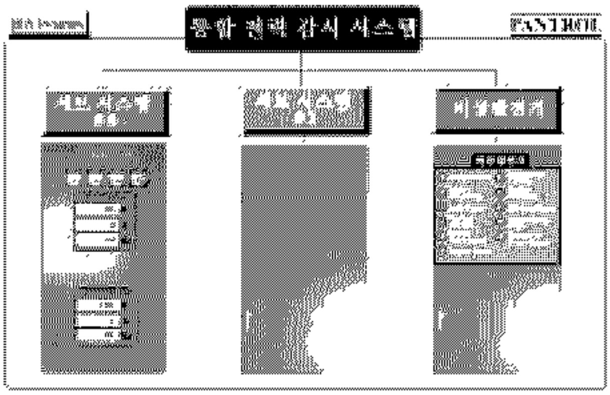

Fig. 10 Main screen of electronic power monitoring program

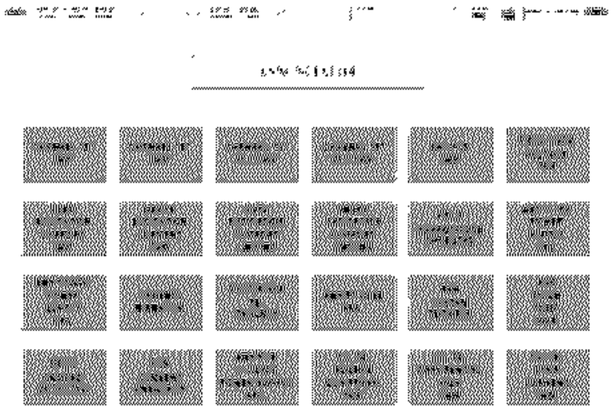

Fig. 11 Annunciator screen

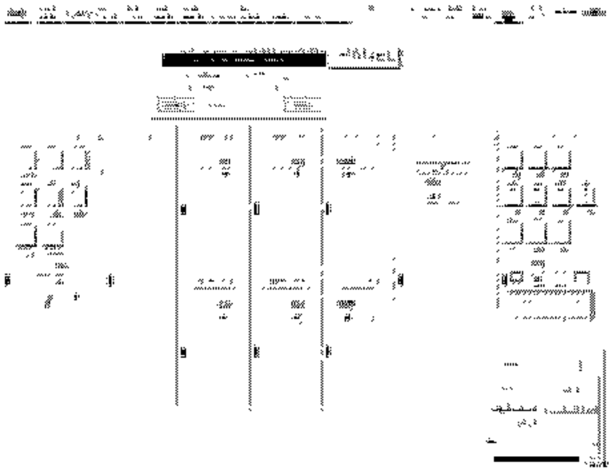

Fig. 12 Switchboard condition screen

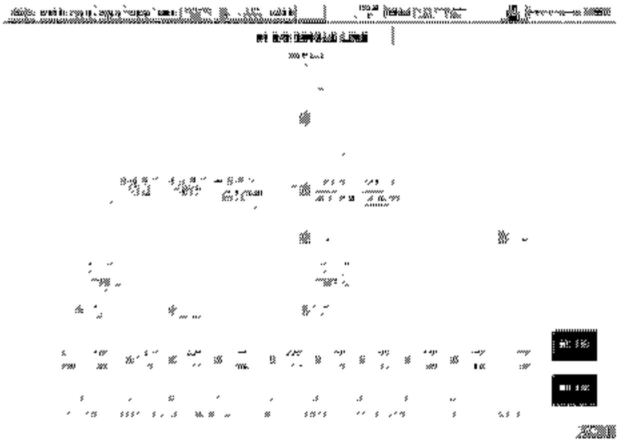

Fig. 13 System one line diagram screen

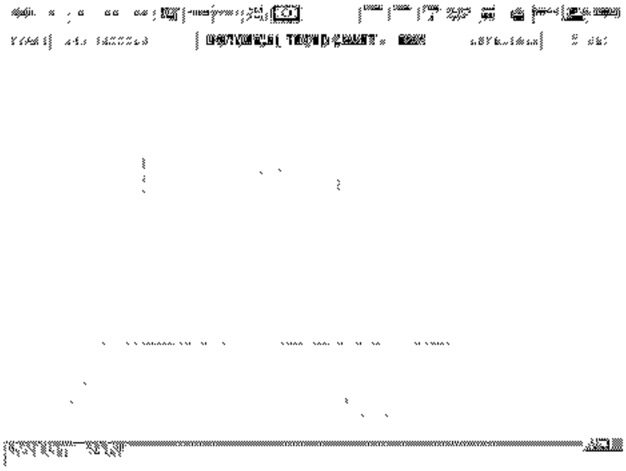

Fig. 14 Data analysis screen

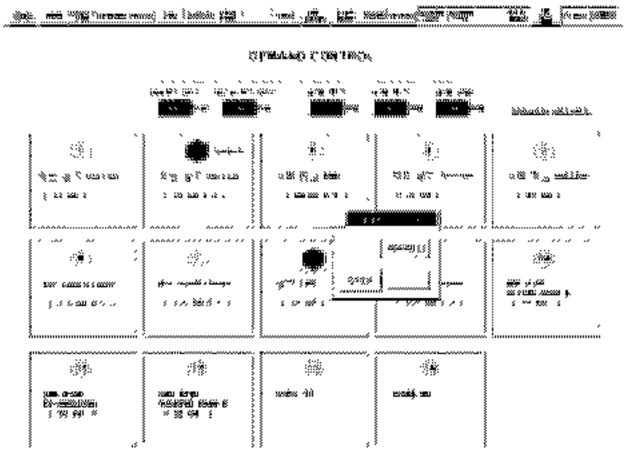

Fig. 15 Demand control screen

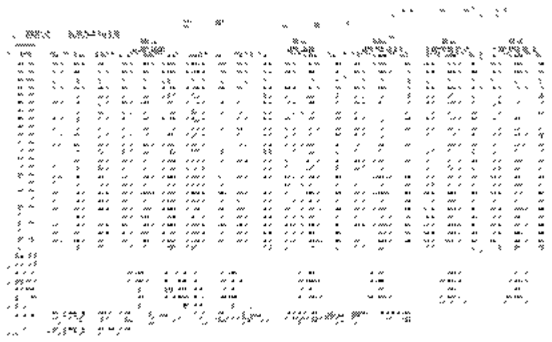

Fig. 16 Report screen

4. Conclusions

This paper suggests electronic power monitoring system using 80C196KC, visual programming and database. This system is described along with the various functions that materialize integrated monitoring, protection, and control systems. As well, some of the more important design considerations are discussed.

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