Low Cost Integrated Substation Protection & Control System

VICTORIA UNIVERSITY OF TECHNOLOGY

Indunil Chanaka Kannangara

Victoria University of Technology
Melbourne
AUSTRALIA

VICTORIA UNIVERSITY OF TECHNOLOGY

Low-Cost Integrated Substation Protection and Control System

by

Indunil Chanaka Kannangara B.Eng (Hons)

A Thesis Submitted to the Department of Electrical & Electronic Engineering for the Research Degree of

Master of Engineering

December 1994

Dedicated to Dr. Kalam
and my wife Shyama

SYNOPSIS

With the recent developments in the digital equipment associated with the power system such as digital relays and transducers the development of integrated substation protection and control systems were possible. In this thesis the use of the currently available very sophisticated and reliable, yet inexpensive high level third generation software to develop such application is dicussed. Low cost integrated system does not depend on any particular power protection or control manufacturers protocol but uses standard IEEE 802.3 Carrier Sense Multiple Accesses/Collision Detection (CSMA/CD) protocol (Ethernet). Data Acquisition and control is done directly so that it could be used on a range of different manufacturers' equipment. These capabilities make this development to act as a system integrator for substation protection and control and will overcome many disadvantages associated with the traditional protection and control systems.

ACKNOWLEDGEMENTS

I take this opportunity to express my gratitude and appreciation to Victoria University of Technology and the Department of Electrical & Electronic Engineering for providing support to obtain my Bachelor of Engineering degree and carry out this Master of Engineering research degree.

Grateful acknowledgments are made to the Head of the Department, Associate Professor Wally Evans, all the academic and support staff and colleagues at VUT for their splendid assistance and enthusiasm at various stages of this work. Special thanks are due to Mr. Carl Vine and Mr. Chris Perera of the computer services department for their generous help in finding the right software.

The work presented in this thesis was initially carried out under Dr. A. Zayegh, whose assistance and guidance was most helpful.

My sincere gratitude is extended to Associate Professor Dr A. Kalam for his constant encouragement, learned suggestions and invaluable support in both academic and personal matters. I would not have achieved what I have achieved today if not for him.

Finally I would like to thank my parents, friends and especially my wife Shyama who stood by me all the time giving me encouragement and support to make this work complete.

Smiles, innocent charm and cuddles of my baby son Lahiru was always a source of encouragement and motivation during the course of this research.

Chanaka Kannangara
December 1994

TABLE OF CONTENTS

LIST OF PUBLICATIONS

Publications related to the work presented in the thesis:

[1] A. Zayegh, A. Kalam, C. Kannangara, "Model of an Integrated Substation Protection and Control System", 2nd International Conference on Modelling and Simulation, Victoria University of Technology, Melbourne, Australia, 12-14, July 1993, pp736-740.

[2] A. Kalam, C. Kannangara, A. Zayegh, "Development of an Educational Integrated Substation Protection and Control System", AUPEC '93 Australasian Universities Power Engineering Conference 1993, University of Wollongong, Wollongong, Australia, 29Sept-1Oct 1993, pp294-299.

[3] C. Kannangara, A. Zayegh, A. Kalam, "Third Generation General Purpose Data Acquisition and Control System Based Substation Protection and Control System", AUPEC'94 Australasian Universities Power Engineering Conference, Adelaide, Australia, 27-29 Sept 1994, pp 439-444.

[4] C. Kannangara, A. Kalam, A. Zayegh, "Local Area Network Based Low Cost Integrated Substation Protection and Control System", Electrical Engineering Congress '94, Sydney, Australia, 24-30 November 1994, pp101-105.

[5] C. Kannangara, A. Kalam, A. Zayegh, "Integrated Substation Digital Protection and Control - A General Purpose Low-Cost Solution", International Power Engineering Conference IPEC '95, Singapore, 29Mar-1April 1995 (on publication).

LIST OF ABBREVIATIONS

A/D	Analog to Digital
ADC	Analog to Digital Converter
API	Application Programming Interface
BIOS	Basic Input / Output System
CIGRE	International Conference on Large High Voltage Electric Systems
CMOS	Complementary Metal Oxide Semiconductor
CMOS	Complementary Metal Oxide Semiconductor
CPU	Central Processing Unit
CRT	Cathode Ray Tube
CSMA/CD	Carrier Sense Multiple Access / Collision Detection
D/A	Digital to Analog
DAC	Digital to Analog Converter
DDE	Dynamic Data Exchange
DDEML	DDE Management Library
DFT	Discrete Fourier Transform
DLL	Dynamic Link Library
DMA	Direct Memory Access
EHV	Extra High Voltage
EISA	Extended Interface System Adaptor

EMI	Electromagnetic Interference
EPRI	Electric Power Research Institute
FFT	Fast Fourier Transform
FIFO	First In First Out
GDI	Graphic Device Interface
GPIB	General Purpose Interface Bus
GUI	Graphic user Interface
I/O	Input/Output
IEEE	Institute of Electrical & Electronic Engineers
IRQ	Interrupt Request
ISA	Interface System Adaptor
ISO	International Standards Organisation
LAN	Local Area Network
LED	Light Emitting Diode
LLC	Logic Link Controller
MAC	Media Access Control
MIDI	Musical Instrument Data Interface
MS-DOS	Microsoft - Disk Operating System
MSB	Most Significant Bit
NDDE	Network Dynamic Data Exchange
NDIS	Network Device Interface Specification
NetBEUI	Network BIOS Extended User Interface
NetBIOS	Network Basic Input Output System
NI-DAQ	National Instrument's Data Accusation Software
OSI	Open System Interconnection
PC	Personal Computer
PIC	Programmable Interrupt Controller

RAM	Random Access Memory
ROM	Read Only Memory
SCADA	Supervisory Control And Data Acquisition
SMB	Server Message Block
TTL	Transistor Transistor logic
VAR	Measuring Unit for Reactive Power
VDD	Virtual Display Driver
VDU	Video Display Unit
vi	Virtual Instrument
VLSI	Very Large Scale Integration
VxD	Virtual Device Drivers

LIST OF FIGURES

LIST OF TABLES

CHAPTER
ONE

INTRODUCTION

1.1 Scope of the Research

Recent advancements of digital equipment associated with the power industry has had a significant impact on power system protection equipment and techniques. The widespread use of microprocessor based digital relaying resulted in easy implementation of integrated substation protection and control systems.

Power system protection, control and monitoring, traditionally include a large number of equipment designed to perform specific tasks. Duplication of equipment, poor man-machine interface, high power consumption, high maintenance costs and lack of self monitoring and fault diagnosis are some of the other disadvantages associated with the traditional systems.

The advancement of multi tasking microprocessors and the availability of intelligent, easy to use standard interfaces, have made the development of customised computer networks a less exhaustive task. In order to develop the integrated protection and control systems, these reliable, low cost computer networks offer an extremely feasible solution. As a result of this, initial fears of high costs involved in sophisticated protection and control systems using computers have diminished.

1.2 Aims

The main objective of this research is to design and implement a low cost integrated power system protection and control system for distribution substations. Sophisticated computer software packages embedded in an integrated software environment are to be used to process data acquired at the substation.

Aim of the research is to develop an integrated substation protection and control system to provide:

- centralised control and distributed processing,
- high quality man-machine interface,
- high reliability and unattended operation,
- on line monitoring and event recording
- integrated software environment with sophisticated packages
- infrastructure of standard hardware and software
- low cost implementation
- modular architecture for future developments

1.3 Research Methodology

Low cost integrated substation protection system illustrated in this thesis is based on a Local Area Network (LAN). This LAN acts as the communication interface between numerous processors that provide protection and control functions.

Emphasis was made on using standard software and hardware. Three major software products were used to implement the system:

- integrated software environment to host the system
- LAN software
- instrumentation software to implement the data acquisition, protection and control functions

1.4 Organisation of the Thesis

The work presented in this thesis consists of eight chapters. In Chapter 1 the scope of research and aims, research methodology employed, organisation of the thesis and the author's contribution to the field of study is given. Chapter 2 discusses the relevant state of the art technology and the feasibility of the research. Architecture of the developed system is provided in Chapter 3, with a critical comparison of traditional systems to the current integrated systems. Chapters 4, 5, and 6, describe in vivid detail, the implemental aspects of the system. Chapter 4 provides the details of LAN, Chapter 5 concentrates on software used and Chapter 6 presents data acquisition and control functions. Output of the developed system and their operation are shown on Chapter 7. Chapter 8 gives the conclusions reached at the end. Recommendations for future work are also given in this chapter.

Several Appendices attached to the end provide, additional details such as program listings, virtual instrument hierarchies etc..

1.5 Contributions of the Thesis

Major contributions of this thesis are:

1) developing a low cost platform for an integrated protection and control system for a distribution substation,
2) reducing the associated costs of development using standard components,
3) providing a modular architecture, so that new features could be added in future.

CHAPTER
TWO

INTEGRATION OF SUBSTATION PROTECTION AND CONTROL
- AN OVERVIEW

2.1 Introduction

Power system protection and control functions of an electric power substation are rapidly changing due to the advancements of electronic technology. Integrated systems for the substation protection, monitoring and control are capable of delivering tangible benefits and significant returns on investment. These benefits can generally be classified in terms of energy cost savings, better equipment utilisation, and increased system reliability. Reliable protection and control systems are of extreme importance as the safety of personnel and capital equipment are much dependent on the reliability of these systems.

In traditional monitoring and control systems, most of the process information were sensed through the transducers. This information was later sent through many wires to the central control area. The control area was equipped with instrument panels, manual controls, automatic control packages that were individually selected, installed and wired. However, advancements in the digital electronics related to the power industry in recent years, lead the manufacturers to build equipment that revolutionised this control approach. In digital systems, analog information is converted to digital form using analog to digital converters, and then multiplexed into single trunks and sent to the central control area. In some other cases local area networks are being used to build the communication links between the field data acquisition terminals and the central control area. In the central control area the computer record data, process control information and offer many other intelligent services.

The main challenges faced by the early developers of such computerised protection and control systems were the crucial data processing speed requirements and the cost of the hardware needed to implement the systems. These factors have hampered the application of the aforementioned technology in real systems to a relatively great extent. Fortunately both these problems are now eased with the arrival of high speed processors at relatively low costs. Advanced microprocessors and computers, standard interfaces, Very Large Scale Integrated (VLSI) system support, digital communication techniques, reliable computer networks, and advanced software tools have made this technology an affordable reality today.

2.2 Background

In the early eighties Deliyannides and Urden [1] discussed the design criteria for an integrated microprocessor-based substation protection system. They referred to an Electric Power Research Institute (EPRI) sponsored program for the development of an integrated substation protection and control system for transmission level substation. They portrayed about the requirements, goals and design approach for an integrated substation protection and control system. Emphasis was placed on issues such as user requirements, criteria of usefulness and design strategies to fulfil these requirements.

New ideas about the topic with the analysis of the operating requirements of the contemporary research were subjected to discussions at the CIGRE study committee at Tokyo in 1983. Digital processing of control, protection and communication functions were presented and discussed in relation to EHV substations by Tesseron et el [2].

Meanwhile the technological advances made the computer networks a very cost effective solution for many distributed processing functions. Puri and Hardy [3] in 1984 showed how a Local Area Network (LAN) could be used for the control and protection functions of a substation.

This idea was further developed by many organisations. Westinghouse Electric Corporation, EPRI, Siemens AG, and Electricite de France are examples of some of these organisations [14][17][18]. In a noticeable experimental project at Electricite de France in 1985-1986, a local area network was implemented in a substation to integrate protection and control functions [2][4][5][14]. In this project, an EHV substation (400kV and 225kV) with line feeders, busbar couplers, busbar sections and auto transformers was connected to four remote devices and one central unit using optical units. Intel 8630 microprocessor boards were used at remote units along with data acquisition boards, output boards and associated interfaces. Digital Equipment PDP-11/44 mini computer was used as the central computer supported by two semi-graphic and graphic Cathode Ray Tubes (CRT), two printers, 140 Mb disks and a switched telephone network remote link (Modem link). Ethernet network protocol was substantially being supported by many manufacturers such as INTEL, 3COM, INTERLAN, etc. even at that time. Due to this, Ethernet was selected as the LAN communication protocol.

With this experiment it was possible to draw some realistic conclusions about the adaptability of LAN technology in substation environment. Conclusions concerning communication software, open structure for application software, connection requirements, data formats, etc. were drawn, relating to the contemporary technology. Future needs of such system were also identified. In the final results it was claimed that Ethernet was successfully adapted to a mixed solution with optical links. It was stated that CSMA/CD based networks such as Ethernet could meet the substation needs provided the continuous flow is less than 1/10 of the maximum flow. Further it showed how a standard product could be adapted for control functions after minor modifications. Aforementioned scheme showed that the solutions for digital communications inside an EHV substation have already reached the realistic age.

The background of the development of computer based systems for substation control and monitoring was presented by Liley et al [6] in 1986. This approach from England was based on a substation database that can supply substation data over standard communication links, to a large number of independent substation computers performing different control and monitoring functions. It outlined a laboratory prototype that was developed to demonstrate the feasibility of such concept and highlighted the benefits of such technique.

Some results of the process of substation automation concept could have been used either as stand alone devices or as a part of the total integrated protection, control and monitoring system [7][12][25]. One such device was the microcomputer-based feeder protection system proposed by Manika, Renz and Koch [7] in the CIGRE Paris meeting in 1986. These relays have been able to provide all the functions necessary for a complete line protection scheme in one integrated unit. A similar feeder protection unit was discussed in relation to the utility experience by Narendorf, Russell and Aucoin [12][20].

CIGRE Paris conference in 1986 yielded number of projects designed, implemented and tested around the world at that time in the area of integration of power system protection and control of substations. In this meeting Kezunovic et al [8][17] presented an integrated substation control and protection system based on several sub systems. These sub systems included, distance relay, transient recorder, local automatic control sub system, communication serial multi drop link, supervisory sub system, and fibre optic point to point link. Among the issues considered, were the design philosophy and functions, system architecture, hardware, software, communications, algorithms, system testing and the future activities.

Year 1986 showed rapid progress in the implementation of prototype systems in the real world. However most of these works were confined to the laboratories even at this time. Nilsson, Petrie, Deliyannedes, and Mankoff [9] who have lead the way for this research trend through EPRI unveiled their work on transmission class substation in the same year. This system based on the distributed microprocessor modules, incorporated line, transformer and bus protection functions as well as the necessary automatic and supervisory control functions. It predicted significant economic and functional payoffs for the future.

Similar system was outlined by dos Santos et al [10] in Brazil and Sucena Paiva [11] in Portugal. Both of these systems were in their initial stages when the authors presented their work in 1986. These systems looked into aspects such as:

- multi-task kernel,
- status and measurement acquisition,
- logging and display of data,

- under voltage load shedding and restoration,
- automatic line reclosure,
- earth fault search,
- transformer loss minimisation,
- transformer tap change control and
- protective relay coordination.

Implementation details of these proposed systems were not available afterwards. It is assumed that technological or budgetary constraints have hampered their implementation.

The progress of the integration of substation protection, control, and monitoring system through the advances in digital technology continued with EPRI, which built systems for commercial use by year 1988. As Douglas [16] outlined in 1988 in an EPRI journal article based on the information provided by their engineers, with integrated systems a new substation could save up to 10-20% in the relay and control equipment. It was stated that substation protection and control systems are the perfect complement to the modern solid state relay equipment and these systems could offer advanced operation and maintenance capabilities. It referred to a commercial product developed by the Westinghouse Corporation.

Same project as outlined by Mankoff and Rockefeller [29] in 1988 in a separate article, had a long history. Initiated in 1978, EPRI sponsored a study to assess the preliminary evaluation of the technology. Subsequently a contract was signed with Westinghouse Electric Corporation to develop the system. In 1981-82 Westinghouse built and operated a small scale laboratory demonstration to test feasibility of such project. During 1983-86 the complete commercial prototype Westinghouse demonstration system was assembled, tested and installed in the Deans substation of

Public Services Electric and Gas Company. In 1988 the Westinghouse integrated system was fully commissioned.

However, Mankoff and Rockefeller [29] admit that resulting local area networks have not seen widespread application in substations even in 1988. They accept the fact that the networks of microprocessors, communicating digitally over optical fibres had technical potential for revolutionising relaying and control in substations. At the same time they point at some fundamental requirements for substation applications that do not apply in most other situations. Some of these attributes are:

- need for reliable performance,
- minimum interaction with human operators,
- need of designing hardware to withstand electromagnetically hostile environment,
- need for correct operation to be tested rigorously, and investigated thoroughly prior to acceptance by the industry

They related to these factors as some of the reasons for the reluctance of application of this technology to electric supply industry. To offset these factors, they suggest that new designs must offer some combination of improved functioning, new capabilities and cost savings as incentives for application [29].

The system described by Mankoff and Rockefeller [29] at the Deans substation was based on three level hierarchy of digital electronics within the substation. At the lowest level, data acquisition units collect analog inputs and status inputs. The second level in the control house consists of protection clusters that receive data streams from data acquisition units. Highest level comprises the station computer that connects to protection clusters via a multi-drop data highway. The substation computer provided a substation database, low speed multi-zone application functions, a local operator interface and communication with remote sites via data links. The station computer was able to replace Supervisory Control And Data Acquisition (SCADA) remote transmission units. However, it was also able to send comprehensive oscillographic and sequence-of-events data through a data highway, to engineering offices or other locations. The switchyard optical cables used glass, while most of the other data communications within the control house used plastic fibres.

One of the most ambitious projects in the automation process of substation protection and control systems was the work presented by Suzuki et el in 1989 [28]. Three large organisations, the Tokyo Electric Power Co. Inc., Toshiba Corporation, Hitachi Limited, and Mitsubishi Electric Corporation joined hands to develop a substation digital protection and control system using fibre-optic local area network [28].

Aforementioned development had its roots going back to 1980. It started with the decision made by the Tokyo Electric Power Company to use digital relays to replace conventional analog relays. The developments continued in order to improve the centralised and remote control functions of substations. At the same time efforts were made to achieve the integration and automation of the power system.

The system mentioned before was developed with certain considerations in mind. Although these considerations were similar to the most of the other systems discussed previously, the distinction of this project lied on the precision and the attention to the very fine detail given in the development process. The system was configured with following considerations in mind:

- removal of electromagnetic interference from communication lines by using an optical fibre data transmission between equipment

- elimination of protection function loss during system failure by using a complete duplicate system structure
- securing the operation of protection relay during a system failure by separating the protection relay from the monitoring and control system and by installing separately and independently each functional unit, such as transmission line protection, bus protection and transformer protection.

The local area network for the system was based on a bus type network with IEEE 802.4 token bus access control protocol [19]. In order to guarantee that the system response for a fault does not get delayed by waiting for the token, they developed a new scheme that assured the token circulated within a predetermined time frame, though the cycle time was not constant.

At the time of development of this system optical fibre data transmission system standards for computer networks have not been finalised by IEEE. Therefore in the physical layer of the LAN the developers defined their own specification for media access and control. This was defined precisely to enable the products from different manufacturers to be linked together. Terminal equipment was also made by number of different manufacturers.

In their conclusions authors proclaim that:

- high quality failure diagnosis could be made by high performance microprocessor,
- system reliability could be improved by self-diagnostic functions,
- use of control cables could be remarkably reduced by using optical fibre,
- system maintenance and operation could be done by the remote relay adjustment functions and precisely defined failure modes.

Kennedy and Rickey's [31] integrated monitoring and control system for industrial power systems focussed on providing a high degree of security, effective and economic operation and maintenance. Their system uses three phase digital instrumentation devices called circuit monitors to monitor and control individual power circuits. These units accept voltage and current from instrument transformers. The circuit monitors feature:

- high speed sampling of current and voltage waveforms,
- sophisticated metering calculations
- communication where all information is industry standard RS-485 link

A high performance LAN provides a communication backbone to support multiple equipment locations. The operating speed of the network used was up to 500 kilo baud [31].

Application of expert systems in substation monitoring, backup protection and control was another idea resulted form integrated substation concept. Trecat and Wang's [24] work explains one such application. They considered building an expert system to carry out the following:

- substation equipment monitoring,
- protective system diagnosis,
- bus bar back up protection,
- normal switching control,
- busbar fault restoration,
- alarm processing.

A LAN approach for whole transformer station protection and automation was described by Yang et el. [36], in their work published in 1993. LAN used in the project interconnected the protection system, fault recorders, and the host computer. The host computer coordinated the functioning of equipment and passed messages from protection relays or fault recorders to the control room. The LAN used BITBUS interconnection standards with an isolated dual-host computer with advanced bus. The system was capable of transmitting at a rate of either 375kbps or 62.5 kbps over a maximum distance of 1200 metres without a repeater [36].

Siemens AG commissioned it's first coordinated substation protection and control system in 1986 [37]. By 1993 there were many systems in successful operation at all voltage levels up to 400kV. Inan and Zeigler [37] presented a second generation system based on the previously mentioned experience. The main characteristics of this system were:

- coordinated system structure,
- optical star configuration,
- high processing power with 32-bit technology,
- standardised serial interfaces and communication protocols,
- uniform design of all components,
- complete range of protection and control functions,
- comprehensive user software support packages.

Communication and data exchange between components were performed via serial data links in the above project. Optical fibre connections were preferred due to Electromagnetic Interference (EMI) considerations. The communication structure was designed as a hierarchical star configuration [37].

A new approach to distribution system protection using adaptive relaying techniques was the basis of work presented by Sachdev et el [40]. They outlined the design of an adaptive relaying system for the distribution network of the City of Saskatoon of Canada. Their work was based on a scheme implemented in the Power System Research Laboratory at the University of Saskatchewan. They examined the consequences of partial and total failure of communications between the station computer and the relays. Also examined were the impacts of the communication failures between station computer and the central computer. Finally the measures to alleviate such situations were discussed [40].

2.3 Feasibility of Developing a Low Cost Solution

The above review of literature associated with integration of protection and control systems of distribution or transmission substation reveals some very important facts. All these projects:

- are large capital expenditure projects;
- had a large amount of fundamental software development including local area network software, graphic user interface software in addition to the data acquisition and control software that is essential for the protection and control functions of substation;
- are more or less custom built systems which did not make emphasis on using standard software or hardware products that could be used over a range of different manufacturers' equipment.

These three key factors hampered the popular application of this technology globally, to a certain extent. However as Mankoff and Rockefeller [29] pointed out, the lack of references about the reliability of these systems was another factor that influenced the reluctance of the protection engineers approving the implementation. The rapid development of digital technology associated with power industry in the eighties had a large impact on the integrated protection and control systems. The improvement of the performance and reliability of computer systems as real time controllers and their continually dwindling prices have also influenced the application of computerised systems for integration of substation protection and control.

Standard software tools available today are generations ahead than their counterparts in early eighties when the research on integration of protection and control of substations originated. These projects were large and needed many years to develop customised software and hardware [29]. While the integrated substation protection and control systems projects continued with their original plans over the years revolutionary advancements took place in the software industry. Many standard software products for diverse software development processes and purposes were available off the shelf in the market. It is observed that these developments of standard software products have been somewhat overlooked and were not incorporated to their original designs by the developers of integrated protection and control systems.

Currently, there are standard software products for range of functions and application so that the fundamental software development for any custom made application could be minimised. Standard software is available to develop custom applications over integrated software environments, local area networks, to develop graphic user interfaces, data transmission networks, instrumentation, and for presentation.

By selecting the right software tools that are compatible with each other in data formats and other attributes, it is easy to build complex systems while saving on the programming effort as well as the development costs. The feasibility of the low cost integrated substation protection and control system was mainly dependent on such selection. In a nutshell, following factors have influenced the feasibility of this project:

- the advancement of digital technology associated with the power industry,
- low cost multi tasking computers with versatile interfaces,
- instrumentation that could be modelled in computers,
- availability of low cost standard integrated software environments with a range of possible embedded applications.

CHAPTER
THREE

SYSTEM ARCHITECTURE

3.1 Introduction

The system architecture of the integrated substation protection system will be discussed in detail in this chapter. To understand the need for an integrated substation protection and control system, a critical analysis of the traditional systems is useful. Therefore, the first part of this chapter is dedicated to examine the inherent disadvantages associated with the traditional designs. After careful consideration of traditional systems the need for integration of substation protection and control functions is investigated. Subsequently, the system architecture of the low cost solution is given followed by its' hardware and software requirements. Finally the functional capabilities of the new system are presented.

3.2 Shortcomings of Traditional Systems

To understand the need for new integrated systems, it is necessary to look into the present systems and identify the needs and demands placed upon them. Once this is done, it is possible to devise new ways to improve and overcome the shortcomings associated with traditional systems. By compromising between the demands of the modification and the capabilities of the available electronic and mechanical technology a feasible solution could be found later. Some of the typical disadvantages of traditional systems are given in the following sections.

3.2.1 Excessive Wiring

Generally separate terminal is provided for each input to the protection and control unit of the system. Each output is again connected individually. As these systems cannot share the inputs or outputs, field control signals and circuits in the traditional systems have to be connected to each device using it. For example, a single current line will have to be connected to an ammeter, power oscilloscope, number of relaying and control systems and in some cases to a SCADA system. Higher the number of connection points, higher the wiring and installation costs.

Integration of functions will help to overcome this situation, so that equipment requires minimum interconnections. With digital technology it is possible to multiplex a number of signals originating from different sources and send them thorough one wire to the required destination.

3.2.2 Lack of Event and Waveform Recording

It is important to have records of equipment response to transient events. With these records it is possible to analyse the patterns and predict the future events, and take precautions to improve the situation. Monitoring conventional protection and control systems require the purchase and installation of additional equipment that is expensive, high in maintenance and itself is highly prone to failure. This type of monitoring equipment could only be connected to a limited number of points. As a result of this, monitoring the system becomes a very expensive exercise. Lack of self diagnosis facility gives rise to the need of periodic checking and monitoring of the system components.

Built in on-line monitoring and event recording facilities enable the operator at the central location to identify the fault condition immediately with the alarm processing facilities, and act upon them through remote control functions. Event recorders can record the full transient information and reproduce the necessary waveforms at a later date.

3.2.3 Need for Periodic Maintenance

Conventional relays and controls may fail without any indication. Therefore many utilities have periodic maintenance programs to ensure the proper operation of their equipment. Here, the equipment is tested and calibrated at regular interval. Frequency of this maintenance operation depends on the statistical information, protection engineers experience and the manufacturers' specifications. These programs are usually very costly and may cause faults even after they are tested.

Integrated protection and control system can offer solutions in this area too. Self diagnosis functions could be built in the digital relays and could be activated remotely. This type of remote testing is possible to carry out at regular intervals far too frequently than in the case of conventional protection and control systems. Further alarm systems built into the system can alert the operator in case of communication failures or in a real contingency situation.

3.2.4 Poor Man-Machine Interface

Monitoring facilities that are available in the conventional substations are limited mostly to target or indicator lights, oscillograms showing connected points and in some cases power oscilloscopes. In a transient situation most of the other data that could be useful in investigating the situation is either lost or stored in a transient recorder using magnetic tape. In most cases, the information is stored in an uncorelated way with many records, making the task of reconstructing incorrect or suspicious situations more difficult.

Screen based equipment with remote control and monitoring facilities, large networked databases, automatic data logging, on-line data acquisition and control features in the digital integrated protection and control system will overcome the aforementioned disadvantages and will offer high quality man-machine interface.

3.3 Need for Integration

Usually the power plants are located further from the load centres and thus reduce the system stability and require fast detection and clearance of faults. The increased use of multi-circuit and multi-terminal lines require more intelligent and more reliable relaying schemes. Since the new substation units with sophisticated relaying schemes use fewer circuit-breakers, the demand on the control equipment has increased, making the relaying schemes more complex. Lower reserve margins, construction delays and increased usage of power make higher reliability needs on the transmission systems and the distribution systems. Above all these, the manpower limitations on the utility have placed an increased significance on reducing installation and maintenance requirements.

There are many diverse factors that urge the need for more research and development work to be done in this promising area. Some general observations and conclusions could be made to establish the need for integration of substation protection and control systems:

- more processing power in the substation computers or the auxiliary equipment will allow more sophisticated decision making capabilities;
- the protective relaying security must be improved, particularly to minimise the tripping of non faulty systems and circuits during a power system fault;
- the emphasis must be given to the reduction of development, equipment, installation and maintenance costs;
- improved information about the power system as well as of the protective relaying must be made available;
- reliable detection of incipient faults in equipment is needed to prevent major disturbances as well as to increase the life of the equipment.

In context of the aforementioned needs and observations it is possible to reach at a set of distinctive requirements that have to be satisfied by integrated substation protection systems.

3.3.1 Sophisticated Relaying and Control Facilities

The most important feature required from an integrated protection and control system point of view, is the security and the dependability for a wide range of power system equipment. It is important to make decisions by rapid discrimination of events by subtle differences in measured signals. Therefore, sophisticated relaying and control devices are needed to be installed. These devices must be integrated to maintain overall reliability and the security of the power system. Additionally, communication facilities to other substations and to the utility control centre are needed.

3.3.2 Centralised Control Functions

An essential part of an effective protection and control system is the ability to discriminate the different signal patterns. In order to achieve such functionality, a variety of sophisticated data acquisition and control functions must respond in a coordinated way. The need for centralised operation stems from this. Most of the information that are collected from the switchyard must be transferred to a central location to facilitate the centralised operation.

3.3.3 Local Processing

The data acquired by the field level computers of the substation can process the data to a certain extent. This will enable these computers to take decisions pertaining to the protection units supervised locally. Local processing includes the tripping off the faulty units, accounting and metering functions. Any data for central processing could later be transferred to the central substation processor over the local area network or through an alternative communication link.

3.3.4 Unattended Operation

Remoteness of some substations, cost of manpower to operate the substation, need for speedy automatic control have significant implications towards the quest for unattended operation. As a result of these, all the ordinary control activities must be performed either automatically or using a command of a remote system operator.

In an integrated environment the emphasis must be given to minimise maintenance of the relays and control. Same applies to the hardware and software to obtain the maximum benefits of the unattended operation. Self diagnosis facilities and external monitoring systems are very important to alert the protection engineers in case of failures.

3.3.5 Event Recording

Another important feature that is expected from the integrated substation protection and control system is the facility of event recording. The operation of control or protection elements has a direct effect on the security of the transmission or distribution network. Therefore, to facilitate minimum manpower operation while monitoring the operation, behaviour and the reliability of these critical devices automatic event recording is compulsory. The recording gear must be able to capture the response to important transient events such as faults, power swings and switching.

With the automatic event recording it is possible to preserve the time relationships of certain events with very high resolutions. It is possible to regenerate these and analyse them later with the graphic and presentation packages. This post analysis is useful in further adaptation of operating and control strategies.

3.3.6 Withstanding the Electromagnetic Interference

Substations are usually electromagnetically hostile environments. Therefore it is vital that any data transmission link is electromagnetically shielded properly. The best solution for this problem is to use optical fibre cables for data transmission. Data transmission is done using light signals in fibre optic transmission which is immune to any electromagnetic noise. However, fibre optics have their own limitations such as high cost, inflexibility, difficulty to tap, need to use more star type couplers, etc.. Alternative approach is to use well-shielded copper wire.

3.4 Hierarchical Architecture

In this thesis, integration of substation protection and control equipment was done using a Local Area Network (LAN). The type of the LAN selected depended on the topology, transmission media, media access control and the operating environment.

This network has two levels of operation:

- Field Level,
- Coordination & Management Level.

In the field level, analogue data from a current transformer or a voltage transformer is acquired and converted to a digital signal by a data acquisition unit. The same terminal equipment can deliver the control information received from the control station to the circuit breakers and switches. The field level of the network could either be a single processor or a low level LAN connecting processors with similar functions; ie a LAN connecting all bus protection units. Using the LAN all the field level processors are connected to a central computer. The coordination & management level computer possesses the intelligence to perform the analysis, supervision of archival data and coordination and reporting of short term data. Further it provides the synchronisation of the processors and maintain links with the outside world.

As the system eventually will be operating in a highly electromagnetically hostile environment the transmission media used in the LAN should be able to withstand electro-magnetic interference (EMI). Ideally fibre optic cable is the best solution. Yet, due to cost constraints a double shielded coaxial cables were used as the LAN cabling medium.

For the media access control IEEE 802.3 Carrier Sense Multiple Access/Collision Detection (CSMA/CD) protocol was used. Networks using this protocol are usually referred to as Ethernet. Therefore a 10Mb Ethernet bus was used to interconnect system components. A block diagram of the design of the system is shown in Figure 3.1.

Main roles of each of the components are explained in subsequent sections.

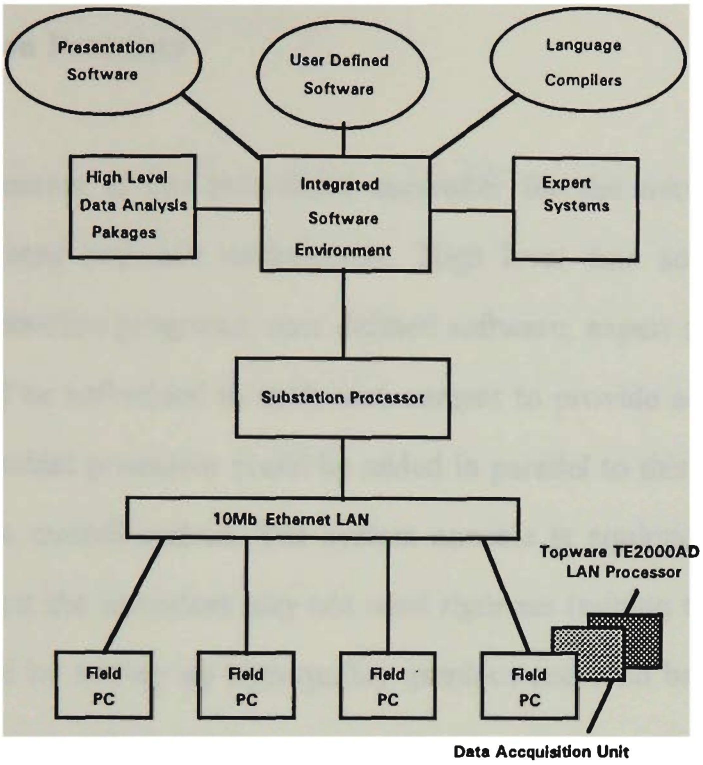


Figure 3.1 Block diagram of the two level hierarchy of the low cost integrated protection and control system

3.4.1 The Local PC

The local PC is an IBM 486/386 or compatible computer and has the following functions:

- a local controller unit providing the digital relaying scheme required; eg. Overcurrent Relay. Using a data acquisition unit, it will continuously monitor the protected equipment in substation field; eg. Bus-bar, Transformer, etc., and provide the trip signal to the circuit breaker;
- a local monitor for specific terminal activity for the field operator;
- member of low level network communicating with the central computer and the other computers in its level. (LAN card is installed in each PC).

3.4.2 Substation Processor

Substation Processor is the centralised controller for the network. Additionally, it hosts an integrated software environment. High level data acquisition and analysis packages, presentation programs, user defined software, expert systems and language compilers could be embedded to such environment to provide added versatility to the system. A redundant processor could be added in parallel to this processor to increase reliability of the overall system. The system console is equipped with user friendly interfaces, so that the operators may not need rigorous training to operate the system. This is achieved by setting up high quality graphics and icon based operations in the integrated software environment.

As the improved protection and control functions are necessary to meet the increasing demands of the power system security, the designed system will provide intelligence to cope up with the requirements manifested by engineers. This is achieved by using advanced microprocessor based digital relaying techniques.

While offering distributed processing facilities to process short term data at local levels the system will maintain centralised protection, control and monitoring functions. In other words, the data acquired from the lower levels of the hierarchy is transferred to higher levels for further processing to influence the control decisions. All control functions offered are in real time; ie. data acquisition, processing and transfer is done with minimum delay.

3.5 Facilities and Equipment

The system is implemented using IBM PC 486/386 or compatible computers. This is essential so as to satisfy the requirements of the software environment and the analysis packages that is used in the project. Further, higher processing speeds are necessary to comply with the power industry standards for protection and control. The computers are connected to form a LAN using thin Ethernet cable. Topware 2000AD High-level Data link layer controller card was used to set up the communication interface. The system was developed as an application over a commercially available Ethernet based LAN. To be compatible with the software environment selected, Windows for Workgroups Local Area Network was used as the backbone local area network. Microsoft Windows 3.1 is used as the base software environment for the project.

For data acquisition, analysis and presentation National Instrument's LABVIEW for Windows data analysis package is used. With this software it will be possible to provide the user with the Fast Fourier Transform (FFT), Discrete Fourier Transform (DFT), power spectrum, digital filters, interactive interface, multi-graphs, strip charts, etc. as well as direct link with Lotus 1-2-3 or Symphony spreadsheet, ready for analysis. National Instrument's "LAB PC+" multi-function Input/Output (I/O) board with "NI-DAQ" software driver is used as the data acquisition unit for this application. This data acquisition unit hosts a 12-bit Analogue to Digital Converter (ADC), two 12-bit double buffered Digital to Analogue Converter (DAC), 24 digital I/O lines, three independent 16 bit counters and 8 bit Direct Memory Access (DMA) interface provides an excellent array of data acquisition utilities.

Microprocessor technology has brought many benefits of sophisticated signal analysis, flexibility, high quality man machine interface, detailed data retrieval and storage, self-monitoring ability and reduced space and power requirements. With this technology many facilities that seemed difficult to achieve in the past have been implemented. Detailed architecture of the project is shown in Figure 3.2.

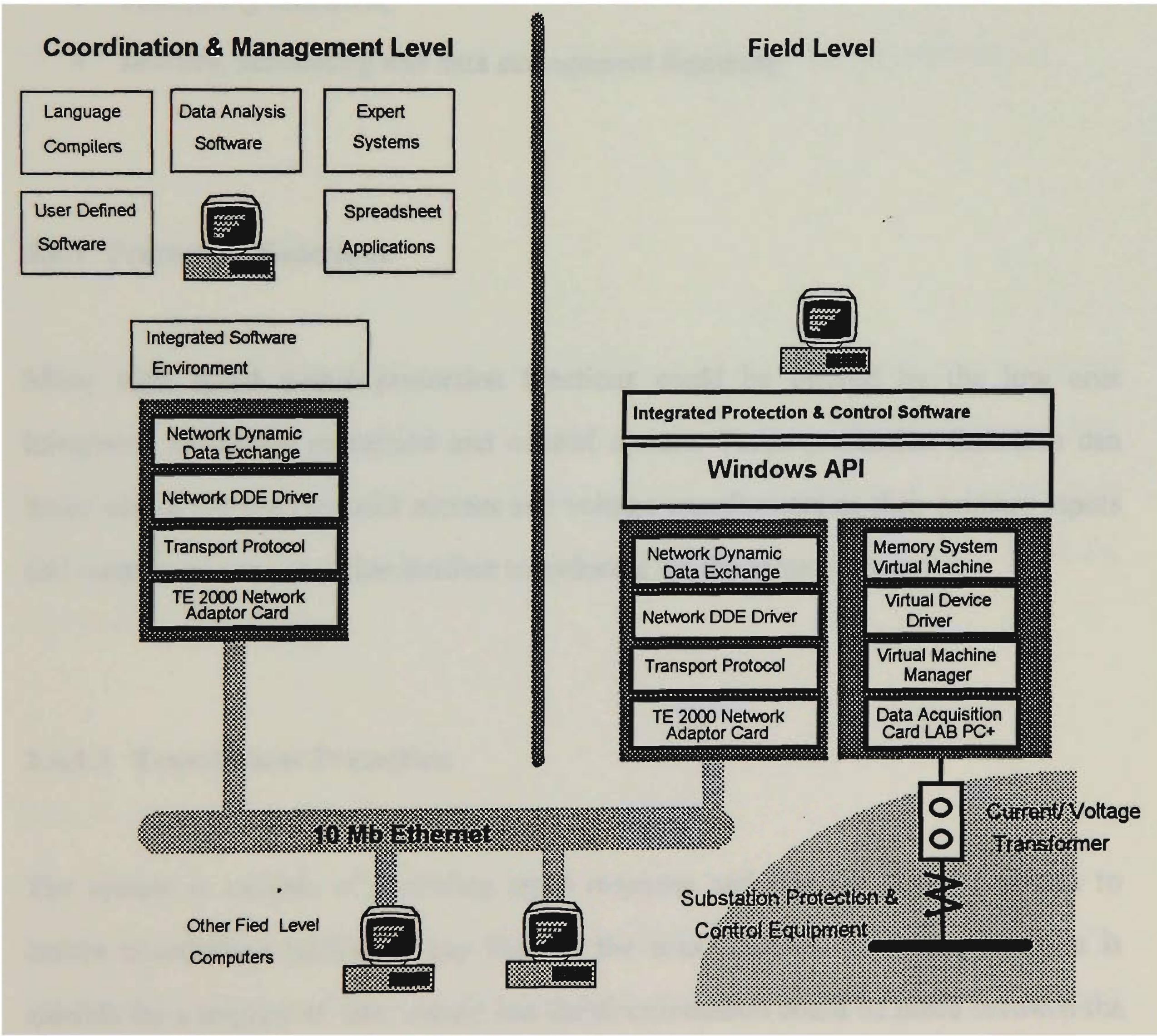


Figure 3.2 Detailed System Architecture

3.6 System Capabilities

System capabilities could be broadly classified as:

- protection functions,
- automated control functions,
- monitoring functions,
- security, accounting and data management functions.

3.6.1 Protection Functions

Many high speed digital protection functions could be offered by the low cost integrated substation protection and control system. These protection functions can make use of the conventional current and voltage transformers as their primary inputs and outputs or can use other modern transducers for the same purpose.

3.6.1.1 Transformer Protection

The system is capable of providing rapid response and trip the circuit breakers to isolate transformer banks for any fault in the area. Differential type protection is suitable for a scheme of this nature and the discrimination could be made between the internal faults, through faults and inrush currents. Tripping logic can accommodate effects of over-excitation, overcurrent time periods, sudden pressure increases, over-temperature conditions and gas analysis if the appropriate equipment or transducers are provided for the measurement of above entities [1] [43].

3.6.1.2 Line Protection

Circuit breakers at each terminal could be made to trip at high speed for a fault anywhere along the protected transmission line. With the digital systems both pilot and on-pilot schemes could be incorporated. In case of a line failure at the remote terminal time delayed remote backup protection units could be used. Distant protection algorithms are sought for these schemes. However, pilot logic could also be used as they are compatible with the modern directional comparison blocking schemes [1].

3.6.1.3 Bus Protection

For the bus protection, phase percentage differential protection schemes could be implemented with ground differential overcurrent protection schemes as the backup protection function. Conventional iron-core current transformers could be used to acquire signals as wired interconnections or matched ratios are not required for these digital protection schemes.

3.6.1.4 Shunt Reactor Protection

Overcurrent, differential and impedance measurement functions could detect the faults in line-connected or tertiary reactors. Further protection could also be provided through turn-to-turn fault detection and protection.

3.6.1.5 Breaker Failure Protection

When a faulty breaker does not respond to the tripping signal within the required time, functions could be modelled to initiate the tripping of all the adjacent circuit breakers to isolate the faulty breaker and the fault itself. Backup tripping functions could be made available through the current transformers connected to the circuit breaker and the ground.

3.6.1.6 Remote Tripping

Remote tripping could be done using the existing transfer-trip transmitters by routing the remote trip request. Where dual channels are used, receiver outputs are compared for inconsistencies. Transfer or remote tripping could be backed up by closing a high speed grounding switch if provided.

3.6.2 Control Functions

Control functions could be utilised to control the voltage and VAR flow of the substation. Functions can be made available to measure the VAR flow at the substation or at any remote point by operating the transformer bank or by switching capacitor banks, reactor banks or synchronous condensers. Following is a list of control functions could be made available with necessary back up equipment:

3.6.2.1 Automatic Reclosing

It is desired to have a reclosing feature after high speed clearing of line faults. After the line fault is cleared reclosing of the breaker is initiated, and repeated if necessary for a specified number of times. Additional supervisory checks such as live-bus, dead line and synchronism could also be incorporated selectively. This feature could be extended for bus faults with minimum modifications in software.

3.6.2.2 Load Shedding

Load shedding could be initiated by the integrated system. Load shedding has to be performed when there is a generation/load imbalance such that the load is greater than generation causing an over-frequency condition in the system. The shed requirement is the difference between total load and total generation. General procedure is to group loads appropriately and shed them in a suitable algorithm to maintain system balance. These algorithms could be incorporated in a dynamic level control by means of an expert system embedded to the integrated protection and control system or as a dedicated function built into the system.

3.6.2.3 Tie Tripping

A trip signal could be initiated from the integrated system when a transmission tie to a neighbouring utility shows sustained heavy power outflow and declining frequency.

3.6.2.4 Synchronising

The magnitude, phase angle and frequency differences between voltages on opposite sides of any open circuit breaker could be measured to determine when it is safe to close the breaker. Integrated system can further offer an automatic closing program considering slip frequency, phase position and breaker contact closing time with the help of digital relaying schemes. With this arrangement it is possible to close the contacts when the phase difference is zero. Control of tap changers, exciters, governors and phase angle regulators could also be provided.

3.6.2.5 Automatic Switching Sequences

Tripping breakers to clear line or bus faults may result in needless isolation of equipment in some cases. With integrated system this could be averted by using post-fault automatic closing control sequences programmed into the system where the equipment could be brought back to services efficiently. Provisions could be made to initiate this process automatically or upon the user request. Some of the sequences that could be programmed are bus transfers, sectionalising, isolation of faulty transformers or a jammed circuit breaker.

3.6.3 Monitoring Functions

Monitoring functions of the system includes remote monitoring through the substation processor and the local monitoring done in the yard. Monitoring functions are important to observe any transient condition and to study the system response to such transient activity. It is also important to monitor the system continuously to verify the proper operation of the substation protection and control functions as well as the system itself. Screen based equipment is used for monitoring purposes mostly with some alarms and other backup accessories. Some of the possible monitoring functions are described in the following sections:

3.6.3.1 Load Monitoring and Out-of-Step Protection

In the case of excessive line currents the system could be trained to identify such situation and give out an alarm signal. Also, the locus of apparent line impedance could be monitored and recorded. When line voltage-angle computations show that machines of power system are slipping out of synchronism, a pre-programmed strategy of splitting the system into balanced islands could be implemented.

3.6.3.2 Monitoring and Control of Breakers and Switches

The position of each breaker and switch could be easily monitored through the analog and digital input channels provided in the system. Monitoring functions will enable proper control and coordination of switches and improve the reliability of the entire protection and control configuration.

Monitoring checks include:

- agreement between auxiliary contacts and current flow or voltage data,
- timing of lagging poles,
- detection of sustained pole disagreement.

Control operations include:

- single pole tripping,
- arbitration of simultaneous or conflicting automatic and manual requests,
- closing supervision through voltage or synchronism checks,
- lockout tag setting and removal logic [1].

3.6.3.3 On-line Monitoring of Transient Events

All the AC signals could be monitored on-line in the foreground or background of the screen terminals. Running statistical functions will monitor the system for any abnormal transient situations and record such data through data logging functions. In the low cost system described in this thesis, running mean, standard deviation, and the running median of the AC signal is monitored continuously to identify transient events. These signals are compared with other readings or threshold values for consistency. Currents are checked using differential relationships on each phase.

Voltages are checked by confirming that the potentials at two connected points on the same phase are the same. Currents and voltages on transformer windings should be related according to the transformer ratio and tap positions. System itself highlights any suspicious or erroneous measurements by comparison with the standard values.

3.6.3.4 Transformer Overload Checking

Transformer temperature, pressure, gas analysis and current in the windings could be monitored if the necessary transducers are provided. These transducers could be connected either in single ended configuration or in the differential configuration to the analog or digital inputs of the data acquisition and control units. Once this is done it is possible to monitor the transformer activity locally or remotely. Further, programs could monitor the hourly peak active and reactive power components and overload history data. This information could be processed further to calculate estimates of remaining loading capabilities of the transformer within the normal or emergency situations.

3.6.3.5 Self Checking Functions

Self checking functions are built into the system covering the proper operation of the local area network, data acquisition units, and other hardware and software. If any of the remote servers is malfunctioning it is shown by a message appearing in the user interface window. The integrity of the hardware elements in the system could be further ensured by executing checking sequences during processor idle time. Diagnostic software is available for the data acquisition unit and network adaptor card. By running this software time to time system can check itself without human intervention.

3.6.4 Security, Accounting and Data Management Functions

Several functions are available in the integrated protection and control system that do not belong to either protection category or the control functions category. These functions are used as added security features of the system, to do metering and accounting, and to manage the data acquired by the system. Graphic user interface and the remote data transmission interface are also included in this group of functions.

3.6.4.1 Graphic User Interface (GUI)

The low cost integrated protection and control system uses Microsoft Windows as the host integrated software environment. Windows offer high quality GUI. Customised Windows based user interfaces are built using the Windows Application Programming Interface. Data acquisition and control system which is based on the LABVIEW instrumentation software also allows the user interfaces to be built using Windows features. By using the above two software products it was possible to reduce the time and the costs involved in developing the GUI. GUI developed offers high quality features such as push buttons, dials, momentary switches, level switches as the inputs to the system via Video Display Unit (VDU) which could be set using the mouse. GUI output includes sweeping graphs, charts, LED indicators, light indicators, all appearing on the VDU.

3.6.4.2 External Data Interface

This could be done using two methods:

- Supervisory Control and Data Acquisition (SCADA) System with a microwave link,
- modem link via normal telephone line.

Using aforementioned techniques, it is possible for the system to interact with a remote supervisory office. The system will respond to the master stations' requests including the data retrieval, control selection and activation. The General Purpose Interface Bus

(GPIB) of the computer could be extended over a telephone cable to a remote master as shown in Figure 3.3

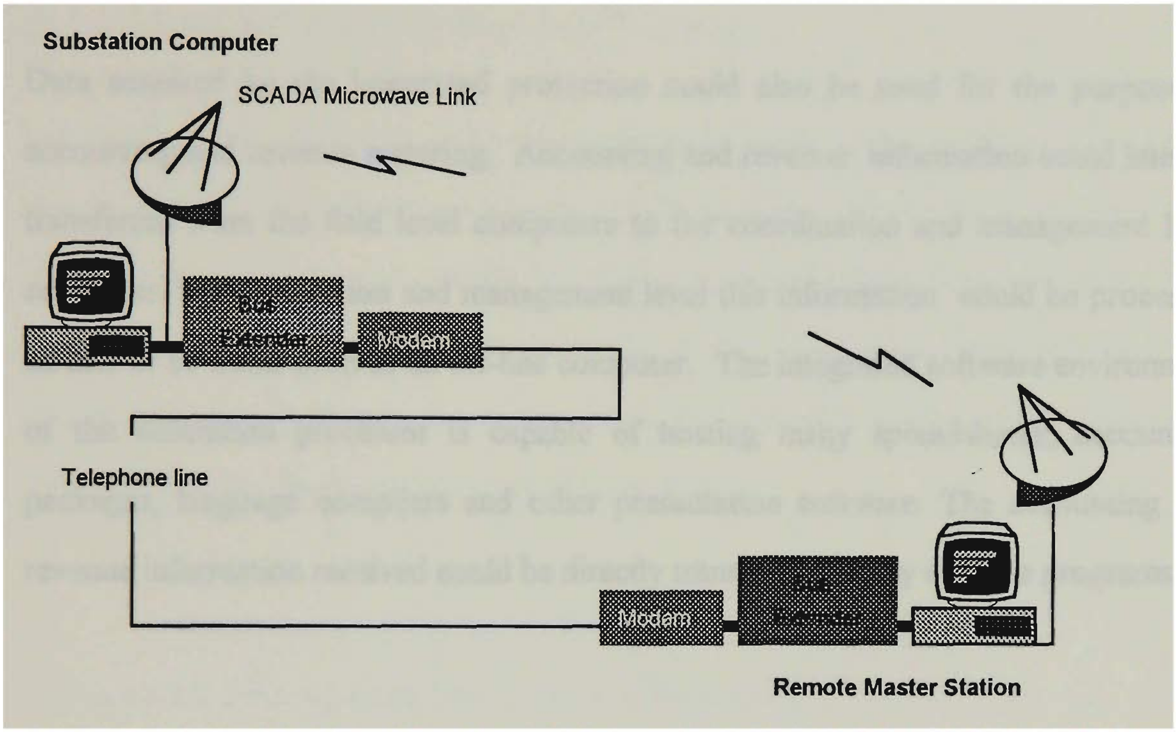


Figure 3.3 The extension of the GPIB of the System via a Telephone Line Connected to a Modem and the SCADA Link Connecting the Remote Master Station

3.6.4.3 Alarm Processing

Limit violations, equipment operations and failures, operator actions, alarm resets, are monitored and recorded. These records could be used to categorise the alarm events. Alarms could be executed either locally or be transmitted to a remote supervisory terminal. Any emergency situation could be highlighted by flashing lights in the VDU or by buzzer signals.

3.6.4.4 Accounting and Revenue Metering

Data acquired by the integrated protection could also be used for the purpose of accounting and revenue metering. Accounting and revenue information could later be transferred from the field level computers to the coordination and management level computer. In coordination and management level this information could be processed further or be transferred to an off-line computer. The integrated software environment of the substation processor is capable of hosting many spreadsheets, accounting packages, language compliers and other presentation software. The accounting and revenue information received could be directly transferred to any of these programs.

3.6.4.5 Data Logging

All recorded operating information could be formatted as binary, text or spreadsheet files and stored off-line on the disks. These data could be retrieved and could be used as source of:

- information to regenerate waveforms,
- do accounting and revenue calculations,
- analyse the transient events.

Any immediate records needed could be targeted to the printer.

3.7 Summary

(I) Integrated Systems Offer Improved Features

Integrated digital substation protection and control using digital technology is usually able to provide many functions that were not possible with the traditional systems. Evidently the functions and capabilities offered by a particular system will differ from the others and there could be a vast number of functions and services yielding from such application. Therefore, the focus of this research was on developing a low cost integrated substation protection and control system.

(II)Low Cost Development Uses Standard Products

A low cost application platform was implemented using standard software and hardware products. The developed system is capable of offering limited number of substation protection functions, but the system is open for improvement and addition of many other functions. Since standard products were used, same or similar techniques and approaches could be used in developing additional features. The detailed implementation of system necessities such as analog and digital data acquisition, waveform generation functions, analog and digital output functions, data communication and transfer functions, local area network implementation, etc., will be discussed in the subsequent chapters. along with The necessary hardware and software details are also investigated.

CHAPTER
FOUR

LOCAL AREA NETWORK

4.1 Introduction

The low cost integrated substation protection and control system uses a local area network (LAN) to communicate between substation protection and control units. The LAN used in this research was based on the standard Institute of Electrical and Electronic Engineers (IEEE) protocol. The type of the LAN used depended on the topology, communication media, media access protocol and the operating environment. In setting up the LAN, emphasis was placed to use standard products. This chapter focuses on how industry standard software and hardware products and protocols were used in setting up this LAN.

4.2 Overview of Networking

A network consists of two or more computers connected together via a communication media. Additionally these computers must have software running on them enabling computers to communicate with each other. Early networks had the standards unique to the developers of those networks and these standards were not entirely compatible [19][44]. In later years standards organisations (ISO) and the IEEE developed models that are globally recognised and accepted as the standard for designing computer networks. For the implementation of the integrated substation protection and control unit a network using the same reference model was considered as it is the current industry standard.

4.3 Open System Interconnection (OSI) Reference Model

In 1984, ISO developed the OSI reference model. This model which is now widely used in describing networking environments relates to the flow of data between the physical connection to the network and the end-user application. As shown in Figure 4.1 OSI layers are numbered from bottom to the top. Most basic functions, such as putting data bits into the network cable are on the bottom, while user application functions are at the top.

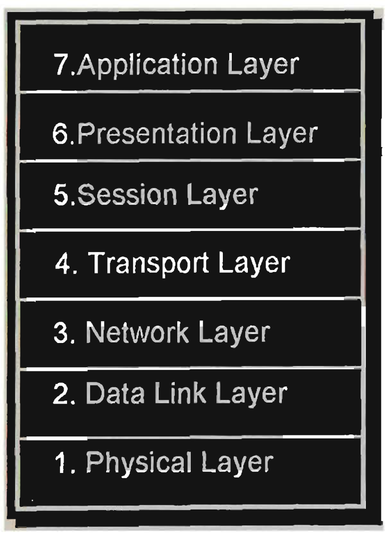


Figure 4.1 OSI reference model

4.3.1 Sending data through OSI reference model

OSI model regulates how data is passed from the end-user application to the network cable. As the data passes through the OSI layers, each layer wraps the data with layer specific information. Later this information, in the form of headers and/or trailers, is read by the corresponding layer on the receiving computer. Figure 4.2 [44] illustrates how each layer adds information to the data stream.

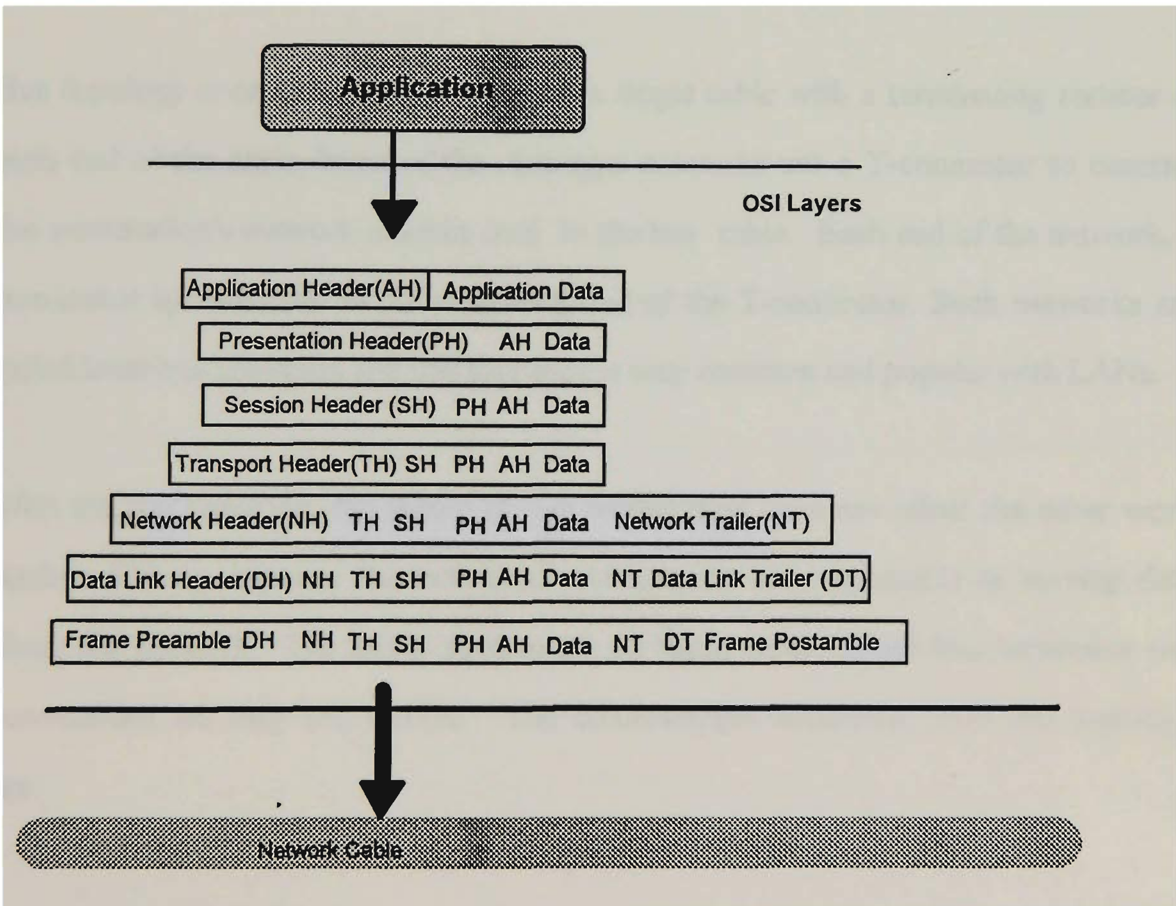


Figure 4.2 How each layer of OSI model contribute to data packet.

4.4 Network Topologies Considered

When considering a desired network topology for this thesis, an evaluation of the standard network topologies was conducted first. The advantages and disadvantages associated with each topology in general and specifically in relation to the project was determined. The outcome of this evaluation is given in following sections:

4.4.1 Bus Topology

Bus topology connects each computer to a single cable with a terminating resistor at each end of the cable. Most of the bus type networks use a T-connector to connect the workstation's network adaptor card to the bus cable. Each end of the network, a terminator is connected to the remaining end of the T-connector. Such networks are called local bus networks and this topology is very common and popular with LANs.

With the bus topology, the failure of one workstation does not affect the other work station. This is because the individual stations are not responsible in moving data along the network. The cables used to set up these networks are less expensive and connections are easy and flexible. The disadvantages associated with this topology are:

- the limited cable length and the number of stations that could be connected to the network,
- difficulties in locating the cabling errors,
- poor performance degradation.

4.4.2 Token-Ring Topology

Token-ring network consists of a ring of workstations connected to each other in a form of a loop. A 'token' is passed from one workstation to another and all the stations are centrally connected to a 'hub'. The token contains the address of the sender and the recipient. In a network using this topology, the cabling failures affect only a small number of users. All stations have equal access to the network. However, the costly cabling and connections is a definite disadvantage associated with token-ring networks.

4.4.3 Star Bus Topology

In a star type network, workstations are connected to a common connection called the 'hub'. Signal splitters are used in these network 'hub's' to send out signals in different directions. Unlike, in some other network topologies adding new stations to the star network is easy. Star topology provides central monitoring and management functions. Main disadvantage with this topology is that whenever the 'hub' is unserviceable the complete network is unable to function.

Table 4.1 summarises the advantages and disadvantages apparent to these three most popular network topologies taken into consideration for this project [44][19].

Once the merits and the demerits of these network topologies were carefully considered they were mapped with the objectives of the research. It was concluded that local bus topology was the best for this application. This decision was taken mainly considering substation control and protection architecture and the costs involved with the application.

Table 4.1 Summary of the feasibility of topologies considered

Network Topology	Advantages	Disadvantages
Bus Topology	Failure of a single workstation does not affect the entire LAN. New stations could be added without shutting the network down. Easy cable connections; flexible cabling. Inexpensive cable and connectors. Passive cables used.	Cable break can affect number of units. Difficult to isolate cabling errors. Performance degradation is not graceful. Collision is a problem at high loads.
Token Ring Topology	Cable failure affects only a small number of users. Equal access for all users. Graceful performance degradation.	Costly wiring and connectors. Terminals have to wait for the token.
Star-Bus Topology	Easy to add new units. Central monitoring and management.	Failure of the hub cripples the whole network.

Protection and control units of the substation need equal access to the network bus for optimum performance. Any information regarding fault occurrences must readily be sent to the other processors. With normal bus type networks, overloading conditions might occur due to too many stations trying to transmit at the same time. Since this network is going to be a dedicated network, only serving the control, protection and monitoring functions of the substation, it seem very unlikely that it will get extremely congested to result an overloaded condition.

Finally, a local bus type of network was considered to be satisfactory in terms of reliability and accessibility. From the cost point of view the local bus is outstanding; due to it's low implementation and maintenance costs.

4.5 Transmission Medium

There are many standard transmission media that is being used in LANs. Most popular among them are:

- coaxial cable,
- twisted pair cable,
- fibre optic cable.

The various transmission media that could be used in the physical layer of the network have different characteristics. These three media was compared with each other to find out the most feasible product for the base LAN cabling media of the integrated protection and control system.

4.5.1 Twisted-Pair Cable

This is the oldest and most common form of network transmission medium. A twisted pair consists of two insulated copper wires about 1mm in thickness twisted together in a helical form. These twisted pairs can be used for either analogue or digital transmission and the bandwidth usually depend on the distance travelled. A shielded twisted-pair cable is less subject to electrical noise and supports higher transmission speeds over long distances than the unshielded twisted-pair cable.

4.5.2 Coaxial Cable

Coaxial cables have two main types:

- baseband coaxial cable,
- broadband coaxial cable.

Baseband coaxial cable which is the 50Ω cable is used in digital transmission and the other which is the 75Ω cable is widely used in the analogue transmission.

Coaxial cable has a conductive centre wire surrounded by an insulating layer, a layer of wire mesh and a non conductive outer layer. This cable is resistant to interference and signal weakening than the other cables and is generally sought for noisier environments and longer distances. Further, they have better data transfer rates. Coaxial cable for networking comes in two popular types:

- Thinnet cable
- Thicknet cable

4.5.2.1 Thinnet Cabling

Thinnet refers to RG-58 cabling. RG-58 is a flexible coaxial cable about 1/4 inch thick, and is used for short-haul links. Thinnet could be connected directly to the network adaptor card's internal transceiver using a T-connector.

4.5.2.2 Thicknet Cabling

Generally Thicknet is used to connect several smaller Thinnets and serves as the backbone of several networks. Thicknet uses reasonably rigid coaxial cable about 1/2 inch in thickness and support greater data transfer rates. The network transceiver is directly connected to the Thicknet cable. Connection from Thicknet cable to the network adaptor card is done through a 'drop cable' (transceiver cable).

4.5.3 Fibre Optic Cable

Fibre optic transmission medium carry signals in a form of modulated pulses of light over ultra thin fibre glass or fused silica. The light source is either an Light Emitting Diode (LED) or a laser diode and the detector is a photo diode. There are two fibres per cable, one to transmit data and one to receive. Fibre optic cables are capable of achieving data transmission speeds up to 100 Mbps. Other most important advantage of fibre optic cables is their immunity to the electromagnetic noise. High costs involved to set up networks and the difficulty to tap the cable are the main disadvantages related to fibre optic cabling.

A summary of the relative merits and demerits of the above physical transmission media is given in the Table 4.2 [44][19].

Table 4.2 Summary of the feasibility of selected physical transmission media

Transmission Medium	**Advantages**	**Disadvantages**
Twisted Pairs	Least expensive. Widely used. Easy to add new units to the network. Existing telephone wires could be used to set up.	Low noise immunity. Distance and bandwidth limitations. Low security. Needs expensive support equipment.
Coaxial cable	Low installation and maintenance cost. Uses commonly available components. Simple to install and tap. Better noise immunity and data transfer rates.	Limited distance and topology. Difficult to change existing topology.
Fibre optic cable	Highest data transfer rates. No electromagnetic interference. Supports multi media. Low transmission losses.	Most expensive medium. Inflexible cabling. Lack of standard components. Requires special installation and maintenance. High set up costs.

When selecting the transmission medium for the integrated substations protection system the transmission media was assessed against the following criteria:

- ability support standard hardware and software,

- cost of components and accessories,
- installation and maintenance costs,
- ability to withstand Electromagnetic Interference (EMI).

Fibre optic cables provided the maximum noise immunity, security and highest data transfer rates. However, lack of standard components and extremely high set up costs prevented it being selected for the development.

Coaxial cables in other hand offered an attractive solution for the system's base LAN transmission medium with Thicknet cabling. With some extra shielding (double shielded) it was possible to withstand the abundant electromagnetic noise in the substation environment. Thicknet cables supported the selected local bus environment very satisfactorily. The ability to add new units to the existing bus using a simple T-connector in seemed to be another advantage in selecting this particular medium.

Ethernet based LAN was the ideal network protocol that supported both local bus topology and the coaxial cable physical transmission medium. Therefore, IEEE 802.3 protocol based Ethernet was selected as the base local area network architecture for the integrated substation protection and control system. However, if there is a need to upgrade this system to incorporate fibre-optic cable at later stage it is possible with minor modifications. The details of this possible upgrade will be discussed in the future work section at the end of this report.

4.6 Ethernet

Ethernet is based on bus architecture with 10Mbps data transmission rate. It uses Carrier Sense Multiple Access/Collision Detection (CSMA/CD) as the media access method. With CSMA/CD protocol, computers listen to the cable for a vacant period to transmit data. Multiple stations will be listening to the cable at the same time, hence it is called a CSMA. The method used to prevent collisions is the collision detection principle[44][19].

Ethernet is wired up in three different configurations :

- 10Base2 (Thinnet),
- 10Base5 (Thicknet),
- 10BaseT (Twisted Pairs).

10Base2 means that this network can transmit at 10Mbps over the Thinnet cable an approximate distance of 2×100 metres. Since the integrated substation protection and control system is based on Thinnet, it will be discussed broadly in the subsequent section.

4.6.1 10 Base2 Ethernet (Thinnet)

Thinnet is a one division of Ethernet which uses the thin RG-58 coaxial cable as the physical transmission medium. This cable can carry signals up to 185 metres without the presence of a repeater. The minimum cable length is 0.5 meters. Thinnet supports local bus topology extremely well. Unlike standard Ethernet, there are no drop cables in Thinnet. The physical medium is directly connected to the network transceiver in the network adaptor card of the computer through an inexpensive T-connector.

Thinnet is an inexpensive way of implementing standard Ethernet in a relatively small environment where not many nodes are needed. One Thinnet network can support about 30 workstations in cable segment with two terminators at each end. Thinnet specification used for the integrated substation protection system is shown on Table 4.3 [49].

Table 4.3 Specification of the Thinnet network used as the base local area network

Topology	Local bus
Cable type	RG-58
Impedance	50Ω
Terminator resistance	50Ω +/– 2Ω
Maximum cable segment length	185 meters
Minimum length between computers	0.5 metres
Maximum connected segments	5
Maximum computers per segment	30

4.7 Network Adaptor Card

Network adaptor card is a part of the network's physical layer. It moves data from and to the local computer by converting them in to analogue signals to fit into the network's cable medium. Network card should be properly configured before using it as the network accessing device for the computer. The three main configuration options available with the network adaptor cards are:

- interrupt,
- base I/O port address
- base memory address.

4.7.1 Interrupt Level

The network card will use the interrupt request line (IRQ) available in the computer to send a signal to the computer's central processing unit (CPU). Each auxiliary device of the computer uses a different IRQ line to inform the computer their need to communicate with the CPU. Usually the IRQ 3 or IRQ 5 is used as the desired IRQ line for the network adaptor card.

4.7.2 Base Input/Output Port

Normal Intel 8086 family of microprocessors use memory mapped input/output devices. This means that any data or information that has to be transferred to an I/O device are written to a particular address segment of the memory. This memory segment will act as a channel to pass the information to the specific I/O device associated with that address segment. Hence, the I/O device appears as an address to the CPU. This address segment is usually called the base I/O port of the device.

Each hardware device connected to the bus expansion slots of the computer must have a unique I/O port number. Some of the I/O port addresses are traditionally used by common auxiliary devices of the computer such as mouse or hard-disk controller. Therefore, it is important to configure the network adaptor card to an unused I/O port address to avoid conflicts with the other I/O devices.

4.7.3 Base Memory Address

Base memory address is the address in the computer Random Access Memory (RAM), through which computer exchanges data with the network adaptor card. This is the RAM starting address of the memory through which the computer shares information with the other computers of the network. Often for the network data exchange the base memory address is $D8000_{16}$. Usually this is referred to as D800 by omitting the last zero. While configuring the base memory address some attention must be given to the chunk of memory that is allocated for this purpose. Usually options are available for 8K, 16K or 32K RAM allocation, and will depend on the particular network adaptor card in use.

4.8 TE2000AD Network Adaptor

The network card used in the integrated substation protection and control system is Topware TE2000AD single-chip Ethernet card. Topware TE2000AD network adaptor card provides faster and easier options for network establishment and expansion. This is a single-chip Ethernet adaptor suitable for both twisted pair or thin Ethernet cable networks, which are the most popular Ethernet standards. Therefore with TE2000AD adaptor card it is possible to configure both 10Base2 and 10BaseT network configurations. This card is possible to be installed in either 8-bit or 16-bit XT or AT bus expansion slot. TE 2000AD performs true 8-bit or 16-bit transfer of data to and from the PC bus. This card is suitable for use in all IBM PC/AT and PS/2 model 30 and their compatibles.

4.8.1 Operational Features of the Network Adaptor Card

The particular network adaptor card that was used in this application offered many features that made it a standard product over many network configurations. Some operational features of this card are:

- full compliance with IEEE 802.3, 10BaseT and 10Base2 Ethernet standards,
- 10Mbps network data transfer rate,
- 100% compatibility with:
    i. Novell NE-1000,
    ii. Novell NE-2000,
    iii. Western Digital/SMC Ethercard Plus (WD8003E)
    iv. and Western Digital/SMC Ethercard Plus-16 (WD8013EBT)
- jumperless operation,
- software configuration options for:
    i. IRQ lines,
    ii. I/O base address,
    iii. boot ROM base address,
    iv. boot ROM size (8K, 16K, 32K, or 64K),
    v. cable type (twisted pair or thin coaxial).
- ability to be reconfigured even in the face of a configuration conflict,
- zero wait state operation,
- 10BaseT/10Base2 auto-detection,
- 10BaseT polarity autorecorrection,
- ability to store current card configuration and identification data in a simple data file,
- remote boot facility for diskless work stations,
- manchester encoder/decoder.

The network adaptor card specification is given in Table 4.4 [49].

Table 4.4 Network adaptor card specification

Network Type	Twisted Pair Thin Ethernet
Protocol	CSMA/CD
Standard	IEEE 802.3 10BaseT IEEE 802.3 10Base2
Network Compatibility	Novell NE-1000 (8-bit mode) Novell NE-2000 (16-bit mode) Western Digital WD8003E (8-bit) Western Digital WD8031EBT (16-bit)
Hardware Compatibility	Standard IBM XT or AT bus
Media Interface	RJ-45 (24-26 AWG) Twisted Pair Cable RG-58 Coaxial Cable
RAM Buffer	16K bytes shared I/O or shared memory 8K bytes shared I/O or shared memory
Data Transfer Rate	10 Mbps

4.9 Summary

A LAN is used to communicate between the protection and control units of the low cost integrated substation protection and control system. Local bus type network based on IEEE 802.3 Ethernet protocol was found to be a feasible solution. Thinnet coaxial cable was used as the transmission medium. The LAN was implemented using inexpensive and standard components. Data transfer rates of the LAN were adequate for the requirements of the integrated substation protection and control system. This LAN was fully compatible with the other software and hardware used in the project.

CHAPTER
FIVE

SYSTEM SOFTWARE

5.1 Introduction

The integrated substation protection and control system is based on number of standard software products. These software products were selectively chosen in order to ensure that:

- the development costs are minimised;
- the system could expand in future without any compatibility problems;
- and any product from different manufacturers could be integrated to the system at any instant.

This system was developed using three key standard software products:

- integrated software environment for the operating system interface, graphic user interface and multi-tasking capability;
- third generation instrument software for instrumentation, data acquisition and analysis and presentation;
- local area network software for control and the management of the LAN.

These products were selected carefully to have full compatibility with each other with no hassle in data exchange or control. As a result of this choice, the implementation of the integrated substation protection and control system became a manageable task. Fundamental system software development was made minimum. Software for direct hardware interface, to run a local area network or for GUI were not developed from very fundamentals. Due to this, significant savings on software development costs were achieved .

However, the quality of the GUI, reliability of the network operation, the accuracy of the instrumentation and control and the speed considerations of data acquisition and dispatch were implemented to a very high standard.

5.2 Integrated Software Environment

Microsoft Window 3.1 was used as the host software environment of the low cost integrated substation protection and control system. Windows environment was selected for it's multi-taking capabilities, object-oriented nature and user friendliness. Windows is the most popular high quality icon based graphical interface for MS-DOS (Microsoft Disk Operating System). By selecting Windows platform, it was possible to make permanent. or ad-hoc data links with other Windows-based applications easily. Data acquired by the integrated protection and control system was made available for Windows-based spreadsheets such as Microsoft Excel, or for language compilers such as C++, or for word processing packages. Data links or object linking and embedding was used to implement the aforementioned interactive processes.

5.2.1 Windows Environment and Main Components

Windows architecture usually consists of three main components:

- Windows Application Programming Interface (API),
- Windows core,
- Windows extensions and drivers.

The unique way these components are developed, enables the developer to use Windows API to write Windows-based applications without knowing their internal details. Windows applications developers need not to know about how Windows core routines work internally, or how Windows device drivers communicate with hardware. This unique feature makes the development of large software projects easy. Figure 5.1 [44] shows how the integrated protection and control system was implemented on the Windows platform. Additional network features shown in the figure belongs to the Windows for Workgroup software which was used as the backbone LAN.

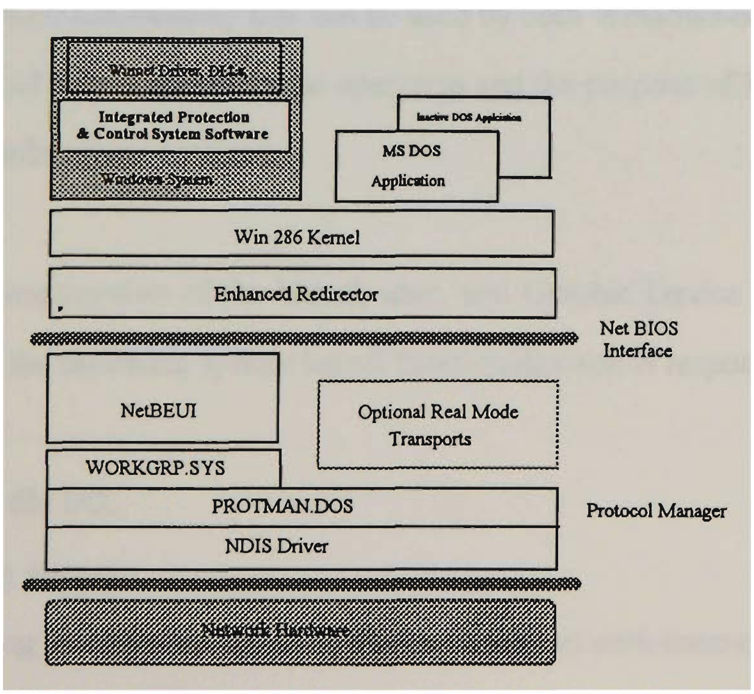


Figure 5.1. How software is implemented in Windows platform

5.2.1.1 Windows Application Programming Interface (Windows API)

Windows based applications use Windows API [44][48] to call routines present at the Windows core or Windows extensions. At the Windows Application Layer the calls to the Windows core and extension routines are independent of the hardware configuration of the computers and the associated devices. This was taken as an advantage to develop the integrated protection and control system software to function over a range of different hardware configurations.

5.2.1.2 Windows Core

The next layer is the Windows Core. This is the main functional area of the Windows environment. This layer consists of the operating system kernel and the operating system support routines. Extensions to the Windows environment are also present in this layer. Windows extensions are provided in the form of Dynamic Link Libraries (DLLs) and provide functionality that can be used by both Windows-based applications and by elements of Windows itself. The operation and the purpose of having DLLs will be explained in subsequent sections.

The Windows core consists of the kernel, user, and Graphic Device Interface (GDI). Kernel provides the operating system kernel functionality and is responsible for:

- handling file I/O,
- managing memory,
- performing system task scheduling in the Windows environment.

The version of Kernel used for standard mode and 386 enhanced mode depends on the processor type used by the particular computer. It also is dependent on the amount of memory installed. User is responsible for:

- handling user input and output,
- managing the keyboard, mouse, sound driver,
- managing communication ports,
- managing and keeping track of elements of the user interface that includes the components such as Windows, icons, menus and dialogue boxes.

The GDI manages the drawing of graphic primitives, manipulating bitmaps and handling interaction with the device-dependent drivers layer including display and printer output devices.

5.2.1.3 Windows Extensions

Windows extensions include additional support routines for supporting common functionality universal to all Windows-based applications. Standardised dialogue boxes for common user interface operations are supported by the common dialogues' extension, a high level way for managing Dynamic Data Exchange (DDE) sessions. DDEs are used in the integrated protection and control system as a vehicle to transfer data from one computer to another over the network using Network Dynamic Data Exchange (NDDE) facilities. DDE sessions are supported by DDE Management Library (DDEML). DDEs are supported by another library which provides services for applications to support multi-media functionality. Playing and recording audio with waveform and Musical Instrument Digital Interface (MIDI) audio devices are supported by the multi-media systems extensions.

5.2.1.4 Windows Device Drivers

Windows device drivers are the lowest layer of the Windows environment. It consists of the device drivers that tell Windows how to communicate with a particular hardware device. These hardware devices could be a display adaptor, printer, network adaptor device or an audio device. For example, a video display driver tells Windows how to manipulate bits on a video adaptor card to display images. Another example is a mouse driver that tells Windows how to interact with the mouse to detect when the mouse is moved. Standard hardware device drivers are built in to Windows. Any additional drivers for hardware devices are written by their manufacturers and supplied with the relevant hardware devices.

5.2.2 Dynamic Link Libraries (DLLs)

Many Windows components are written as DLLs. A DLL is an executable file that enables applications to share code and the other resources needed to perform particular tasks. Therefore, Windows software developers could extend the Windows environment by creating relevant DLLs that provides code and routines to perform desired operations. These customised DLLs could be made available to other Windows developers and other Windows based applications. There would be no compatibility problems in data structures and coding. DLL can appear with .DLL extension or with .EXE extension. DDEML.DLL, SHELL.EXE, KERNEL.EXE, USER.EXE are some examples of the DLLs available in Windows. DLLs provide code, data or routines to applications running in the Windows operating system.

There are two mechanisms available for telling an application program how to interact with a software function library:

- static binding
- dynamic binding

Static binding is used to interact when a software developer wants to incorporate software routines into the application program but keep the function routines internal to the program. In other words the software functions are only available to application that contains the library. When the software developer creates the final executable program the language linker statically resolves the function calls in the main application program. Function routines in the function library are used for this purpose. This happens only at the time the executable program is being built.

Dynamic binding is the other mechanism for telling application programs how to interact with a software function library. In dynamic binding the function call references in main application program are dynamically resolved with the function routines in the functions library. This is done at the time the application program is running. Each and every time the application program runs, this process takes place. Windows uses dynamic binding to tie function references in a Windows-based application programs to functions in a DLL.

Another advantage of having DLLs is the way it interacts with the Windows environment. Windows will only load into memory components of the function library that is required at a given time. When the application that called the DLL function is finished with the function, Windows may remove from memory the components of the DLL that it doesn't need. In the case of developing the integrated substation protection and control system these built in memory management facilities have been very useful for the optimisation of the operating speed of the system. However, the memory management of the system was transparent to the actual software development.

5.3 Operating Modes

Windows 3.1 support two operating modes;

- standard mode
- 386 enhanced mode.

The default operating mode is determined by the computer's hardware configuration, the amount of memory and any start up switches specified. The integrated substation and protection unit is based on the normal Windows functionality that ensures the auto detection of the operating mode of the particular station. An overview of these modes and their inter-activity with the software and hardware is looked at in the following sections:

5.3.1 Standard Mode

Windows standard mode require a computer with an 80286 processor or higher. This mode provides access to extended memory for Windows-based applications. Windows does not use virtual memory in this mode. MS-DOS-based applications run in full screen rather than in windows.

In standard mode, Windows does not provide the ability to multi-task with MS-DOS-based applications. When an MS-DOS-based application is invoked, Windows program swaps the components that resides in conventional memory to disk in order to allow the MS-DOS based application to run. Any running Windows-based applications are suspended. When the user switches back to the Windows environment, Windows program loads its components back from the disk and resumes running any Windows-based applications that were previously running.

5.3.2 386 Enhanced Mode

Intel 80386 or higher processor with a minimum 3MB of memory is needed to run the Windows or Windows for Workgroups (the network software tool used in the project) in 386 enhanced mode. In order to support the network functionality, the memory requirements will be slightly higher than that required by Windows 3.1.

Windows for Workgroups terminal running in 386 enhanced mode can act as both client and a server in the network. Therefore it can both access and share resources. A network terminal in 386 mode can also use the NDDE functionality provided with Windows for Workgroups to access and share information with remote terminals. Integrated substation protection system uses NDDE functions to exchange data between the terminals. Windows for Workgroups running in 386 enhanced mode takes advantage of the Windows 3.1 architecture and implements many of its networking components as virtual device drivers (VxD).

5.4 Virtual Device Drivers (VxD)

A VxD is a 32-bit, protected mode, dynamic link library that manages a system resource, such as a hardware device or installed software. This enables more than one application to use the resource at the same time. The term VxD is used to refer to a general virtual device driver, where x represents the type of device driver. For example, a virtual device driver for a display device known as a VDD. Windows running in 386 enhanced mode uses virtual devices to support multi-tasking for MS-DOS applications. Virtual devices work in conjunction with Windows to process interrupts and carry out I/O operations for a given application without disrupting other applications.

Virtual device drivers support all hardware devices for a typical computer. This may include:

- the programmable interrupt controller (PIC),
- timer,
- direct memory access (DMA) device,
- disk controller,
- serial ports,
- parallel port,
- keyboard device,
- math co-processor,
- display adaptor.

A virtual device can contain the device specific code needed to carry out operations on the device. A virtual device is required for any hardware device that retains data over any period of time. In other words, if the state of the hardware device can be disrupted by switching between multiple applications, the device must have a corresponding virtual device. The virtual device keeps track of the state of the device for each application and ensures that the device is in the correct state whenever an application continues.

Although most virtual devices manage hardware, some manage only installed software, such as the NI-DAQ virtual software device driver used in the integrated substation protection and control project. This NI-DAQ virtual device driver is a custom software tool from National Instruments[46]. It is a powerful application programming interface between the user application and the National Instruments' data acquisition adaptor boards for Interface System Adaptor (ISA), Extended Interface System Adaptor

(EISA) and Micro channel bus computers. The details about this virtual device driver will be explained later in the chapter on data acquisition and control.

Software device drivers such as above are usually terminate-and-stay-resident programs. Such virtual devices often contain code that either emulates the software or ensures that the data is applied only to the currently running application. ROM BIOS, MS-DOS, MS-DOS device drivers, and terminate stay resident programs provide driver specific routines and operating system functions. These routines and functions are used by applications to access the hardware devices indirectly. Virtual devices are sometimes used to improve the performance of installed software.

5.5 Local Area Network Software

Second major software product used in the low cost integrated substation protection and control system was the software used to run the base local area network. The software product used in this case was the Windows for Workgroups 3.1. Windows for Workgroups architecture builds on the architecture implemented in Windows 3.1 by providing integrated network functionality in the base operating system. The incorporation of networking components in Windows for Workgroups helps to define a standard platform for stations in the network to communicate and exchange information.

The Windows for Workgroups network functionality is based on the following components:

- Protocol Manager (PROTMAN.DOS)
- NDIS-compatible network adaptor card driver

- Workgroups driver (WORKGROUP.SYS)
- NetBEUI transport protocol
- NETBIOS interface
- Network redirector
- Windows for Workgroups Winnet driver
- Windows for Workgroups Server virtual device driver

The implementation of the Protocol Manager, the NDIS network adaptor card driver, and the Workgroups driver is the same whether running Windows for Workgroups in standard mode or 386 enhanced mode. In order to start the network software and to bind the real-mode network drivers, the 'net start' command needs to be entered before starting the Windows for Workgroups.

5.5.1 Network Device Interface Specification (NDIS)

The second layer of the Open System Interconnection (OSI) model is divided into two sub layers by the IEEE project 802 - Media Access Control (MAC) and Logical Link Control (LLC). Device drivers at these sub layers move data received in the physical layer by the network adaptor card. Finally this data is passed up the other OSI layers to the destination application.

MAC driver which is a device driver located at the MAC sub layer provides the low-level access to the network adaptors. This is achieved by providing data transmission support and some basic management functions. These MAC drivers are usually known as network adaptor card drivers.

NDIS is a standard defining an interface for communication between the MAC layer and the transport protocol drivers that resides on layers 3 and 4 of the OSI model. NDIS allows for a flexible environment for data exchange. It defines the software interface called NDIS interface used by the network transport protocols to communicate with the network adaptor card.

NDIS is flexible due to standardised implementation used in the network industry. Any protocol that conforms to the NDIS standard can pass data to any another NDIS conferment MAC driver, and vice versa. A process called binding is used to establish the initial communication channel between the protocol manager and the MAC driver, and vice versa.

5.5.2 Protocol Manager

The software driver that is used to bind the MAC and the transport protocols is called the Protocol Manager. NDIS version used by the Windows for Workgroups allows a single computer to have as many as four network adaptor cards installed. Each network card can support a maximum of four protocols, with no more than eight protocols supported in a computer.

Supporting more than one protocol driver on a single network card gives simultaneous access to different type of network servers, each using different transport protocol. Using this adaptor card it is possible to MS LAN Manager and Novell netware server simultaneously. The protocol Manager differentiates between the multiple protocols and MAC drivers, routing incoming network requests to the appropriate driver.

5.5.3 Network Protocols and Transports

The packaging and routing data and application messages in the Network and Transport layers of the OSI model is called a protocol. A protocol driver sometimes manages all functions through the Transport layer using one protocol. These protocols do not need to bind a separate MAC drivers to the internal network adaptor card driver. Network transports that conform to NDIS require an NDIS compliant network adaptor card driver to provide support for MAC layer communication. Topware TE 2000AD network adaptor card used in the integrated substation protection and control system was completely NDIS conferment. Hence, there was no need for an extra hardware for the MAC layer communication.

The protocol organises the network data. Further it defines how data should be presented to the next receiving layer, and packages data accordingly. It passes data to the MAC layer, and to the application layer through the session layer interface located at the session layer, as shown in Figure 5.2.

5.5.4 NetBIOS Extended User Interface (NetBEUI)

NetBEUI is a small and efficient protocol designed for use on small networks of up to 200 nodes. This is the primary protocol used by the Windows for Workgroups which is the networking backbone of the integrated protection and control system. Networks using this protocol could be extended by including gateways. With gateways it is possible to communicate with different types of networks.

This NetBEUI protocol has powerful flow control and most robust error correction and detection. It is small and efficient and supports high data throughput rates.

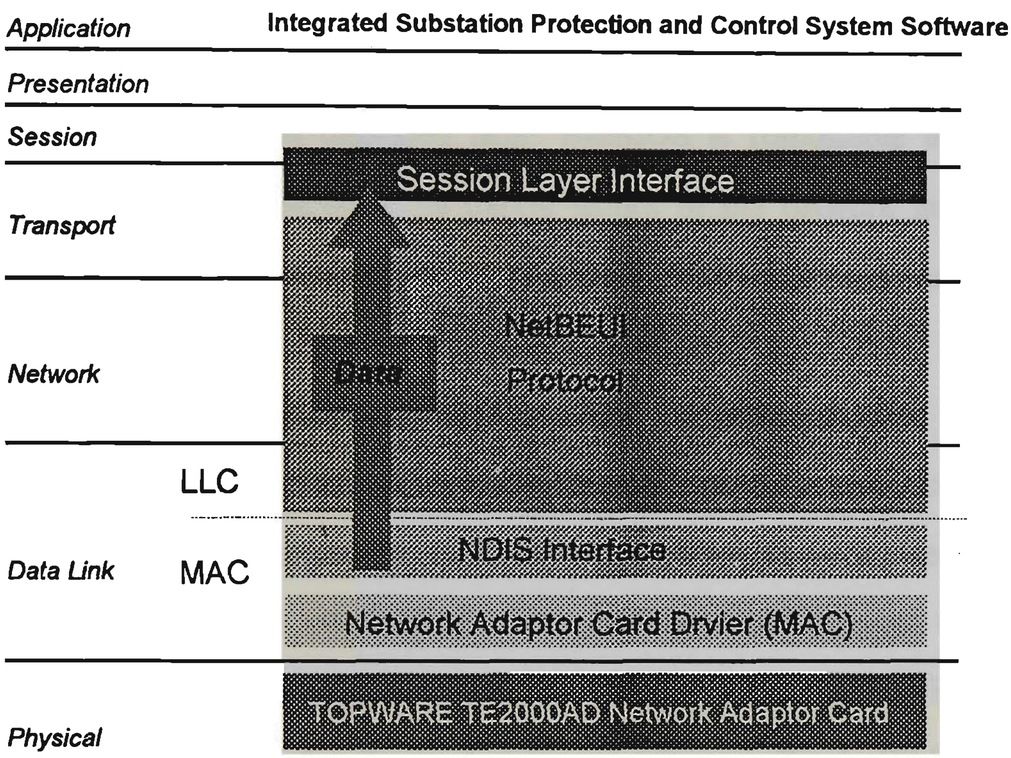


Figure 5.2 How data is sent between the application through different layers and NDIS interface

5.5.5 Communication Between Network Transports and Software Application

To conclude the discussion of how the network software of the integrated substation protection and control system relates to the OSI model, attention is drawn in this section on the Session, Presentation and Application layers. These three layers support communication between applications on different computers by defining data exchange formats, and providing application support services.

5.5.5.1 Network Basic Input/Output System (NetBIOS)

NetBIOS is a high-level interface used by applications to communicate with NetBIOS complaint transports such as NetBEUI. An example of a NetBIOS application is the network redirector that is discussed later. NetBIOS is responsible in establishing connections or sessions between the logical names of the network and supporting reliable data transfer between computers that have established connections.

NetBIOS uses a unique logical name to identify a network node for handling communications between nodes. Communications between networked computers can also be in the form of conversation. Such two-way communication between computers is carried out by NetBIOS by establishing a logical connection between them. Once a logical connection is established, the computers can then exchange data in the form of NetBIOS requests or in the form of a Server Message Block (SMB). Network Dynamic Data Exchange functions used to send and receive data between the field level computers and the substation processors in the integrated substation protection and control system is an example for such connections and will be discussed in following sections.

5.6 Dynamic Data Exchange (DDE)

Generally Windows uses two mechanisms to exchange data between Windows-based applications. They are;

- clipboard transfers
- dynamic data exchange

Integrated substation protection system was built in the Windows environment and one of the above techniques has to be used to exchange data between the terminals. The criterion in selecting the most appropriate method of data transfer was:

- the ability to transfer data to the remote terminals
- the ability to implement permanent data links between the applications.

In the requirement point of view it was understood that the Windows DDE offered a far superior facility than the clipboard transfers.

The Windows DDE protocol is a standard for the exchange of data between Windows based applications. This protocol enables the applications to exchange data by means of Windows messages.

DDE identifies the units of data that is passed between the client and server applications by using a three level hierarchy of application, topic and item names. Each DDE conversation is uniquely defined by the application name and topic. At the beginning of the conversation the client and server determine the application name and topic. The application name is usually the name of the server application or the name of the application at the sending terminal.

A DDE data item is the information related to the conversation topic that is exchanged between the applications. These values can be transferred to and from the server to the client. Data can be passed with any of the standard clipboard formats or with a registered clipboard format. A special clipboard format named Link is used to identify the items in a DDE conversation.

5.6.1 Permanent DDE links

Once a conversation has been established, the client machine can establish one or more permanent data links with the server. A data link is a communication mechanism between the server and client which notifies the client whenever the value of a given data item changes. This process continues until the until the data link or the DDE conversation itself is ended.

5.6.2 Dynamic Data Exchange Messages

Because DDE is message based protocol, it employs no special Windows functions or libraries. All DDE transactions are conducted by passing certain defined DDE messages between the client and server windows. In LABVIEW, these messages are embedded to the system so it possible to initiate a conversation, update a link, send data on request and many other DDE operations. These messages play a major role in sending and receiving data between the substation terminal and the field level terminals. However so far it was not discussed how the message flow could be maintained through the network between terminals. A special function called Network Dynamic Data Exchange or NDDE, is used for this purpose. Details of NDDE is discussed in the next section.

5.6.3 Network Dynamic Data Exchange

Network DDE uses same DDE functions and extends it over the network to facilitate the data links to remote stations. The Network DDE consists of the Network DDE application, the Network DDE driver, Network API library, Clipboard Viewer and Clipbook Server.

Network DDE is implemented as a Windows-based application that runs in the background of the Windows for Workgroups workstation, and is loaded by the Windows for Workgroups network driver at the start up. Network DDE is not visible to the user.

Network DDE driver uses NetBIOS to communicate with remote stations over a transport protocol such as NetBEUI, and establish a Network DDE conversation. This process is shown in Figure 5.3

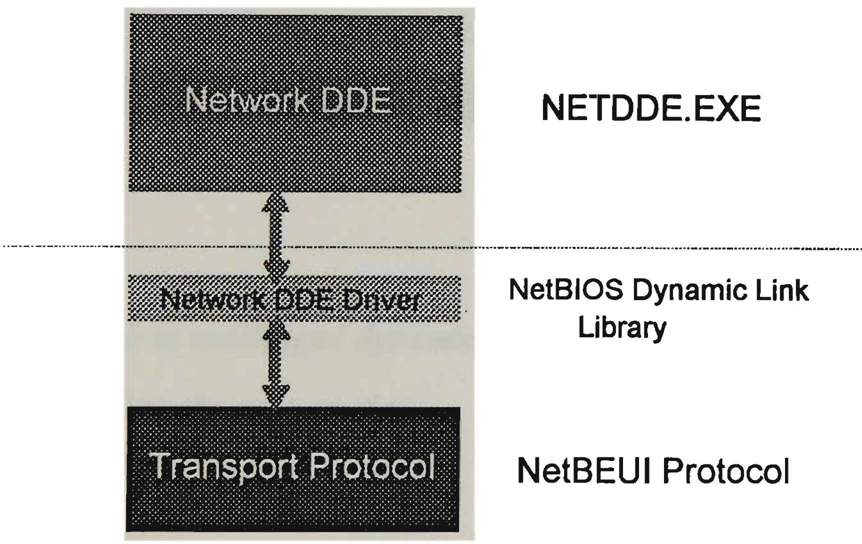


Figure 5.3 Relationship of Network DDE to the Network DDE driver and the transport protocol

Network DDE uses object linking and embedding to establish a conversation between the local workstation and the client application. This will establish a dynamic

Network DDE link between the client application running on the local workstation and the server application running on the remote workstation as shown in the Figure 5.4.

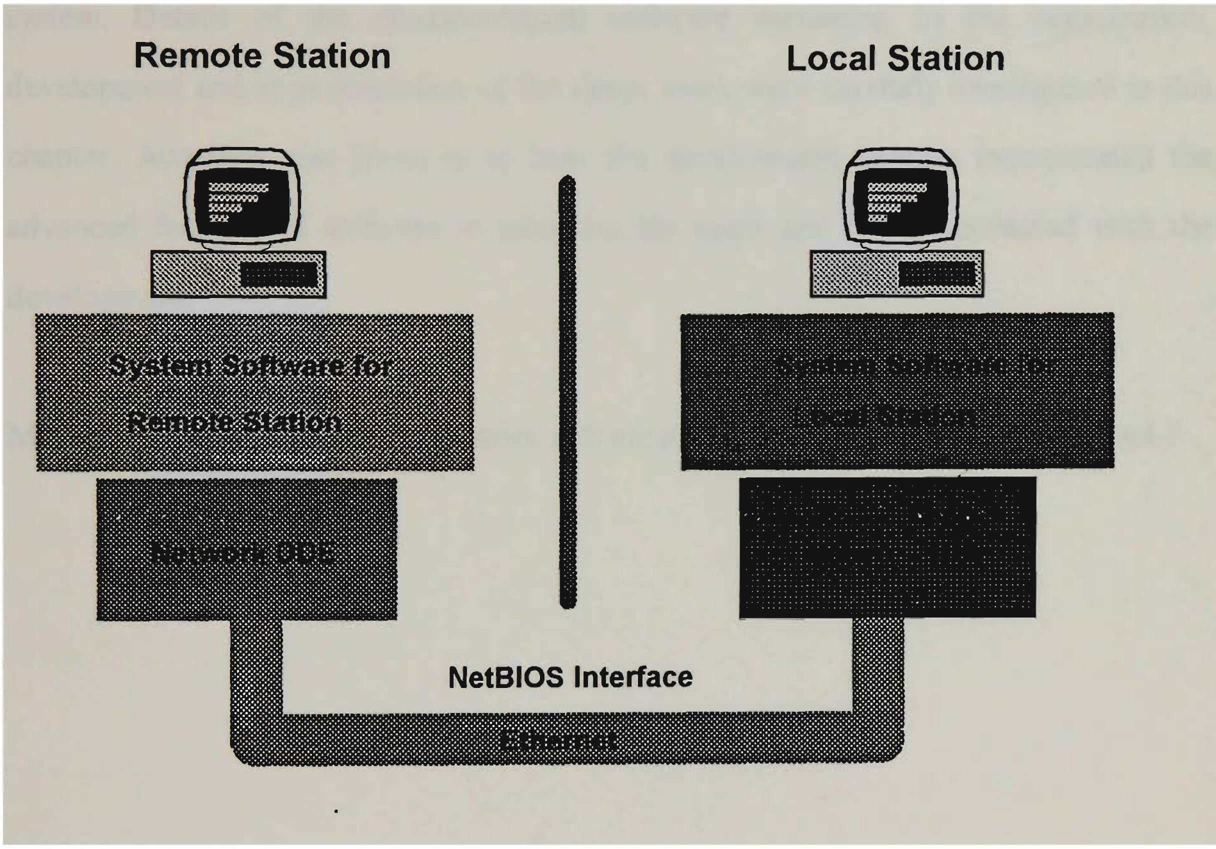


Figure 5.4 How data is exchanged dynamically between the remote stations after establishing the conversation

5.7 Summary

Three standard software products were used to develop the low cost integrated substation protection and control system. These products were:

- an integrated software environment,
- LAN software,
- instrumentation software.

Inter-operability of these software, their high quality and dependability enhanced the performance of the developed low cost integrated substation protection and control system. Details of the aforementioned software pertaining to the organisation, development and implementation of the thesis work were carefully investigated in this chapter. Attention was given as to how the development process incorporated the advanced features of software to minimise the costs and time associated with the development.

More details about the instrumentation software will be discussed in chapters 6 and 7.

CHAPTER

SIX

DATA ACQUISITION AND CONTROL

6.1 Introduction

Data acquisition and control is one of the major important areas of the integrated substation protection and control system. The analog signals from the substation protection and control units are monitored through current or voltage transformer. These signals are then fed to the data acquisition cards connected to the computer. The data acquisition unit used in the project is the National Instrument LAB PC+ card. This card along with virtual software device driver NI-DAQ provide a strong platform for data acquisition and control. When the control signals are needed to pass over to the relevant protection and control units same card could be used as it provides both input and output facilities. The signals acquired this way could be processed locally for the local decision making or could be transferred over the network to the substation main computer for further processing. In this chapter the attention is given to the software and hardware involved in the data acquisition and control process. Further, details of construction and implementation of these units are closely looked onto.

6.2 Software Device Driver for Data Acquisition

The software device driver used for data acquisition and control was the National Instruments' NI-DAQ version 4.3 [46]. This is powerful application programming interface between the data acquisition application and the National Instruments data acquisition boards used in ISA, EISA and Micro channel bus computers. This device driver allows the application to be written in any of the high level languages; Microsoft or Borland C, Pascal or BASIC languages and run it under DOS or Microsoft Windows. DOS languages include Microsoft Quick BASIC, professional BASIC, Microsoft C, Turbo C, Turbo C++, Borland C++ and Turbo Pascal. Windows languages include Visual Basic, Turbo Pascal, Borland C++, and Microsoft SDK. The NI-DAQ for DOS/Windows software also includes test and measurement utility.

With NI- DAQ there are many functions available. They are software routines that perform specific tasks using the data acquisition boards. These functions include:

- data acquisition,
- board configuration,
- initialisation and utilities,
- single and multiple point analog inputs,
- simultaneous sample/hold using single scanning and multiple scanning techniques,
- analog output functions with single and multiple point output,

- waveform generation,
- digital input and output,
- counter and timer functions.

As explained in the previous chapter on software NI-DAQ is a virtual device driver in the Windows and DOS domain which was used as an interface between the data acquisition and control cards and the software used in the integrated substation protection project. Figure 6.1 [44] explains the NI-DAQs role in the integrated substation protection and control implementation.

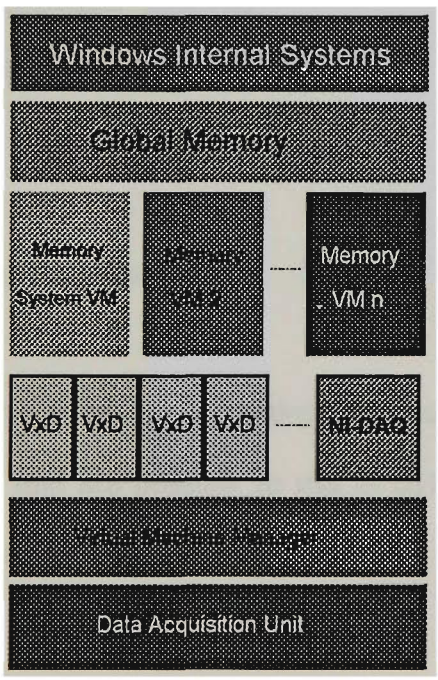


Figure 6.1 Use of virtual software device driver as the software interface between the data acquisition card and the Windows based software environment.

6.2.1 Initialisation and Utilities

The initialisation/utilities class of functions were used for:

- board initialisation,
- timeout configurations,
- establishing master-slave relationship,
- retrieval of board configuration information,
- adjustment of the usage of interrupts and DMA to transfer data,
- aligning data in the buffer to avoid physical DMA page boundary,
- establishing hysteresis trigger window,
- retrieving the NI-DAQ library version number.

6.2.2 Board Configuration Functions

These functions are used to perform calibration and configuration of the various National Instrument boards that are possible to use as data acquisition devices. Each function panel is specific to a single type of a board.

6.2.3 Analog Input Functions

Analog inputs used in the data acquisition boards were treated as:

- single point inputs
- multiple point input.

Usually, this choice is dependent on the type of the input required and the rate they were acquired at. For example to acquire a waveform, multiple input functions were needed whereas to acquire a relay contact setting a single point input was sufficient.

6.2.3.1 Single Point Inputs

Single point functions perform analog to digital conversions of a single sample. This class of functions have all the functions to perform analog input functions. These functions were used to:

- measure voltage,
- clear analog input,
- read analog input as a binary,
- scale binary to voltage,
- set up, check and configure analog inputs.

All these functions were grouped under one class of functions and used for the single point input operations only.

6.2.3.2 Multiple Point Inputs

These functions will perform clocked, buffered multiple analog to digital conversions typically used to capture waveforms. They could be classified as:

- high level functions
- low level functions.

High level functions are used for synchronous acquisitions. In synchronous acquisitions the application is frozen till the required number of acquisitions are performed. With high level functions in the multiple point category, the provisions are made for acquisition of both single channel inputs and multi channel inputs. Scanning single channels to disk, and multiple channels for disks were also provided.

Low level functions on the other hand are asynchronous. This means that the applications continue to run while the analog to digital conversions are performed in the background. These low level functions also offer double buffering for the needy cases. The functions provided by the low level functions include:

- setting up and starting scan,
- starting data acquisition,
- checking data acquisition or scan,
- monitoring data acquisition or scan,
- clearing data acquisition or scan,
- reordering scan
- scaling data acquisition or scan

Enabling functions provided by the low level functions are:

- configuring data acquisition and pre triggering
- enabling double buffering
- Status checking of the half buffer,
- half buffer to array functions
- half buffer to string functions

6.2.4 Simultaneous Sample/Hold Functions

These functions could be used in the boards with simultaneous sample and hold architecture . The functions offered here could be classified as:

- single scan functions
- multiple scan functions.

Here again single scan subclass contains functions that acquire just one scan of analog input data. Multi scan functions refers to the functions that perform clocked, buffered multiple-scan analog to digital conversions.

Functions offered under the single scan subclass include:

- selection of AC or DC coupling,
- setting up multiple channel inputs,
- enabling and disabling selected inputs,
- reading, scaling and clearing multiple channel analog inputs,
- selecting the trigger and setting trigger delays,

Multiple scanning functions are used for:

- setting the scan rate
- Setting up, starting, reading, checking, stopping and clearing inputs

6.2.5 Analog Output Functions

This class of functions contain all the functions that perform digital to analog conversions. In this class the functions are further classified as single point functions and waveform generation functions.

6.2.5.1 Single Point Output

Single point functions in the analog output class are:

- generating a particular analog voltage for the corresponding digital value,
- scaling voltage to a binary value,
- writing analog binary values,
- updating analog digital to analog conversions,
- configuring the analog output to the required output range,
- selections of the polarity for each analog output channel.

Single point analog functions are useful in cases such as measuring the setting of an overcurrent relay.

6.2.5.2 Multiple Point Output

With multiple output functions generate buffered analog outputs. Buffered analog outputs make it possible to generate waveforms. Two main sources of digital information to generate waveforms could come from two main sources. These two sources are:

- from a digital array
- from disk containing digital information.

A range of low level functions are also provided with multiple point outputs, to control and scale the properties of the generated waveforms. Some of those functions are:

- scaling the waveform buffer,
- converting the waveform rate,
- loading the waveform buffer,
- checking the waveform channel.

In addition to these functions low level functions control the waveform generation. Those functions include:

- assigning one or more analog output channels to a waveform generation group,
- transferring new data from a character buffer to waveform buffers
- enabling double buffering,
- pausing and resuming the waveform channels,
- checking half buffer ready status,

- copy binary arrays to waveform buffer,
- copy string arrays to waveform buffer.

6.2.6 Digital Input/Output Functions

These functions are designed to perform digital input and output operations. There are two subclasses in this group. Group mode contain the functions for handshaked digital input and output operations. Block Transfer is the other subclass which contain functions for either handshaked or clocked, buffered or double buffered digital input and output operations.

6.2.6.1 General Digital Functions

General digital functions available in the system are:

- port configuration functions,
- line configurations functions,
- read and write functions form the port and to the port,
- read and write functions from line and to line,
- port status check function which returns a status word indicating the handshaked status of the specified port.

6.2.6.2 Group Mode Functions

The group mode digital/input output functions perform handshaked input/output on groups of ports. They can be used to configure, read and write group of ports, to halt ongoing asynchronous transfers and to initiate new asynchronous transfers.

Another subclass of functions are available under the group mode functions for block transfer. They handle the read, write, check and clear operations of block transfers. Additional functions are available to set up pattern generations and to set up digital scanning. Control and enable functions available for group mode and block transfers are:

- double buffer enabling function,
- half buffer check function transfers from array and string,
- transfer to arrays and string.

6.2.7 Counter and Timer Functions

Counter and Timer functions provide the necessary counting and timing functions for data acquisition and control. For PC based data acquisition systems interval counters are also provided. The functions available in this group can do the following:

- set the output of the selected counter to a specified state,
- return the current contents of the selected counter without disturbing the counting process and returns the count,
- period or pulse width measurement,

- convert frequency and duty-cycle values of a desired square wave into the time-base and period parameters needed to produce a square wave,
- starting, stopping, restarting, and reading the counter,
- counting events and periods are also provided.

Interval counter functions available for PCs provide facilities to set up, read and reset interval counters.

Overview of the all functions available for data acquisition and control are shown in the function tree given in Appendix A [47].

6.3 Data Acquisition Hardware

Hardware device used for the data acquisition and control in this project was the National Instruments LAB PC+ low cost multi-function input/output board. This board is specifically designed to be used in IBM PC/XT/AT computers and their compatibles and IBM PS/2 models 25 and 30 computers. The LAB PC+ contains a 12-bit successive approximation analog to digital converter with eight analog inputs which can be configured to eight single ended and four differential channels. It has two 12-bit digital to analog converters with voltage outputs, 24 lines of TTL compatible digital input/output, and 6 counter/ timer channels for timing input/output.

This low cost system was used to acquire signals through current or voltage transformers from substation protection and control equipment. It was also used to deliver necessary control signals to solid state relays and other protective gear. The multi-channel analog input has been very useful in acquiring multiple point signals such as waveforms for transient analysis, and data logging functions. The 12-bit analog to digital converter was used for precision measurements related to alarm functions, and DC voltage measurement.

The analog output channels are useful in generating experimental waveforms and also in delivering control signals to substation protection gear. Analog outputs were used for function generation in some occasions. The 24 TTL compatible digital input/output lines were used for switching devices and solid state relays. Further they were used for the purpose of reading the status of external digital devices and generating interrupts.

To synchronise the operations the counter/timer was used. They were further used to generate pulses, and measure frequency and time. In general, this data acquisition unit provided a versatile, cost effective platform for the data acquisition and control needs of the integrated substation protection and control system.

Using the NI-DAQ software device driver with this data acquisition unit it is possible to develop software for LABVIEW for Windows or LABWindows for DOS. NI-DAQ provides an application program interface between the data acquisition unit hardware and the development software. This makes the tedious operations of controlling hardware, transparent to the software programmer. Additionally, NI-DAQ will enable the user to modify the developed system or add any extra modules to the present integrated substation protection and control system with minimum difficulty.

Same data acquisition unit could be used with another products by National Instruments to control data acquisition hardware. Aforementioned products can place data directly into a Lotus 1-2-3 or Symphony spreadsheets.

6.3.1 Principal of Operation

Data acquisition unit consists of following components:

- personal computer input/output circuitry,
- analog input and data acquisition circuitry,
- analog output circuitry,
- digital input/output circuitry,
- timing input/output circuitry.

The functional block diagram of the unit is shown in Figure 6.2 [47].

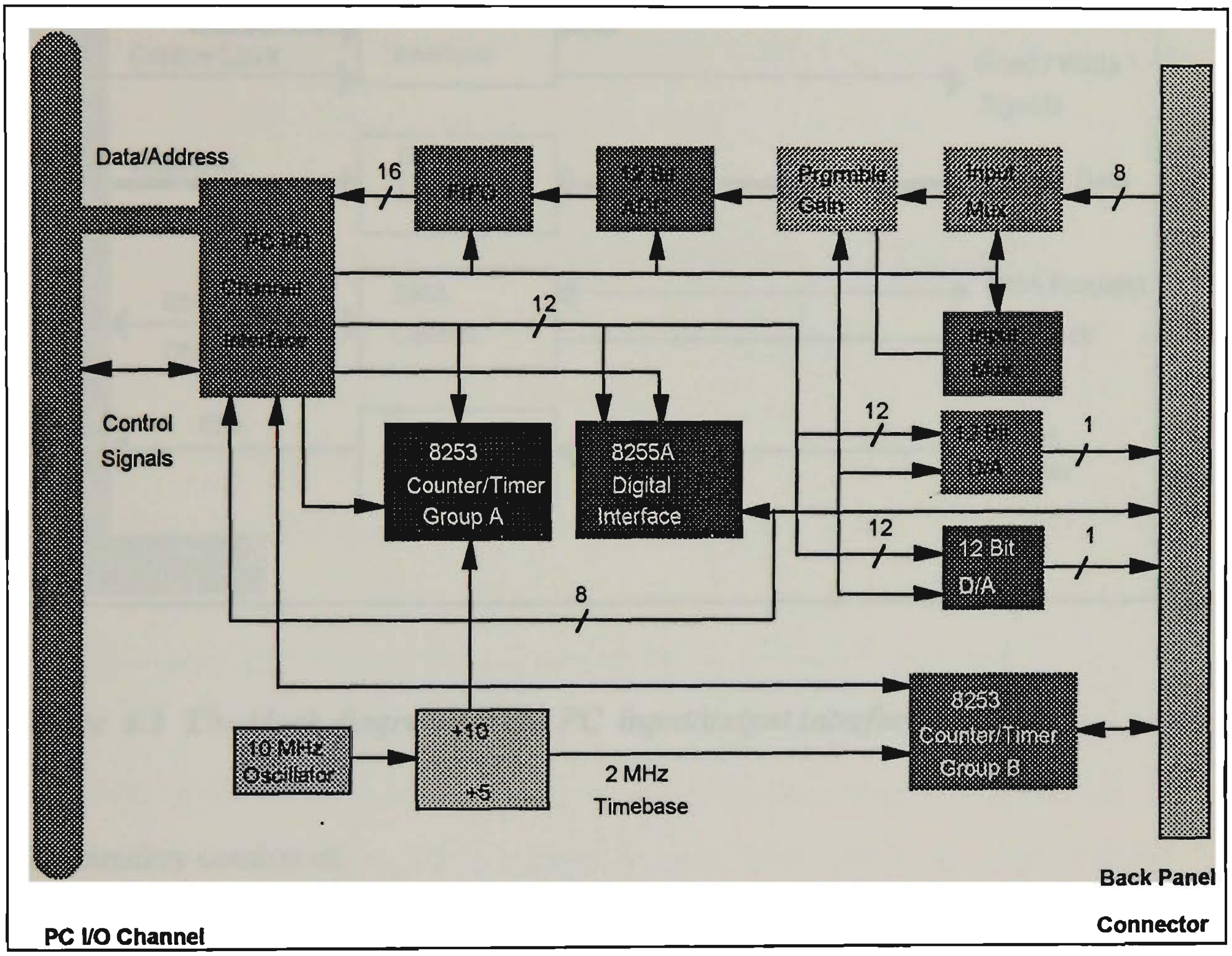


Figure 6.2 The functional block diagram of the data acquisition and control unit

6.3.1.1 Computer Input/Output Channel Interface Circuitry

An interface channel for the PC consists of an address bus, a data bus, a bus for Direct Memory Access (DMA) transfers, interrupt lines and other control and status signal lines. The block diagram for the PC input/output interface circuitry is shown in Figure 6.3 [47].

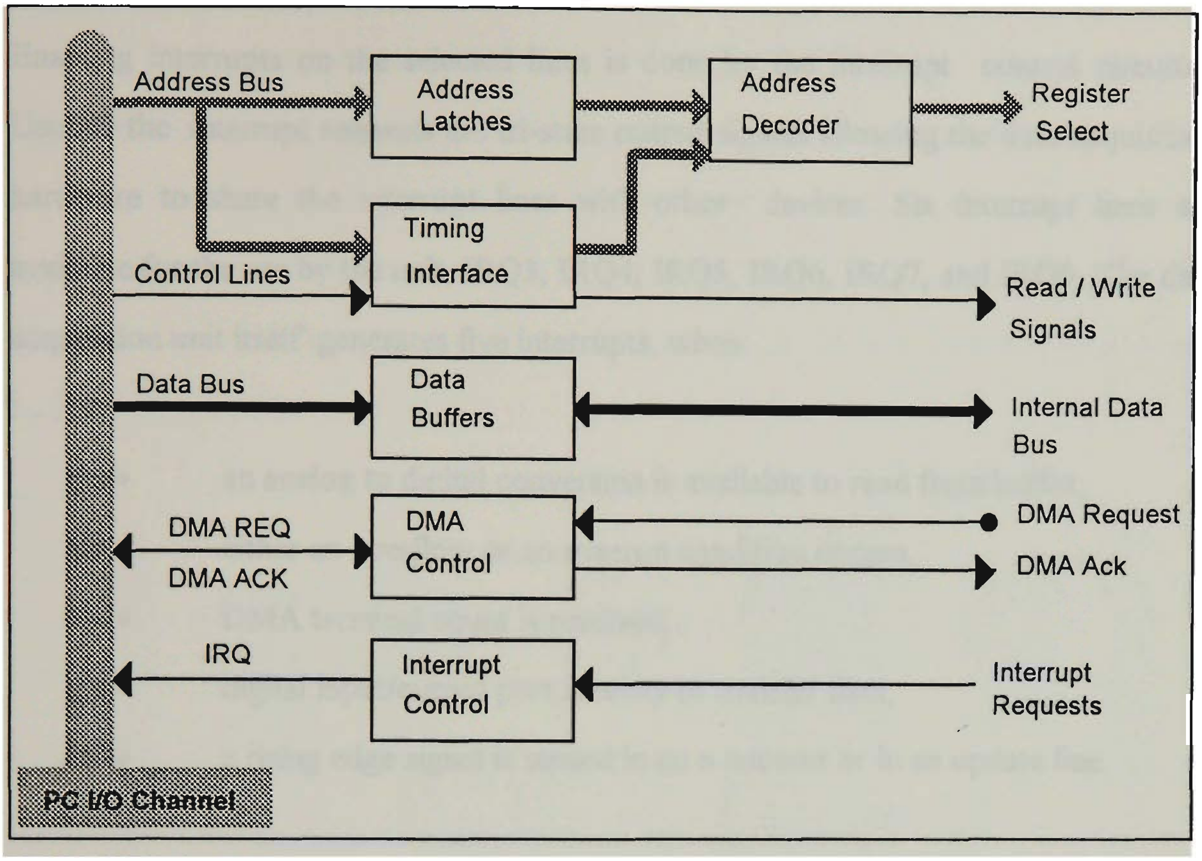


Figure 6.3 The block diagram for the PC input/output interface circuitry

This circuitry consists of:

- address latches,
- address decoders,
- data buffers,
- input/output channel interface timing circuitry,
- interrupt control circuitry and DMA control circuitry.

PC channel interface circuitry monitors 5 address lines to generate the board enable signal, and uses other 5 address lines and additional timing signals to generate the on board register select signals and read/write signals. The data buffers control the direction of data transfer on the bi-directional data lines based on whether the transfer is read or write.

Enabling interrupts on the selected lines is done by the interrupt control circuitry. Usually the interrupt requests are tri-state output signals allowing the data acquisition hardware to share the interrupt lines with other devices. Six interrupt lines are available for the use by the unit, IRQ3, IRQ4, IRQ5, IRQ6, IRQ7, and IRQ9. The data acquisition unit itself generates five interrupts, when:

- an analog to digital conversion is available to read from buffer,
- either an overflow or an overrun condition occurs,
- DMA terminal count is received,
- digital input/output port is ready to transfer data,
- a rising edge signal is sensed in on a counter or in an update line.

Interrupts are individually enabled and cleared whenever they are occurred.

Whenever an analog to digital conversion result is available from the buffer and the DMA transfer is enabled the DMA control circuitry generates a DMA request signal. This data acquisition unit in the integrated substation protection and control system supports 8-bit DMA transfers. In the PC DMA channels 1,2, and 3 are made available and used for such transfers.

6.3.1.2 Analog Input and Data Acquisition Circuitry

Eight channels for analog input with software programmable gain and 12-bit analog to digital conversions are provided by the data acquisition and control unit. These functions are used for current and voltage measurements, alarm monitoring, load sensing and various other applications. Further provisions are made to utilise these resources in later stages with some software programming.

Using timing circuitry, the data acquisition unit can also automatically time multiply analog to digital conversions. Figure 6.4 [47] shows the block diagram of the analog input and data acquisition circuitry. The data acquisition unit used in the integrated protection and control system can perform both single-channel data acquisition and multiple channel data acquisition.

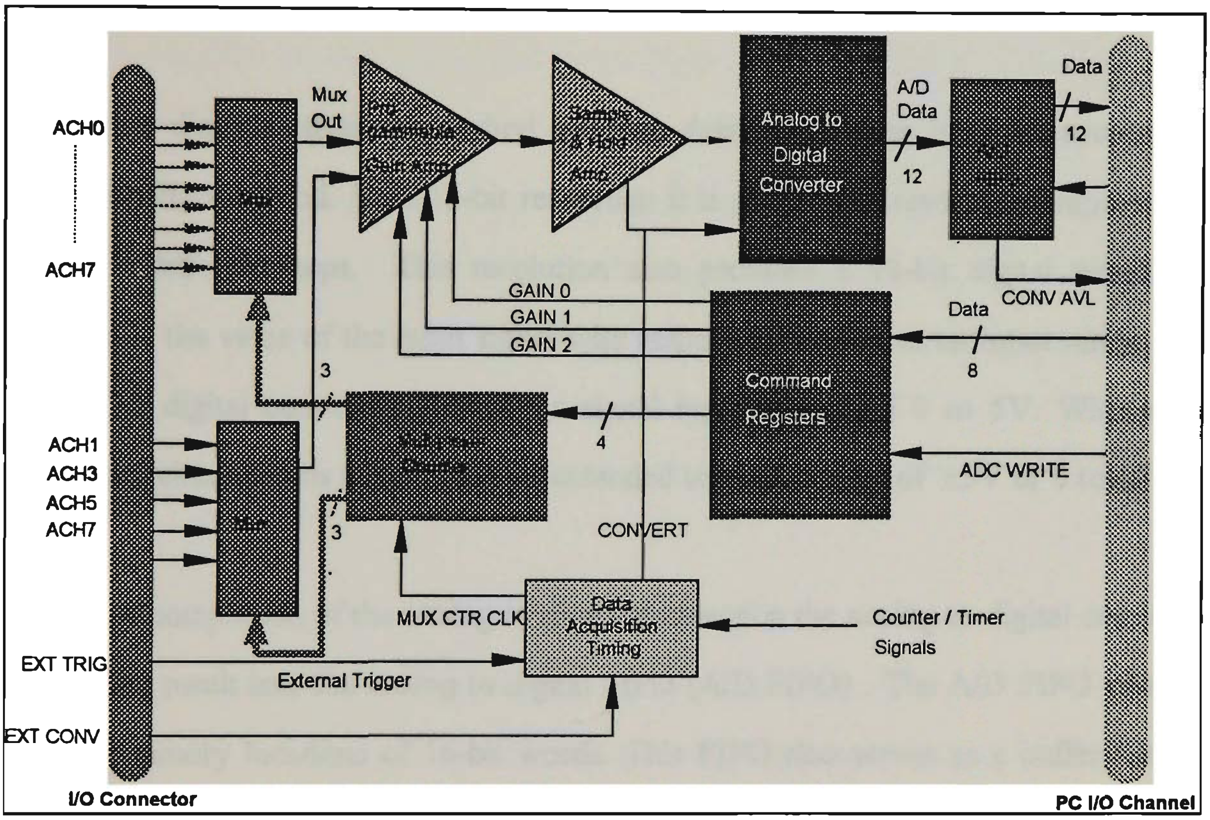


Figure 6.4 Block diagram for the analog input and data acquisition circuitry

6.3.1.2.1 Analog Input Circuit

This analog input circuitry consists of two analog input multiplexers, a gain amplifier, a 12-bit analog to digital converter and a 12-bit First in First Out (FIFO) memory that is sign extended to 16-bits. The gain amplifier is software programmable.

The two multiplexers are configured in a special way so that one of them provides single input channels and the other differential channels. The input multiplexes are capable of providing input voltage protection of ±45V, powered on or off.

To enhance the measurement accuracy and resolution, the analog input signals are amplified by the gain amplifier before they are sampled and converted. The gain of this amplifier could be soft programmable to provide gains of 1, 2, 5, 10, 20, 50 and 100.

Analog to digital conversion method used for data acquisition is 12-bit successive-approximation method. With 12-bit resolution it is possible to resolve the input range to 4096 different steps. This resolution also provides a 12-bit digital word that represents the value of the input signal with respect to the converter input range. The analog to digital converter itself has a signal input range of 0 to 5V. With some additional circuitry this range could be extended to allow inputs of ±5V or 0 to 10V.

Upon the completion of the analog to digital conversion the analog to digital converter clocks the result into the analog to digital FIFO (A/D FIFO) . The A/D FIFO consists of 512 memory locations of 16-bit words. This FIFO also serves as a buffer for the inputs. Whenever an analog to digital conversion is complete this buffer saves the value in it for later reading. This makes the analog to digital converter free for a new conversion. Further the A/D FIFO can collect up to 16 analog to digital conversion values before any information is lost. This capacity allows software up to 16 times the sample interval to catch up with the hardware.

Error condition will occur if more than 16 values are stored in the A/D FIFO before reading operation is done on A/D FIFO. This causes an overflow of the A/D FIFO and this error condition will be notified to the front panel through software. A signal will be

generated by the A/D FIFO when it contains the analog to digital conversion data. This signal could be read by the software through the status register.
The output of the analog to digital converter could be read as either straight binary or two's complement depending on whether the input mode is unipolar or bipolar. In unipolar mode, data from analog to digital converter is interpreted as a 12-bit straight binary number with a range of 0 to +4,095. In the bipolar mode, data from the analog to digital converter is interpreted as a 12-bit two's complement number with a range of -2,048 to +2,047. In this mode, the Most Significant Bit (MSB) of the analog to digital converter result is inverted to make it two's complement. The output from the analog to digital converter is then sign extended to 16 bits, causing either a leading 0_{16} or a leading F_{16} to be added depending on the coding and the sign.

6.3.1.2.2 Timing Circuit

The time between the successive analog to digital conversions or the sample interval as it is widely known has to be timed with precision. Timing circuit for data acquisition consists of various clock and timing signals that perform this required task. Data acquisition unit can perform both single-channel data acquisition and multiple-channel data acquisition in continuous mode and interval mode. The device uses a counter to switch between analog input channels automatically during scanned data acquisition.

An 8253 programmable CMOS interval timer built into the device will provide signals that initiate a data acquisition operation, initiate individual analog to digital conversions, gate the data acquisition operation, and generate scanning clocks.

A16-bit down counter is used as a sample interval timer to generate sample intervals ranging from 2μsec to 65,535μsec. Sample timer also can use the output from the counter of the 8253 programmable interval timer that is built into the data acquisition unit. Each time the sample interval timer reaches 0, it generates the signal pulse and reloads the value of the programmed sample interval count. Until a new value appears in the programmed sample interval count, this process will continue.

Only one counter is usually required for the data acquisition operations in the free-run mode. The software is keeping a track of the events and the conversions that have taken place and turn off this counter after the required number of conversions are done. Yet, in the controlled acquisition mode two counters are used for the data acquisition operation. The first counter generates the conversion pulses and the second counter will gate off the first counter after the programmed count has expired.

6.3.1.2.3 Single Channel Data Acquisition

In the single channel data acquisition process, the channel and the gain of the process has to be determined by the hardware before the data acquisition operation is initiated. These gain and multiplexer settings remain constant during the entire data acquisition process. Therefore, all the analog to digital conversion data is read from a single channel.

6.3.1.2.4 Scanned Data Acquisition

Scanned data acquisition is done using multiple channels to acquire data. Integrated substation protection and control system uses this type of scanning to acquire waveforms of the power system. Multiple channel scanning is controlled by a scanning counter.

Scanning counter decrements from the highest numbered channel through to the channel 0 and then repeats the sequence. Same gain is used for all the channels used in the scanning process. Any number of channels from two to eight could be scanned in this way.

In the single channel continuous mode the single channels are sampled without any delays. Therefore, in the continuous mode the data acquisition unit scans the selected channels repeatedly without delays and samples them. For this process two additional counters are used. In the single channel interval acquisition mode, a single channel is sampled a pre-programmed number of times, while the device waits for the duration of the scan interval. This cycle is repeated to generate the required scanning process. In the scanned interval acquisition mode the same process is repeated, not for a single channel, but for a number of selected channels in the scanning sequence.

6.3.1.2.5 Data Acquisition Rates

In the data acquisition process the maximum data acquisition rates are determined by the conversion period of the analog to digital converter and the sample and hold acquisition time. However, during multiple channel scanning the data acquisition rates are further limited by the settling time of the input multiplexers and the programmable gain amplifier. After the input multipliers are switched, the amplifier must be allowed to settle to the new input signal value within the 12-bit accuracy, before an analog to digital conversion is performed. Otherwise, the 12-bit accuracy will not be achieved. The settling time also varies with the gain selected. Table 6.1 shows the typical settling times associate with the different gain settings.

Table 6.1 Settling times associated with different gain settings of the analog input

Gain	Settling Time
1	12μsec
2,5,10,20,50	16μsec - 18μsec
100	50μsec

The timing circuitry detects whether the data acquisition rates are higher to keep up with the hardware capabilities and results in a converted data loss. An over-run error condition is signalled if this situation occurs.

In the single channel data acquisition the data can be acquired at the maximum rate at any gain setting. However, the analog input bandwidth is lower for higher gain settings. For the multiple channel data acquisition or the scanning inputs the data acquisition rate may drop to ensure the 12-bit accuracy. Table 6.2 gives the threshold data acquisition rates for different modes and respective gain settings.

Table 6.2 Maximum data acquisition rates for different modes

Data Acquisition Mode	Gain	Rate (ksamples/sec)
Single Channel	1	83.3
	2, 5, 10, 20, 50, 100	71.4
Multiple Channel	1	83.3
	2, 5, 10, 20, 50	55.5 - 62.5
	100	20.0

Gain settings will also have an impact on the input signal voltage range. Also in this case, bipolar and unipolar signals will have their differences again in the respective input voltages. Greater settling times may be required by the signal sources with high impedances. Tables 6.3 and 6.4 show the input signal voltage ranges associated with the different gain settings in both unipolar and bipolar input configurations.

Table 6.3 Bipolar analog input voltage ranges for different gain settings

Gain Setting	**Input Signal Voltage Range**
1	-5V to 4.99576V
2	-2.5V to 2.4978V
5	-1.0 V to 0.99951V
10	-500mV to 499.756mV
20	-250mV to 249.877mV
50	-100mV to 99.951mV
100	-50mV to 49.975mV

Table 6.4 Unipolar analog input voltage ranges for different gain settings

Gain Setting	**Input Signal Range**
1	0V to 9.99756V
2	0V to 4.99878V
5	0V to 1.99957V
10	0mV to 999.756mV
20	0mV to 499.877mV
50	0mV to 199.951mV
100	0mV to 99.975mV

6.3.1.3 Analog Output Circuitry

Two analog output channels are provided by the data acquisition and control unit of the system. They are based on 12-bit digital to analog converters. These analog output channels can provide unipolar or bipolar output. The block diagram of the analog output circuitry is shown in Figure 6.5 [47].

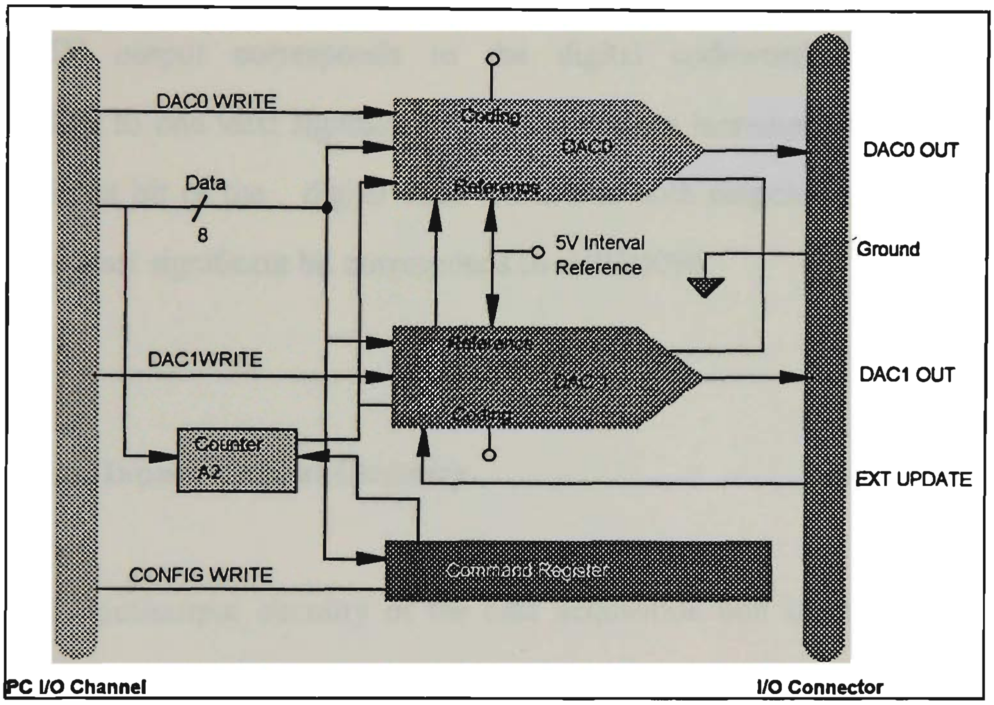


Figure 6.5 Block diagram of the analog output circuitry

The DAC in each analog output channel generates a voltage proportional to the reference input voltage multiplied by the digital code loaded into the digital to DAC. Two D/A registers are used to write a 12-bit digital code to be loaded to the DAC.

DAC voltage can be updated in three ways. In one setting the D/A converted voltage is updated immediately after the corresponding data register is written in to it. In the other methods, DAC voltage does not change until a falling edge is detected either by a counter or by an external update line.

DAC channel can be hardware programmed by changing the jumper settings for either a unipolar or bipolar output voltage range. A unipolar setting can provide an output voltage range of 0V to +9.9976 V. A bipolar output gives an output voltage range of -5V to +4.9976V.

Different digital codewords are associated with the voltage levels in the two settings. For unipolar output 0V output corresponds to digital codeword 0. For the bipolar output, -5V output corresponds to the digital codeword of $F800_{16}$. Value corresponding to one least significant bit is the voltage increment associated with the least significant bit of the digital code word. For both unipolar and bipolar analog outputs one least significant bit corresponds to 10V/4096.

6.3.2 Digital Input / Output Circuitry

The digital input/output circuitry of the data acquisition unit is based mostly on the 8255A CMOS programmable peripheral interface. This general purpose programmable peripheral interface consists of 24 programmable input/output pins. These digital input pins are used to detect the relay settings, alarms and status functions in the substation protection and control equipment. Digital outputs are then used to deliver control signals and trigger the associated auxiliary devices.

The 8255A has a control register to configure each of the input/output ports. These ports can be programmed as two groups of 12 signals or as three individual 8-bit ports. Additionally, the device can be programmed in one of the three modes of operation. These three modes are the basic input/output operation, strobe input/output, and operation as a bi-directional bus. Programming information of the 8255A device could be obtained from the data sheets of the chip.

Three ports available in the 8255A are TTL (Transistor Transistor Logic) compatible. Driving capabilities of the ports are therefore important. When enabled, digital output ports are capable of sinking 2.4mA of current and sourcing 2.6mA of current in each digital input/output line. When not enabled they may act as high impedance inputs. Digital input /output circuitry block diagram is shown in Figure 6.6

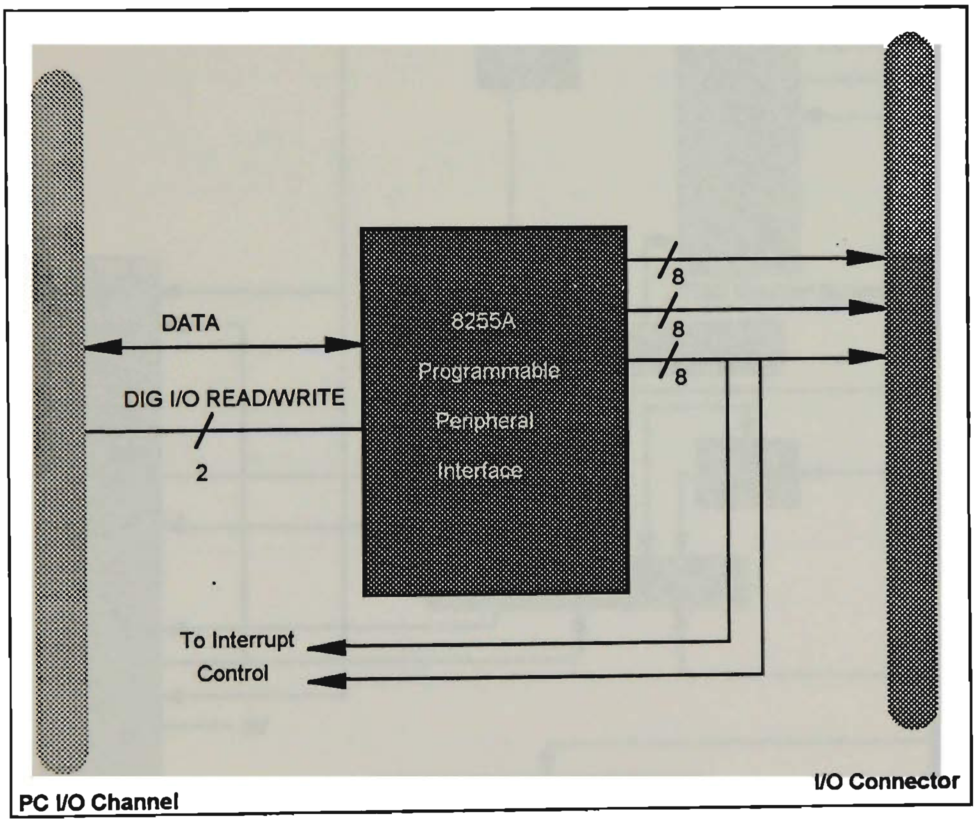


Figure 6.6 Block diagram of the digital input/ output circuitry

6.3.3 Input /Output Timing Circuitry

Timing circuitry of the data acquisition and control unit is based on the 8253 CMOS Programmable Interval Timer. Two of these 8253 timers are used for data acquisition timing and the general purpose timing of the input/output functions. Functionality of the both of these timer are shown in block diagram format in Figure 6.7 [47].

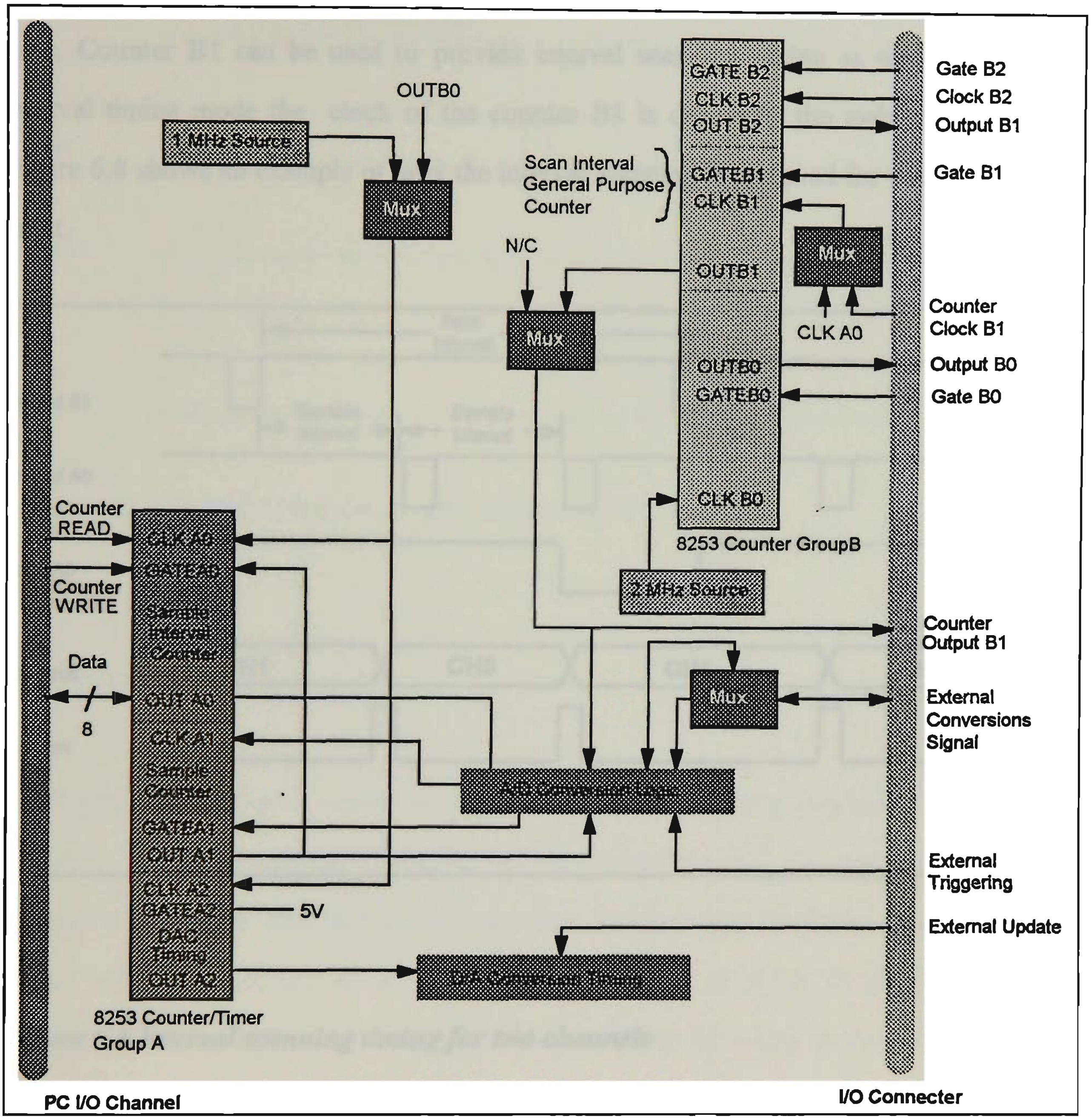


Figure 6.7 Block diagram of the timing input/output circuitry

The 8253 Programmable Interval Timer contains three independent 16 bit counters/timers and one 8-bit mode register. As shown in Figure 6.7 [47] counter group A is reserved for data acquisition timing and counter group B is free for general use. All six counter/timers offered by two 8253 devices can be programmed to operate in several useful timing modes. Further details about programming 8253 could be obtained from the data sheets of the 8253.

Counter group A uses either a 1 MHz clock generated from the on board 10MHz oscillator or the output from counter B0, which has a 2MHz clock source, as it's time base. Counter B1 can be used to provide interval scanning timing as well. In the interval timing mode the clock of the counter B1 is driven by the main clock A0. Figure 6.8 shows an example of how the interval scanning is achieved for two channel input.

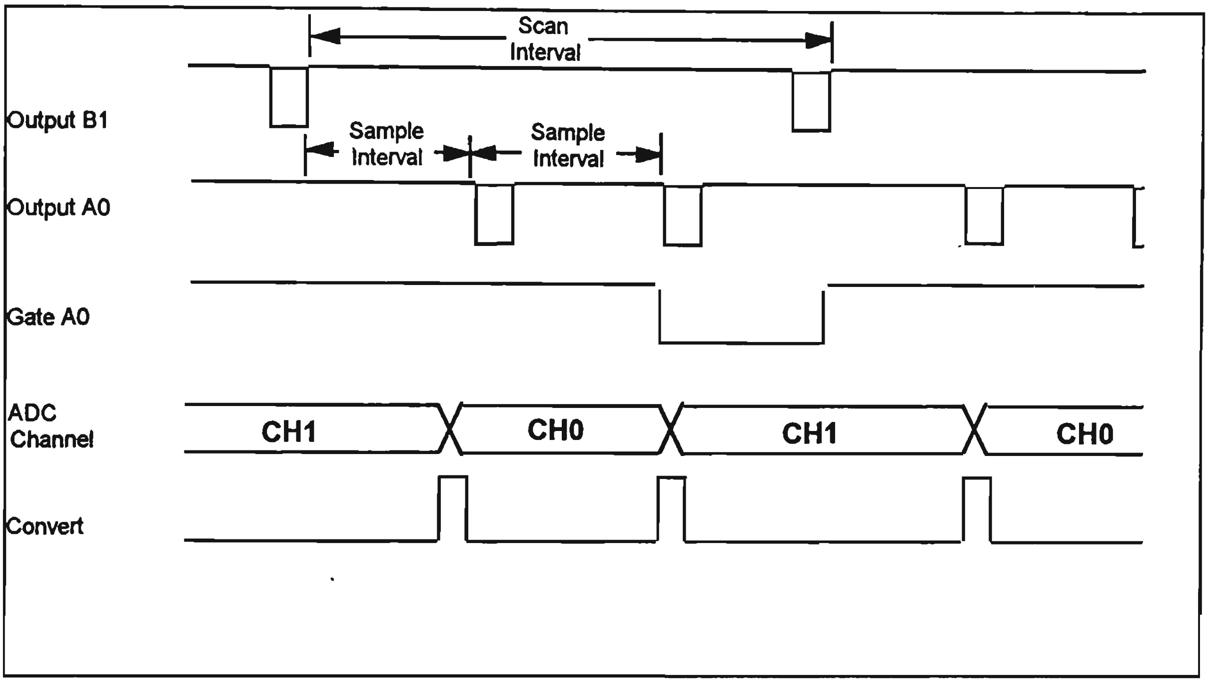


Figure 6.8 Interval scanning timing for two channels

The single channel interval data acquisition uses an additional 8-bit counter. In this mode counter B1 initiates the scan sequences that are separated by the programmable interval time. The interval counter is programmed for the number of samples of the selected channel for each interval. Figure 6.8 shows how interval timing is achieved for single channel [47].

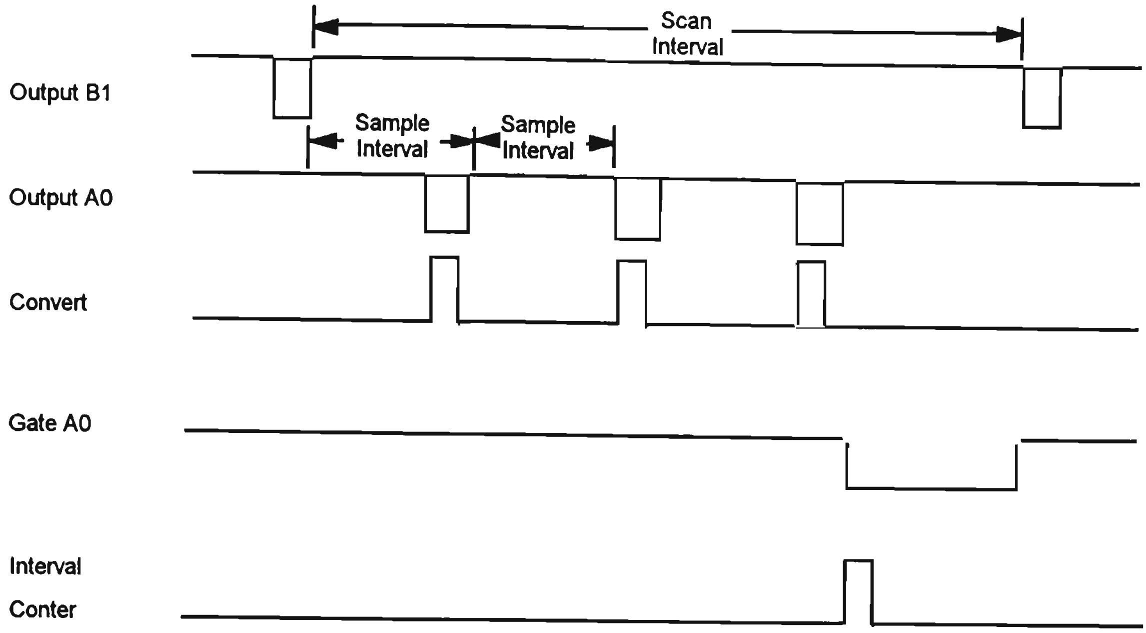


Figure 6.9 Interval timing for single channel input

6.4 Summary

The focus of this chapter was in the data acquisition and control requirements of the low cost integrated substation protection and control system. The contents of the chapter was broadly classified to two sections; software and hardware. Analog and digital inputs and outputs of the system were discussed in detail. Single-point and multiple-point acquisitions and their use in acquiring and delivering useful control and protection signals to the system were also studied.

CHAPTER
SEVEN

SYSTEM OUTPUT

7.1 Introduction

Results of this thesis is given in this chapter. The low cost integrated substation protection system was implemented successfully. Most of the testing of the operation was done in the power engineering laboratory of the Department of Electrical & Electronic Engineering , VUT, Footscray campus.

Assortment of different protection, monitoring and control features were implemented. Nevertheless the system potential is beyond this. It is possible to add more functions at any given instant. However, the functions implemented were considered to be satisfactory for the scope of this research.

Data acquisition and system response time requirements were met. These results were achieved using IBM 486 PC compatible processors. With the advent of the better microprocessor these results could be improved.

7.2 Program Development

The LABVIEW graphical programming language was used to develop relevant instrumentation. LABVIEW is a program development application similar to any other programming language. However LABVIEW is different from those programming languages in one important aspect. Other programming languages use text based languages to create lines of code, while LABVIEW uses a graphical programming language to create programs in block diagram form.

Development of programming was based on a hierarchy of virtual instruments (vi). First the elementary 'vi' s were developed. These 'vi's at lower levels of hierarchy could be used as inputs to the 'vi' s in higher hierarchies. In some cases lower level 'vi' s are embedded in the higher ones. Classical example for a type of an embedded 'vi' is the Remote terminal, which uses analog inputs to acquire its basic waveforms.

In the next sections of this chapter detailed descriptions about the implemented substation facilities are given. Front panel of each device implemented is shown in each sections accompanied by respective descriptions. Program details are given in the Appendix B. Appendix B consists of the outputs form the vi library IPS.LLB which contained all the software developed for the low cost integrated substation protection and control system. Programs structures, data, virtual instrument hierarchies are also given in Appendix B.

7.3 Remote monitoring Terminal

Remote Monitoring Terminal is a device used by field level processors. The field level and the Coorination and Management level were discussed in chapter 2and were illustrated in figures 3.1 and 3.2. Remote Monitoring Terminal acquires analog waveforms of the power system. Instrument voltage transformers are used to sense the signal and step down to a voltage that is handleable by the data acquisition card. Front panel of a Remote Monitoring Terminal is shown in Figure 7.1.

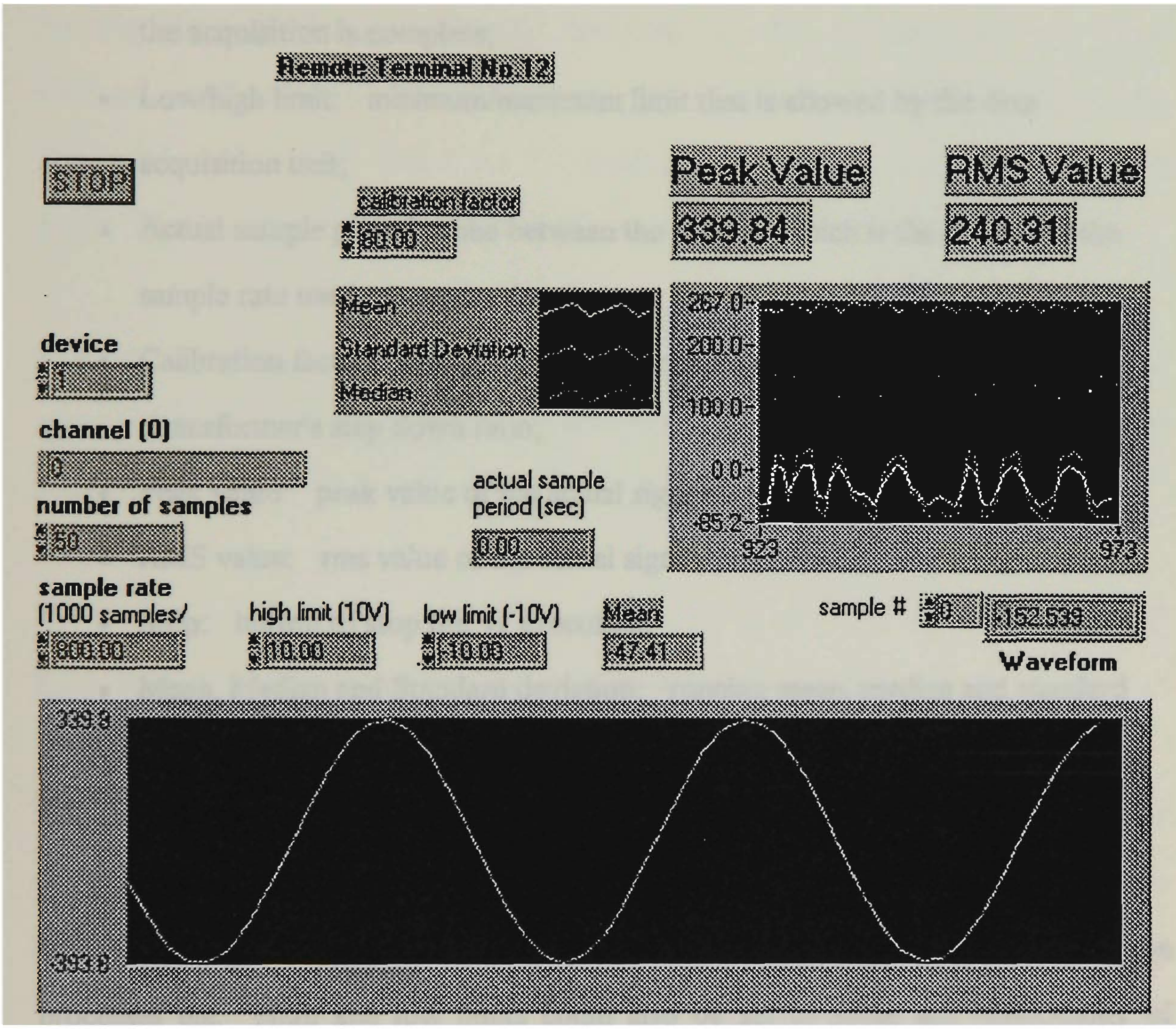


Figure 7.1 Remote Terminal for data acquisition and monitoring

This 'vi' can carry out timed measurement of a waveform on specified analog input channel. Waveform is obtained using multiple voltage readings at a specified sampling rate. If an error occurs, a dialogue box opens and gives the user the option to abort the process or to continue execution.

Following is a brief description of the inputs and outputs of the Remote Monitoring Terminal:

- Device: assigned device number of the plug in data acquisition board;
- Channel: input channel that needs to be measured;
- Number of Samples: the number of single-channel samples acquired before the acquisition is complete;
- Low/high limit: minimum/maximum limit that is allowed by the data acquisition unit;
- Actual sample period: time between the samples which is the inverse of the sample rate used to acquire data;
- Calibration factor: multiplication factor to offset the instrumentation transformer's step down ratio;
- Peak value: peak value of the actual signal;
- RMS value: rms value of the actual signal;
- Stop: button to stop the 'vi' execution;
- Mean, Median and Standard deviation: running mean, median and standard deviation of the acquired signal;
- Waveform: acquired waveform.

It is possible to change the sampling period, number of samples in the waveform processes etc. High and low limits could also be set to sense any abnormality of operation. Once the waveform values are stored in the array, they will be multiplied by the calibration factor. Calibration factor will offset the step down ratio of the instrument transformer. For example if the step down of instrument transformer is 40:1, calibration factor should be set to 40. This property will enable the user to fine tune the system.

Positive and negative peaks are then sensed to verify that the signal is within the specified limits. Alarms could be activated in a limit violation condition. Positive peak is used to calculate the instantaneous rms value. Both these values are shown in the front panel.

Running mean, median and standard deviation are also calculated on-line. Any transient condition will be highlighted in this second graph with a rapid change in the standard deviation trace. Unlike the waveform graph this statistical graph is a sweep graph. That means it will retain it's values for one complete cycle of values.

Remote Monitoring Terminal is the most important field level 'vi'. It acts as inputs to many higher level 'vi's including the remote server and the sent data to spreadsheet sheet 'vi's.

7.3.1 Remote Monitoring Terminal with on-line Data Logging

This is a special kind of Remote Monitoring Terminal. This terminal has all the properties in remote monitoring terminal but is capable of logging the waveform data to a text file. Remote Terminal with data logging facility is shown in Figure 7.2.

In this 'vi' there is an input provided for the file-name and path. If the file name is not entered a special dialogue box appears on the VDU requesting file path information. The 'vi' will continually write to the file until the stop button is pressed.

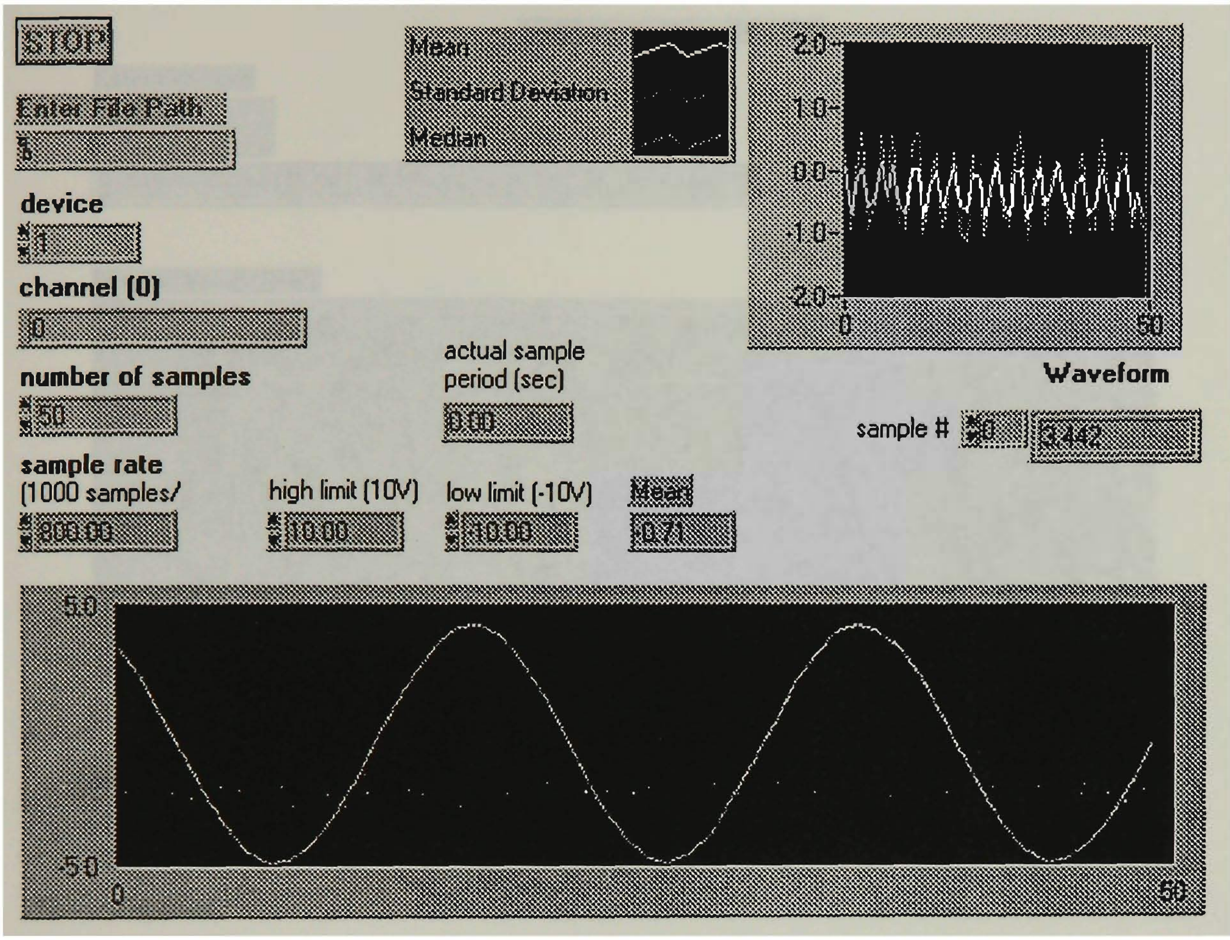


Figure 7.2 Remote Monitoring Terminal with data logging facility.

7.4 Data Retrieval From File

Separate 'vi' was provided to retrieve data from text files. This vi is able to separate the numeric data from string data. Numeric data is subsequently presented in graphical format. Figure 7.3 shows the front panel of Data Retrieval from File 'vi'.

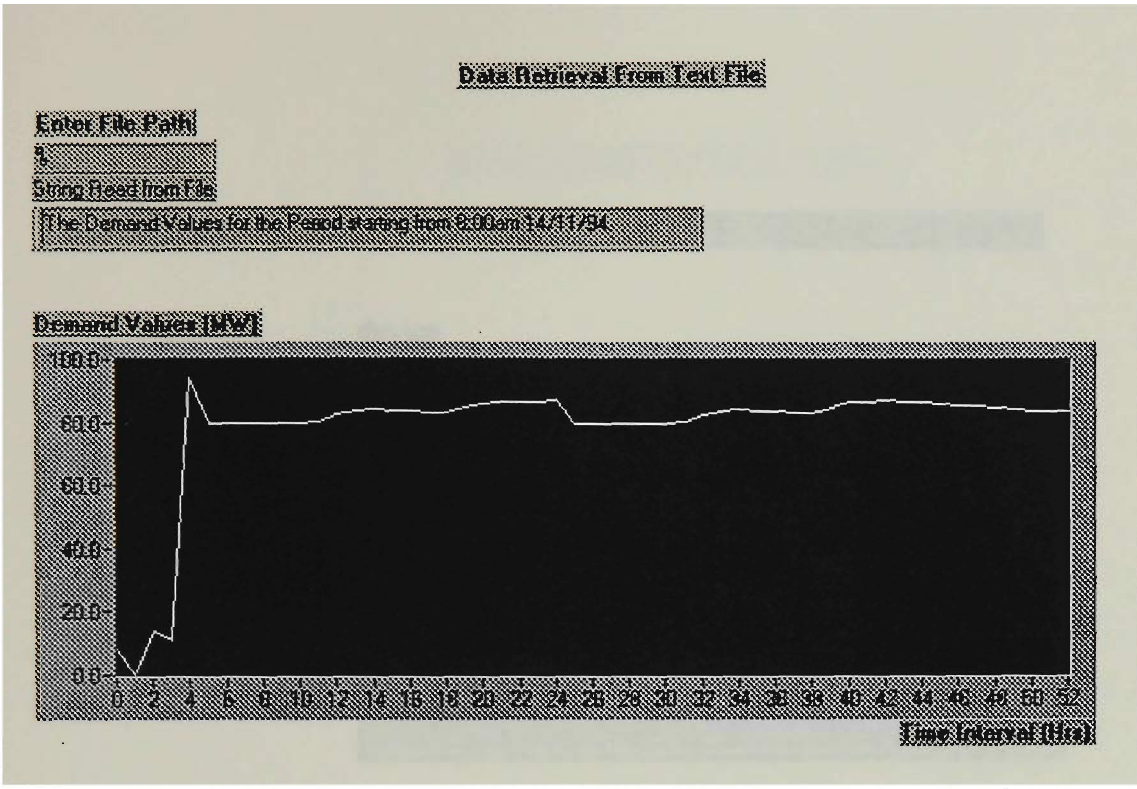


Figure 7.3 Data Retrieval Vi can restore data from text file

7.5 Relay Control

Set Relay 'vi' uses Digital computers to relay contact positions. Up to 32 different settings could be incorporated using digital outputs. Relay contact switches in the front panel could be set using the mouse. On/Off status of each switch is shown next to the switch. Figure 7.4 shows the relay control panel of the Set Relay 'vi'.

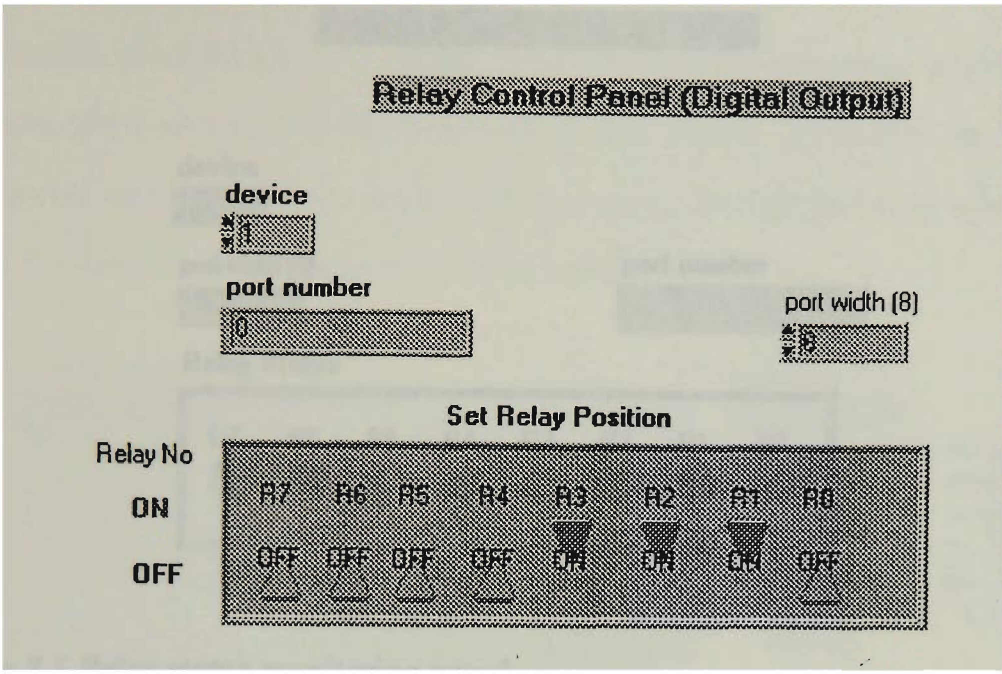


Figure 7.4 Relay control panel can set/reset the relay contact positions

Provisions are given to select different relay clusters by changing the device number or the port number associated with the relay cluster.

7.6 Relay Monitoring

Special 'vi' was designed to monitor the contact positions of the relays. This 'vi' senses the contact position of the relay through the digital inputs of the data acquisition unit and displays relevant status on the screen. A set of light indicators are provided in the screen to indicate the status. If the contact positions are on the respective light indicators are illuminated. Figure 7.5 shows the relay monitoring panel.

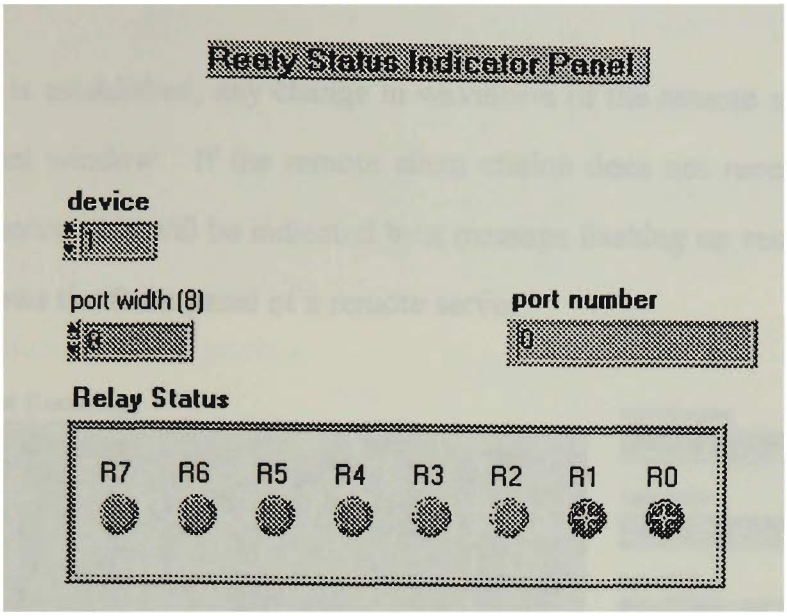


Figure 7.5 Relay status monitoring panel

As in the relay control panel, in this case also, different relay clusters could be monitored by changing the associated port number and device.

7.7 Remote Server Function

Remote Server is a field level function. Remote server 'vi' is responsible for transmitting acquired signals to other processors via LAN. It uses DDE links to establish permanent data links with the Remote Client 'vi'. Data transmitted by remote Server will be received by remote client.

In order to set up a DDE data link, first the application name, topic name, etc., must be entered through the front panel. This information will be used to establish a connection with the remote client. At default state the values are set to establish a conversation with the substation processor. However by choosing the right topic names connections could be made to the other field level processors.

Once the link is established, any change in waveform of the remote server will appear at remote client window. If the remote client station does not receive any response from remote server this will be indicated by a message flashing on remote client panel. Figure 7.6 shows the front panel of a remote server.

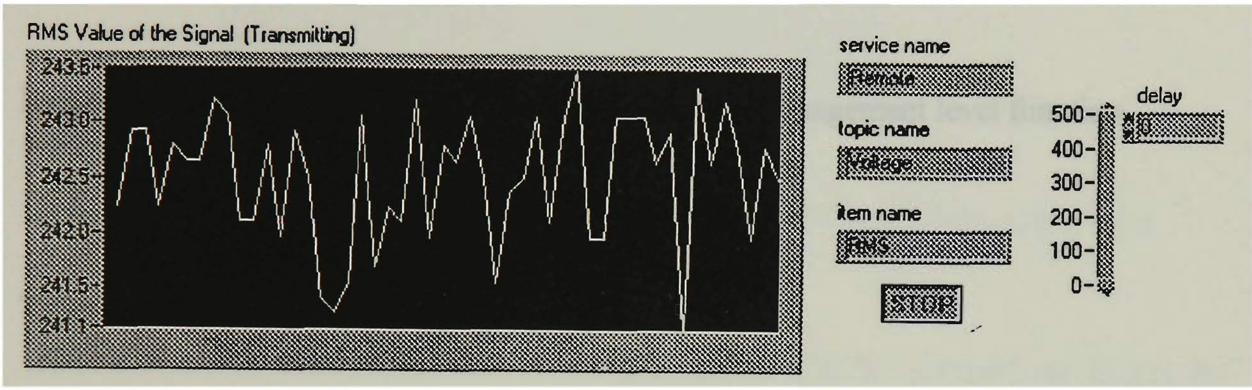


Figure 7.6 Remote sever transmits the waveforms to other stations.

7.8 Remote Client Function

Remote Client function receives the waveforms transmitted by the Remote Server function. A dynamic data link will be established between the two 'vi's and the waveform values will be constantly updated. The input panel of the Remote Client is similar to the Remote Server. The delay dial is useful in synchronising the operation. There are special entries that are required to be made in the Windows Win.ini file to establish the dynamic data exchange over the network. Figure 7.7 illustrates the front panel of the Remote Client function.

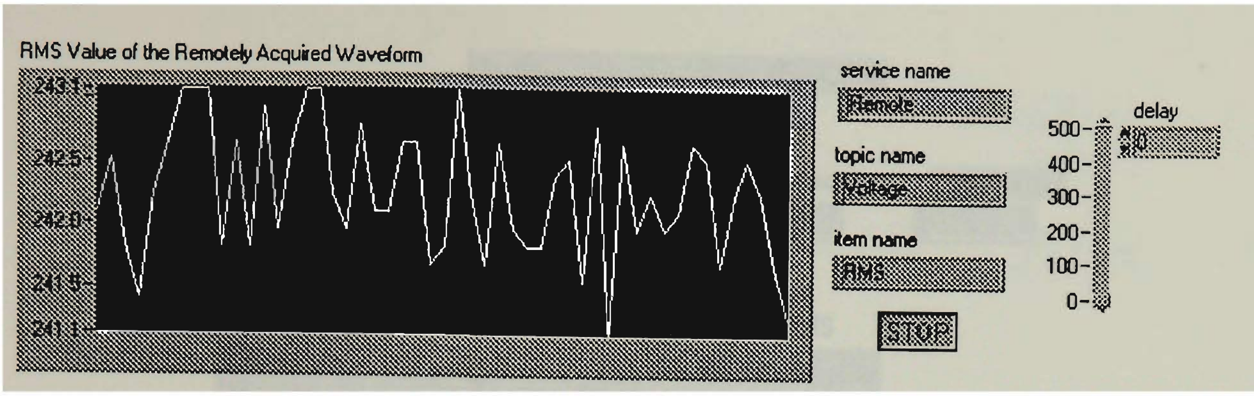


Figure 7.7 Remote Client function

Remote Client function is usually a coordination and management level function.

7.9 Use of Spreadsheets

Another important facility offered by the low cost integrated protection and control system is direct interaction with spreadsheet analysis packages. The system is capable of sending data to EXCEL spreadsheet and vice versa. The data processing could be done by entering the required mathematical operation.

The 'vi' shown in Figure 7.8 uses the Remote Monitoring Terminal to acquire the power system data in pre-determined intervals given by the user. Then this data is sent to the EXCEL spreadsheet where the computations take place. Final results of the analysis is sent back to the instrument panel.

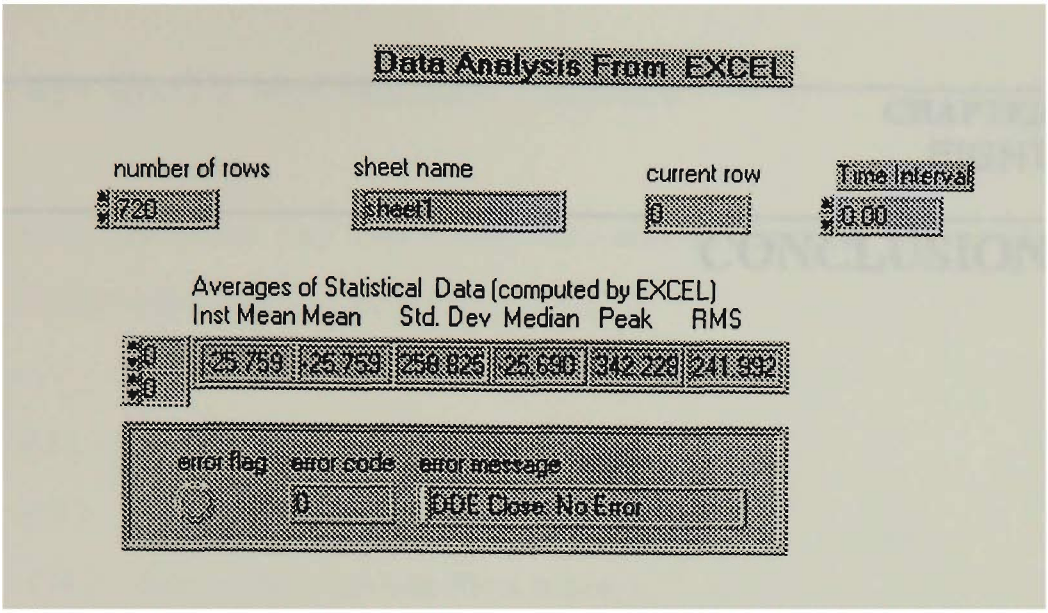


Figure 7.8 System is capable of interacting directly with spreadsheet packages

Data sent to EXCEL is later saved in the appropriate EXCEL spreadsheet format for future records.

7.10 Summary

Given in the previous sections of this chapter are the final results of this thesis work. This low cost development was able to provide functions and features identical to any other complex development. Nevertheless there is a variety of functions that could be added to improve the system capabilities.

The low cost system developed will, bring tangible benefits such as enhanced reliability and efficiency and return in investment in operation and maintenance of modern substations. This improved functionality achieved through integration, will undoubtedly make substation protection and control a less exhaustive task for the future protection engineer.

CHAPTER
EIGHT

CONCLUSION

A low cost Integrated substation was developed. The developed system has fulfilled the intended requirements, as set out in the needs and objectives of Chapter 1.

8.1 On Line Control and Monitoring

One of the requirements set out in the needs specification was the need for on-line control and monitoring. The implemented system provided on-line monitoring and control functions through it's data acquisition unit. Some on-line control and monitoring features include:

(i) remote monitoring terminals;

(ii) relay status monitoring;

(iii) relay contact setting;

(iv) remote relay monitoring and setting.

8.2 High Quality Man-Machine Interface

The system provides a very high quality man-machine Interface. The screen based control and monitoring terminals, provide:

(i) high resolution multi-colour graphics;

(ii) mouse driven switches and dials;

(iii) clear, informative waveform traces;

(iv) menu driven system.

The developed system is based on the most popular icon-based graphical interface for PCs. On-line help functions and information sections help the user to learn the system easily.

8.3 Unattended Operation

Unattended operation is supported by the low cost integrated substation protection and control system. Automatic control monitoring functions supervise the relays, accessories, and detect any abnormalities. Some of theses features are:

(i) automatic level detection;

(ii) on line transient analysis;

(iii) run time generation of statistical information and identifying transient events;

(iv) automatic scaling and peak detection;

(v) automatic alarms.

8.4 Low Cost Development

One of the noteworthy achievements of the system was it's low developmental cost. Even though the system is comparable to any other development in terms of functionality, in terms of it's cost of development it is unique. This included hardware, and software licenses.

8.5 Reliability

Standard software and hardware products were used to build the system. This reflects the proven reliability and quality of the system. The criterion of system design was to monitor the substation equipment continually (eg. relay monitoring system). Cross checking functions were built-in to the system to check network integrity and functionality, and operation. Any ill-conditioning situation is notified by alarms or messages appearing on the screen.

8.6 Integrated Software Environment with Sophisticated Packages

Based on the Microsoft Windows environment the system is capable of hosting many other application software. The system can exchange data with these applications for further processing. Transferring substation data to Excel spreadsheet shown in previous chapter was one such application. Data could be made available for user defined software or customised programs through text files.

The system's capacity is extensive in providing numerous features that were not possible before with traditional systems. The absence of references in monitoring and control of actual substations is the only issue that prompts a protection engineer to hesitate or delay installation of the system. According to Klebenovski [43], "protection engineers are very suspicious people and may not be willing to accept a new system without proven credentials".

The enthusiasm and interest generated while presenting this work nationally and internationally (Appendix C) was a testimony for the practical utilisation of this project in the electric supply industry. In conclusion the author's feeling is that this work will be a prototype for many similar low cost developments in future.

8.7 Recommendations for Future Work

The basic low cost integrated platform for substation protection and control is provided by this work. However system is open for improvements.

8.7.1 Improving the Protection and Control Functions

Features and functions that could be added in terms of improving protection and control needs of substations include:

(i) implementing new relaying algorithms and functions,

(ii) addition of expert systems in the integrated software environment to assist the decision making of the system,

(iii) inclusion of algorithms and associated peripherals for load shedding and restoration,

(iv) investigating the possibilities of configuring the system to incorporate the protection and control needs of interconnection of private cogeneration plants to utility's grid.

8.7.2 Improving the Transmission Media

The present system used a double shielded coaxial cable as the physical transmission media. New standard protocol converters are available in the market and, it is possible to upgrade the system to use fibre-optic cable as the backbone transmission medium. Figure 8.1 illustrates one such example.

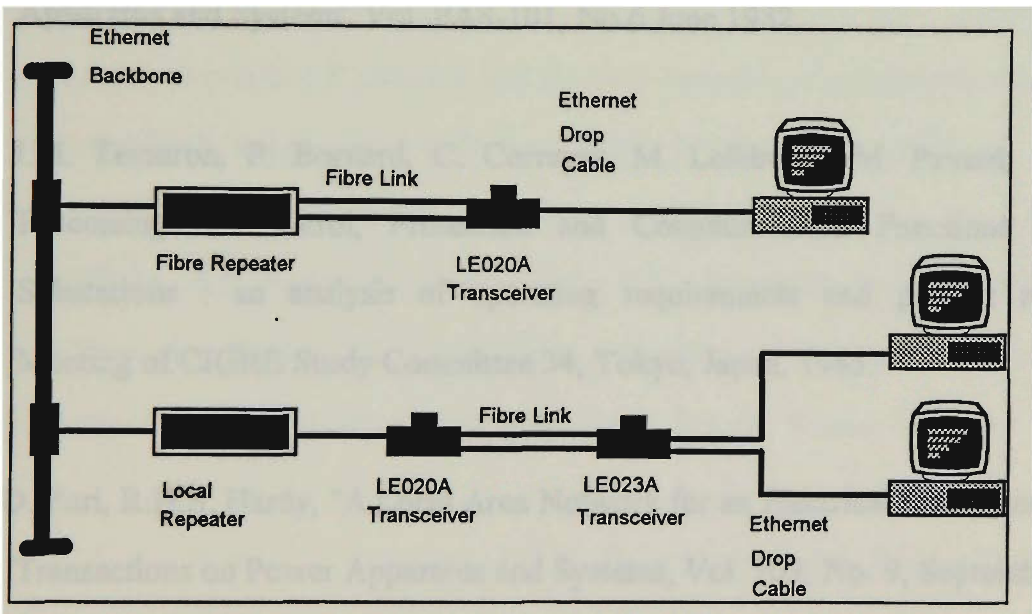


Figure 8.1 Adapting fibre-optic links to Ethernet LAN using transceivers to improve immunity to the electromagnetic noise

This solution is based on fibre optic transceivers which are fully compatible with IEEE 802.3 Ethernet specification [46].

BIBLIOGRAPHY

[1] J. S. Deliyannides, E.A. Urden. "Design Criteria for an Integrated Microprocessor-based Substation Protection and Control System." IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No.6 June 1982.

[2] J.M. Tesseron, P. Bornard, C. Correyer, M. Lefebvere, M. Pavard, "Digital Processing of Control, Protection and Communication Functions in EHV Substations : an analysis of operating requirements and present research", Meeting of CIGRE Study Committee 34, Tokyo, Japan, 1983.

[3] D. Puri, R.H.S. Hardy, "A Local Area Network for an Electrical Substation", IEEE Transactions on Power Apparatus and Systems, Vol. 103, No. 9, September 1984.

[4] J.M. Tesseron, P. Bornard, G. Cotto, "Use of Digital Techniques for Protection and Control Functions in French EHV Substation", IEE Developments in Power System Protections, April 1985.

[5] T. Lefebvere, M. Nourris, P. Bornard, "A Local Area Network for Control Functions in EHV Substation", Second International Conference on Power System Monitoring and Control, Durham, England, July 1986.

[6] R.A. Liley, C. Seymour, P.G. Bishop, F.D. Pullen, "Co-ordinated Substation Control and Monitoring", International Conference on Large High Voltage Electric Systems, Paris, France, August 1986.

[7] M. Manika, K. Renz, G. Koch, "Design Aspects of a Fully Microcomputer-Based Feeder Protection System for HV Lines", International Conference on Large High Voltage Electric Systems, Paris, France, August 1986.

[8] M. Kezunovic, S. Kreso, P. Vujovic, B. Perunicic, S. Sadivic, "Application of Digital Computer Technology to the Implementation and the Testing of an Integrated Substation Protection and Control System", International Conference on Large High Voltage Electric Systems, Paris, France, August 1986.

[9] S.L. Nillson, H.R. Petrie, J.S. Deliyannides, L.L. Mankoff, "New Digital Control and Protection System for Transmission Substations", International Conference on Large High Voltage Electric Systems, Paris, France, August 1986.

[10] C.M.F. dos Santos, J. Szczupak, J.C.N. Bianco, A. Tureli, "Digital Distributed System for Measurement, Protection and Control", Planning and Operation of Electric Energy Systems, IFAC Symposium, Rio de Janeiro, Brazil, 1986.

[11] J.P. Sucena Paiva, J.L. Pinto de Sa, L. Barruncho, V. Abelaira, "Integrated Data Acquisition and Automation in Distribution Substations", Planning and Operation of Electric Energy Systems, IFAC Symposium, Rio de Janeiro, Brazil, 1986.

[12] M. Narendorf, B.D. Russell, M. Aucoin, "Microcomputer-based Feeder Protection and Monitoring System - Utility Experience", IEEE Power Engineering Society Winter Meeting, New Orleans, LA, USA, February 1987.

[13] J. Ventosa, J. Novella, "Distributed and Integrated Station Control-Telecontrol System: Operating Economic Issues", Power Industry Computer Applications Conference, Montreal, Quebec, Canada, May 1987.

[14] P. Bornard, "Efficient Methodology for Steady State Security Assessment of Power Systems", Electrical Power & Energy Systems, Vol. 10, No. 2, April 1988.

[15] F.F. Wu, "Power System Protection and Substation Control: Trends, Opportunities and Problems", Electrical Power Systems, Vol. 10, No. 2, April 1988.

[16] J. Douglas, "Building the Smarter Substation", EPRI Journal, Vol. 13, No. 4, June 1988.

[17] M. Kezunovic, B.D. Russell, "Microprocessor Applications to Substation Control and Protection", IEEE Computer Applications in Power, Vol. 1, No. 4, October 1988.

[18] P. Bornard, "Power System Protection and Control: Trends, Opportunities and Problems", Electricite de France, Bulletin de la Direction des Etudes et Recherches, Series B, 1988.

[19] A. S. Tanenbaum, "Computer Networks - second edition", Prentice-Hall, 1988.

[20] B.D. Russell et al. "Application of Microcomputer-Based Systems in Power Substations", IEEE Transactions on Power delivery, Vol 4, No. 1, January 1989

[21] J.S. Lawler, J.S. Lai, L.D. Monteen, J.B. Patton, D.T. Thomas, "Impact of Automation on the Reliability of the Athens Utilities Board's Distribution System", IEEE Transactions on Power Delivery, Vol. 4, No. 1, January 1989.

[22] E. Bondia, E. Suarez, F. Cobelo, " Integrated Protection and Control for Rural Substations", 4th International Conference on Developments in Power System Protection, Edinburgh, England, April 1989.

[23] C.Y. Two, T.W. Chan, "Overall Assessment of Distribution Back up Protection using Microcomputer", 4th International Conference on Developments in Power System Protection, Edinburgh, England, April 1989.

[24] J.Trecat, J.Wang, "Expert System Applications in Substation Monitoring, Back-up Protection and Control", 4th International Conference on Developments in Power System Protection, Edinburgh, England, April 1989.

[25] D. Konick, J. Rupar, B. Suhel, J. Gorisek, "Microprocessor-based Integrated Feeder Protection RIR 2000", 4th International Conference on Developments in Power System Protection, Edinburgh, England, April 1989.

[26] W.Cheetham, P. Craddock, "Substation Protection and Control: A Look into the Future", 10th International Conference on Electricity Distribution, Brighton, England, May 1989.

[27] B. Jeyasurya, S.S. Venkata, S.V. Vadari, J. Postforoosh, "Fault Diagnosis Using Substation Computer", Power Industry Computer Application Conference, Seattle, WA, USA, May 1989.

[28] M. Suzuki, T. Matsuda, N. Ohashi, R. Tsukui, Y. Sano and T. Yoshida, " Development of a Substation Digital Protection and Control System Using Fibre-Optic Local Area Network" IEEE Transaction on Power Delivery, Vol. 4, No.3, July 1989.

[29] L.L. Mankoff, G.D. Rockefeller, "EPRI R&D Programs with Digital Systems for Hierarchical Integrated Protection and Control", Southern Electric Industry Applications Symposium, New Orleans, LA, USA, November 1989.

[30] B.S. Stognii, A.V. Kirilenko, E.S. Kokhno, "Reliability of Failure Resistant Microprocessor Systems for Automation and Protection", Soviet Electrical Engineering, Vol. 60, No. 5, 1989.

[31] R.A. Kennedy, D.N. Rickey, "Monitoring and Control of Industrial Power Systems", IEEE Computer Applications in Power, Vol. 2, No. 4, 1989.

[32] C.J. Krug, B.R. Quayle, "Networking Communication for Power Monitoring and Control of Mill Power Distribution", Annual Pulp and Paper Industry Technical Conference, Seattle, WA, USA, 1990.

[33] J.J. Rogers Jr, "Advantages of Distributed Control Systems in Plant and Transmission Operations for Power System Control and Security", 33rd Power Instrumentation Symposium, Toronto, Ontario, Canada, May 1990.

[34] W.H. Kwon et al., " Real-time fibre optic network for an Integrated Digital Protection and Control System", IEEE Transactions on Power delivery, Vol 7, No. 1, January 1992.

[35] A. Zayegh, A. Kalam and Z. Chen, " 32-bit Microprocessor Based Digital Relaying Techniques for Overcorrect and Differential Protection", International AMSE Conference. " Application of Signals, Data System Methodologies to Engineering Problems", Alexandria (Egypt), Dec 1992.

[36] Q. Yang, Y. Zhao, R. Watson, "Whole Transformer Station Protection and Automation - A Local Area Network Approach", Fifth International Conference on Development in Power System Protection, University of York UK, Mar 1993.

[37] A. Inam , G. Ziegler, "Advanced Substation Protection and Control - Design and Introduction of the Second Generation", Fifth International Conference on Development in Power System Protection, University of York UK, Mar 1993.

[38] L.G. Anderson, C. Ohlen, W. Wimmer, I. De Mesmaeker, T. Jones, "The Intelligent Protection, Control and Monitoring Terminal", Fifth International Conference on Development in Power System Protection, University of York UK, Mar 1993.

[39] C.Booth, J.R. McDonald, R.W. Stewart, W.J. Laycock, A. Bennet, " Coordinated Control and Protection : Functionality Enhancements via Information Technology", Fifth International Conference on Development in Power System Protection, University of York UK, Mar 1993.

[40] M.S Sachdev, B. Chattopadhyay, T.S. Sidhu, "A New Approach to Distribution Protection- Adaptive Relaying", Fifth International Conference on Development in Power System Protection, University of York UK, Mar 1993.

[41] L.G. Anderson et al., " The Integrated Protection, Control and Monitoring Terminal", Fifth International Conference on Development in Power System Protection, University of York UK, Mar 1993..

[42] A.Zayegh, A.Kalam, C. Kannangara, "Model of an Integrated Substation and Protection and Control System", Modelling and Simulation '93 Conference, Victoria University of Technology, Melbourne, Australia, July 1993.

[44] Windows for Workgroups Resource Kit Version 3.1, Microsoft Corporation, 1992

[45] Labview, Graphical Programming for Instrumentation, Reference Manuals, National Instruments, August 1993.

[46] NI-DAQ Functions Reference Manual for DOS/Windows/Lab Windows, National Instruments Corporation, March 1992.

[47] Lab PC+ User Manual, February 1993, National Instruments Corporation, February 1993.

[48] Borland C++ and Application Frameworks for Windows and DOS, Version 3.1, User Manuals, Borland International Inc., 1992.

[49] Topware TE2000AD Installation and Configuration Guide.

[50] Black Box Catalogue - The source of connectivity, Black Box Catalogue Australia Pty. Ltd. Issue 2, 1993.

APPENDIX A

NI-DAQ Function Tree for Data Acquisition and Control

Data Acquisition

- **Initialisation/Utilities**
  - Init_DA_Brds
  - Timeout_Config
  - Master_Slave_Config
  - Get_DA_Brds_Info
  - Set_DAQ_Mode
  - Align_DMA_Buffer
  - Trigger_Window_Config
  - Get_NI_DAQ_Version
- **Analog Input**
  - **Single Point**
    - AI_VRead
    - AI_Clear
    - AI_Read
    - AI_VScale
    - AI_Setup
    - AI_Check
    - AI_Configure
  - **Multiple Point**
    - DAQ_Op
    - SCAN_Op
    - Lab_SCAN_Op
    - DAQ_to_Disk
    - SCAN_to_Disk
    - Lab_SCAN_to_Disk
    - **Low Level Functions**
      - DAQ_Rate
      - DAQ_Start
      - SCAN_Setup
      - SCAN_Start
      - DAQ_Check
      - DAQ_Monitor
      - Lab_SCAN_Start
      - Lab_SCAN_Check
      - DAQ_Clear
      - DAQ_VScale
      - SCAN_Demux
      - DAQ_Config
      - DAQ_Trigger_Config
      - DAQ_DB_Config
      - DAQ_DB_HalfReady
      - DAQ_DB_Transfer
      - DAQ_DB_StrTransfer
  - **Simultaneous Sample/Hold**
    - **Single_Scan (MAI)**
      - MAI_Coupling
      - MAI_Setup
      - MAI_Arm
      - MAI_Read
      - MAI_Scale
      - MAI_Clear
    - **Multiple Scan (MDAQ)**
      - MDAQ_Trig_Select
      - MDAQ_TRig_Delay
      - MDAQ_ScanRate
      - MDAQ_Setup
      - MDAQ_Start
      - MDAQ_Get
      - MDAQ_Check
      - MDAQ_Stop
      - MDAQ_Clear
- **Analog Output**
  - **Single Point**
    - AO_VWrite
    - AO_VScale
    - AO_Write
    - AO_Update
    - AO_Config
  - **Waveform Generation**
    - WFM_Op
    - WFM_from_Disk
    - Low Level Functions
      - WFM_Scale
      - WFM_Rate
      - WFM_Group_Setup
      - WFM_Load
      - WFM_ClockRate
      - WFM_Group_Control
      - WFM_Chan_Control
      - WFM_Check
      - WFM_DB_Config
      - WFM_DB_Transfer
      - WFM_DB_StrTransfer
- **Digital Input/Output**
  - DIG_Prt_Config
  - DIG_Line_Config
  - DIG_In_Port
  - DIG_In_Line
  - DIG_Out_Port
  - DIG_Out_Line
  - DIG_Prt_Status
  - **Group Mode**
    - DIG_Grp_Config
    - DIG_In_Grp
    - DIG_Out_Grp
    - DIG_Grp_Status
    - DIG_Grp_Mode
    - **Block Transfer**
      - DIG_Block_In
      - DIG_Block_Out
      - DIG_Block_Check
      - DIG_Block_Clear
      - DIG_Block_PG_Config
      - DIG_SCAN_Setup
      - DIG_DB_Config
      - DIG_DB_HalfReady
      - DIG_DB_Transfer
      - DIG_DB_StrTransfer
- **Counter/Timer**
  - CTR_Config
  - CTR_EvCount
  - CTR_Period
  - CTR_Stop
  - CTR_Restart
  - CTR_Reset
  - CTR_State
  - CTR_Rate
  - CTR_Pulse
  - CTR_Square
  - CTR_FOUT_Config
  - CTR_Simul_Op
  - **Interval Counters**
    - ICTR_Setup
    - ICTR_Read
    - ICTR_Reset

Appendix A - Function Tree for Data Acquistion

APPENDIX B

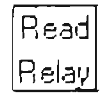
Program Details

This Appendix contains the details of the software developed under LABVIEW graphical instrumentation software package. The software library IPS.LLB was created which contained following virtual instruments.

- Data Retrieval from File . vi
- Demand to File . vi
- Analogue Input Waveform Acquire. vi
- Monitoring Terminal (1 - 13) . vi s
- Read Relay Status. vi
- Remote Client . vi
- Remote Server . vi
- Save Text File .vi
- Send Data to EXCEL . vi
- Set Relay . vi

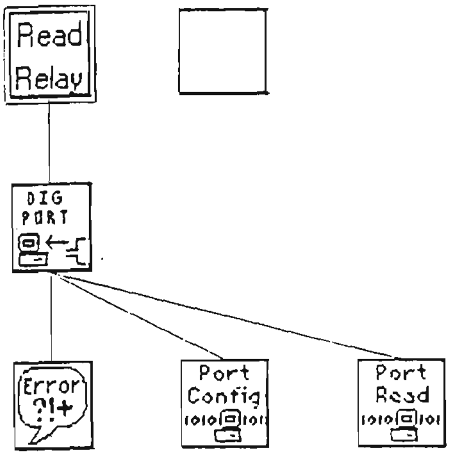
Details about the aforementioned software programs are given in this Appendix. The contents include,

- Object hierarchy of the program
- Front Panel of the output
- Block diagram of the program

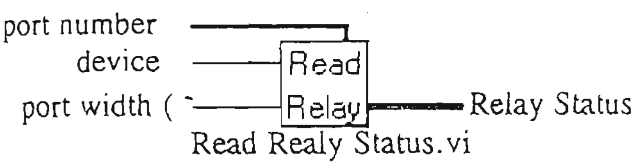


Read Realy Status.vi
12/01/94 02:55 AM

Position in Hierarchy

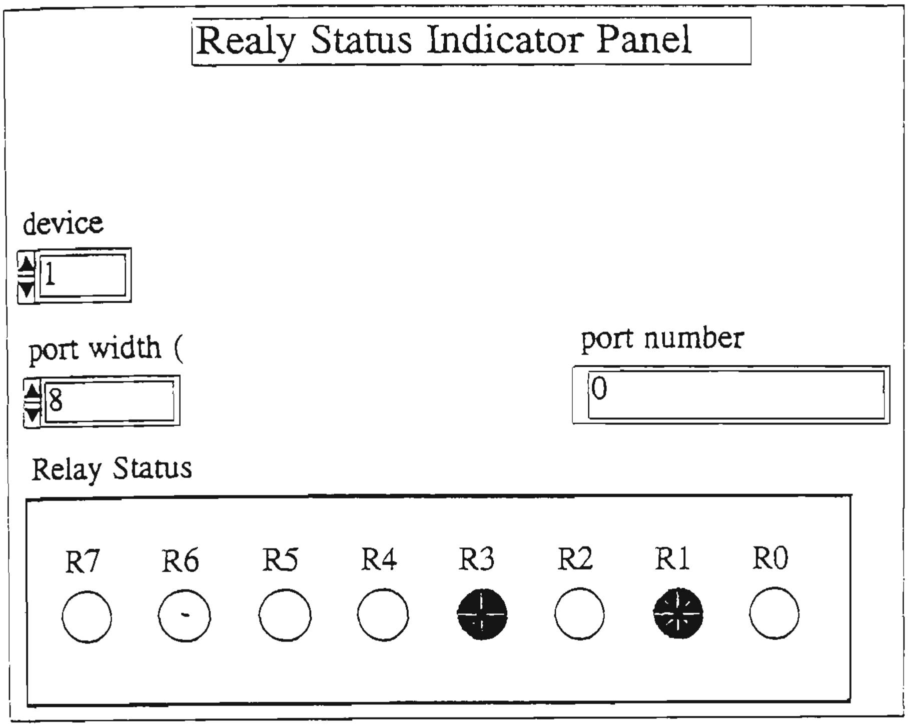


Connector Pane

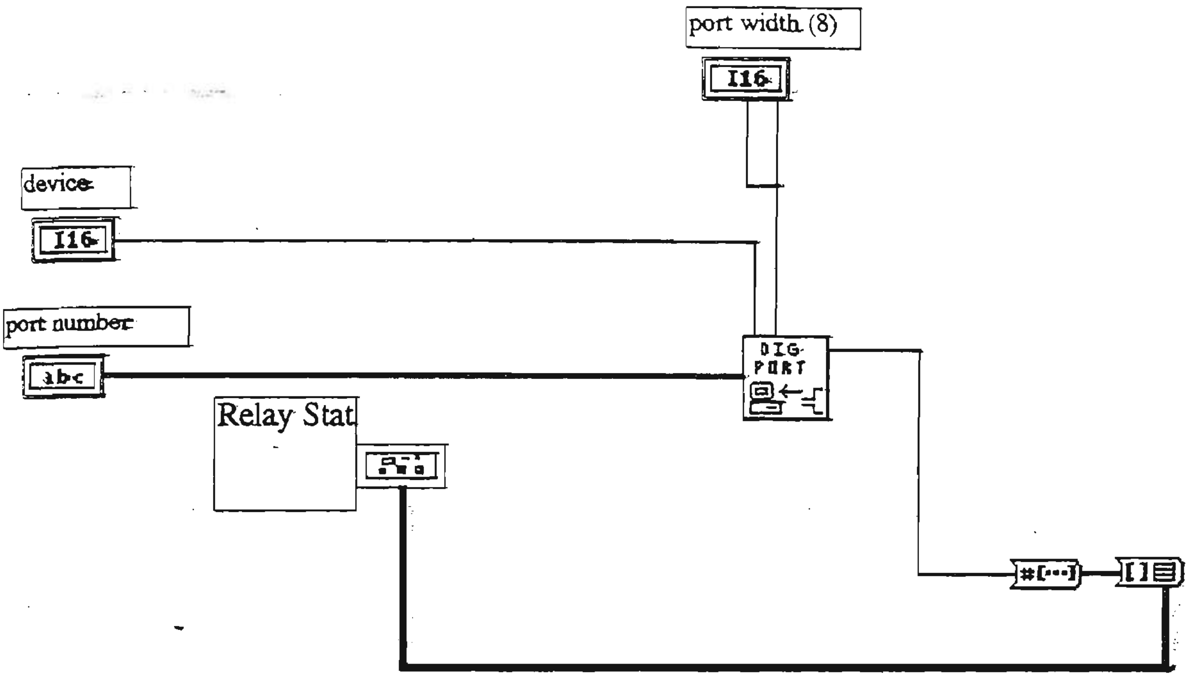


Get Realy Status vi senses the relay contactors and indicates the relay position through the light indicators in the front panel. This field level vi uses digital input to determine the relay status.

Front Panel

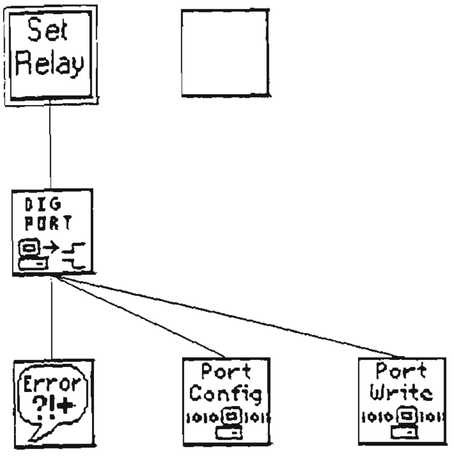

Realy Status Indicator Panel
device
1
port width (
8
port number
0
Relay Status
R7
R6
R5
R4
R3
R2
R1
R0

Block Diagram

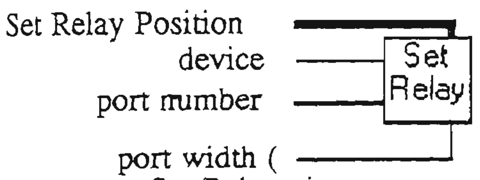


Set Relay.vi
12/01/94 02:58 AM

Position in Hierarchy



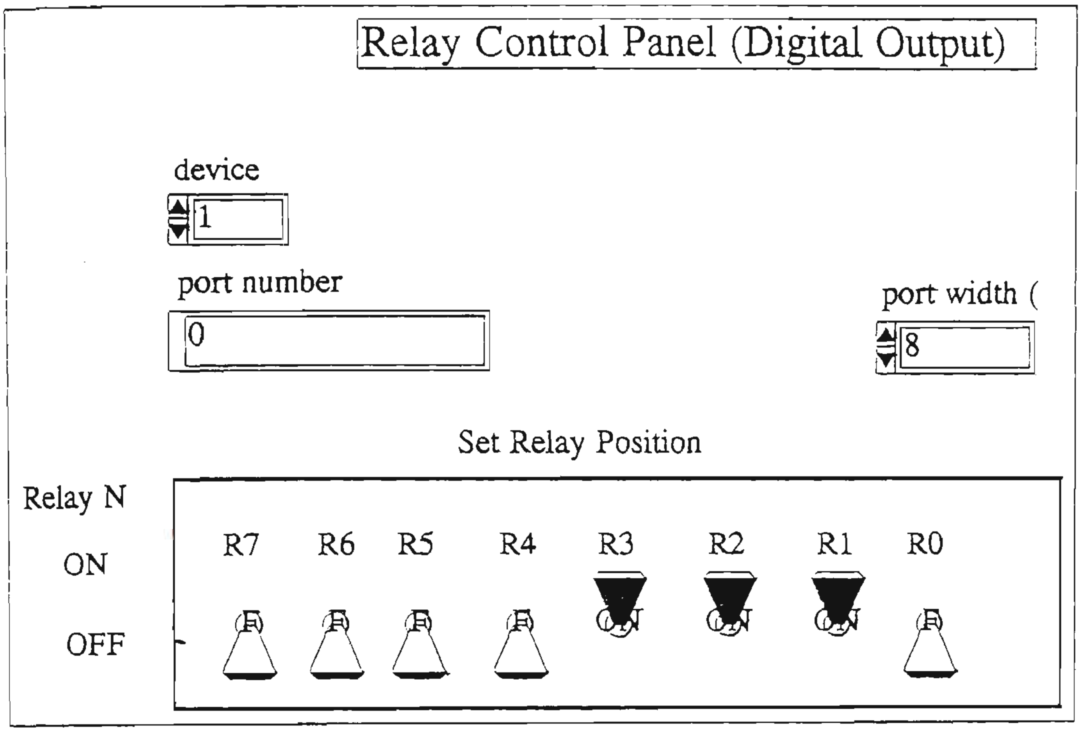
Connector Pane



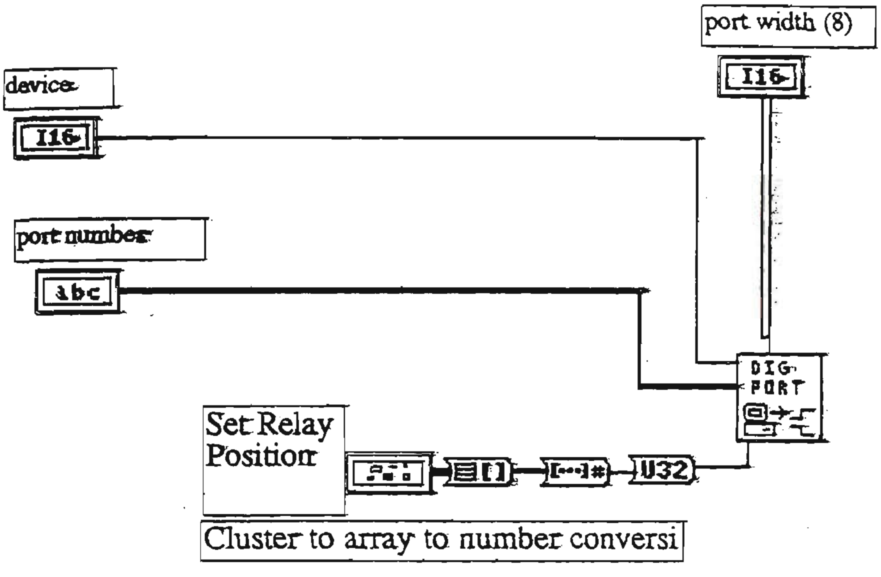
Set Relay.vi

Set relay.vi will set the relay contact position to ON or OFF state. The switches provided in the panel are used to set or reset realys. This field level function uses digital outputs to activate relay settings.

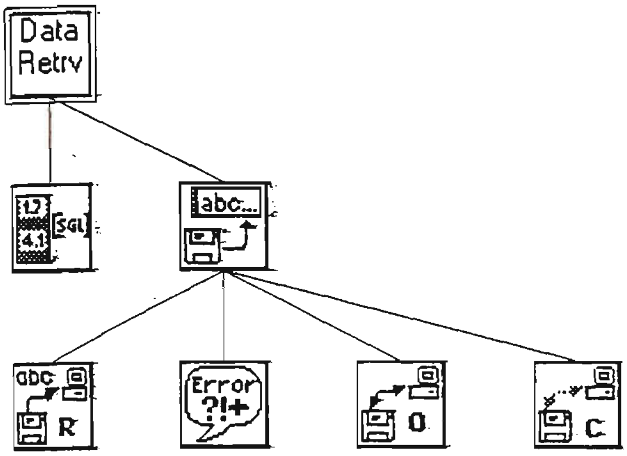
Front Panel


Relay Control Panel (Digital Output)
device
1
port number
0
port width (
8
Set Relay Position
Relay N
ON
OFF
R7
R6
R5
R4
R3
R2
R1
R0

Block Diagram



Position in Hierarchy



Connector Pane

Data Retrieval from file.vi

This virtual insatrument reads data saved in a file in text format. First the description appearing in string form displayed in a waveform chart. Good to save transient information or demand values.

Front Panel

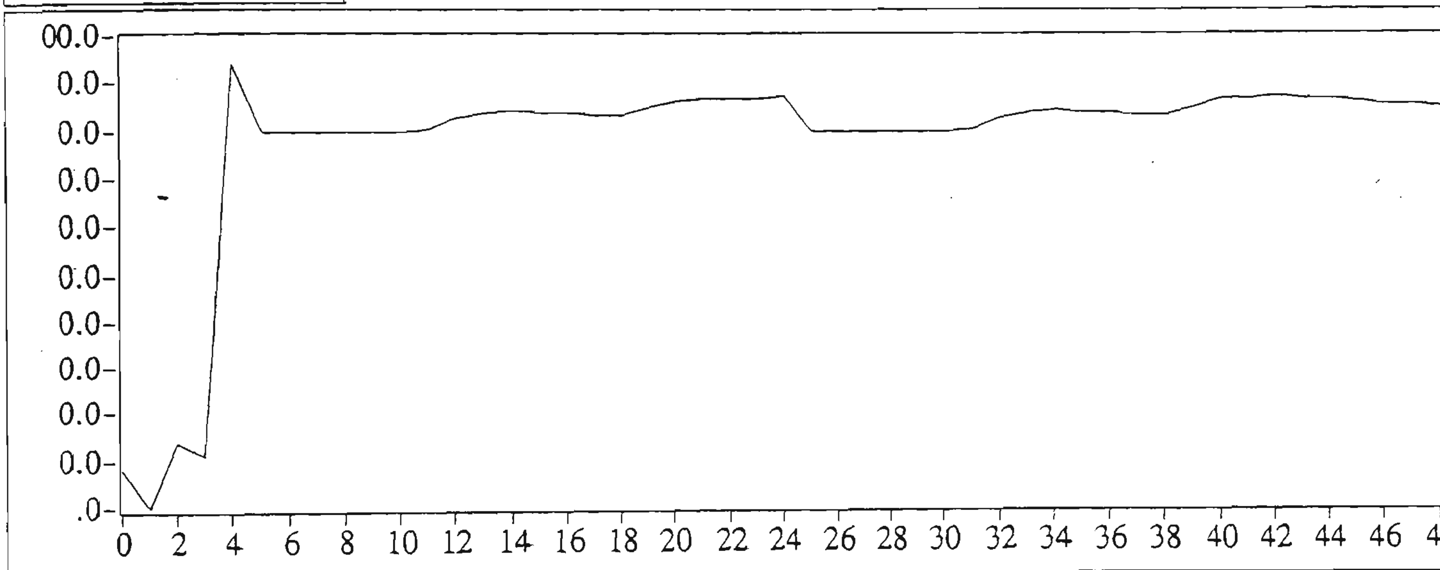
Data Retrieval From Text File

Enter File Path

String Read from F

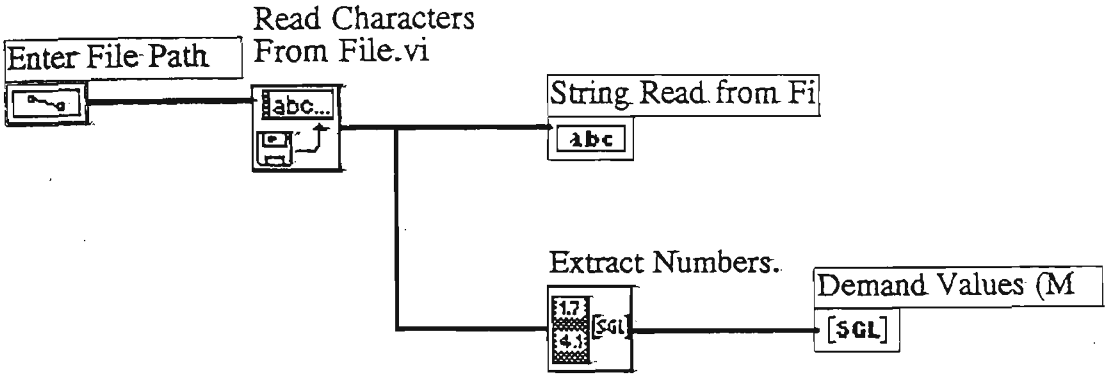
The Demand Values for the Period starting from 8:00am 14/11/94.

Demand Values (MW)



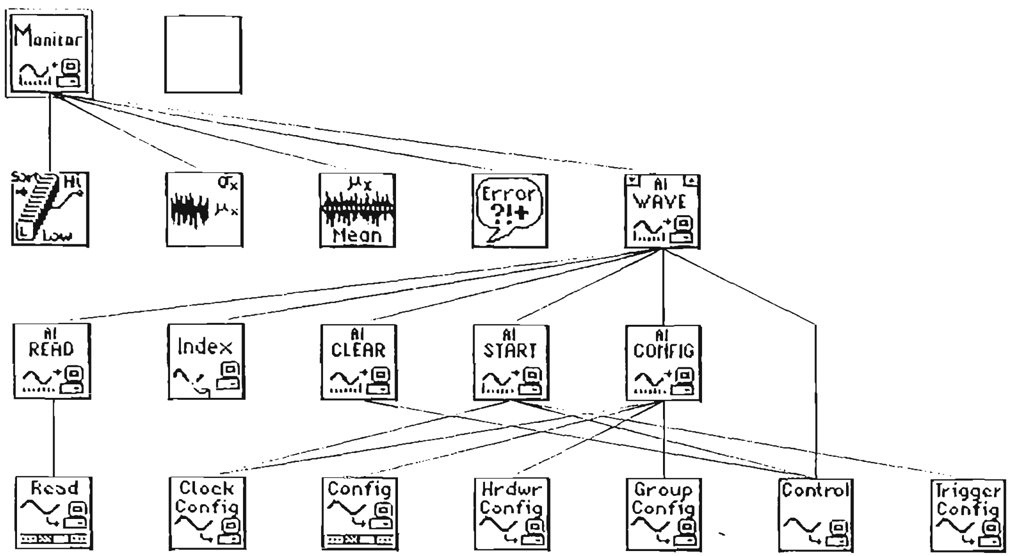
Time Inter

Block Diagram

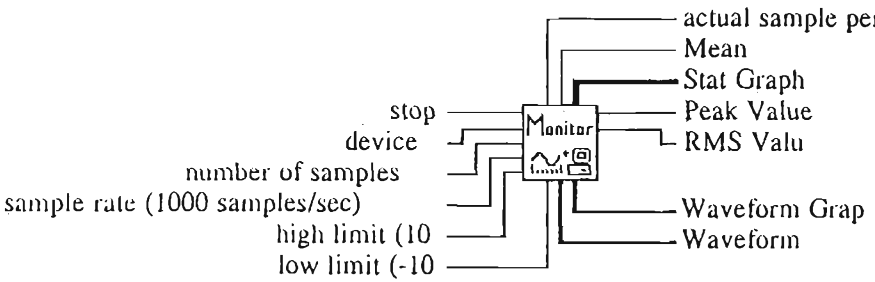


Monitoring Terminal 12.vi
12/01/94 02:40 AM

Position in Hierarchy



Connector Pane



Monitoring Terminal 12.vi

Monitoring Terminal 12.vi
12/01/94 02:45 AM

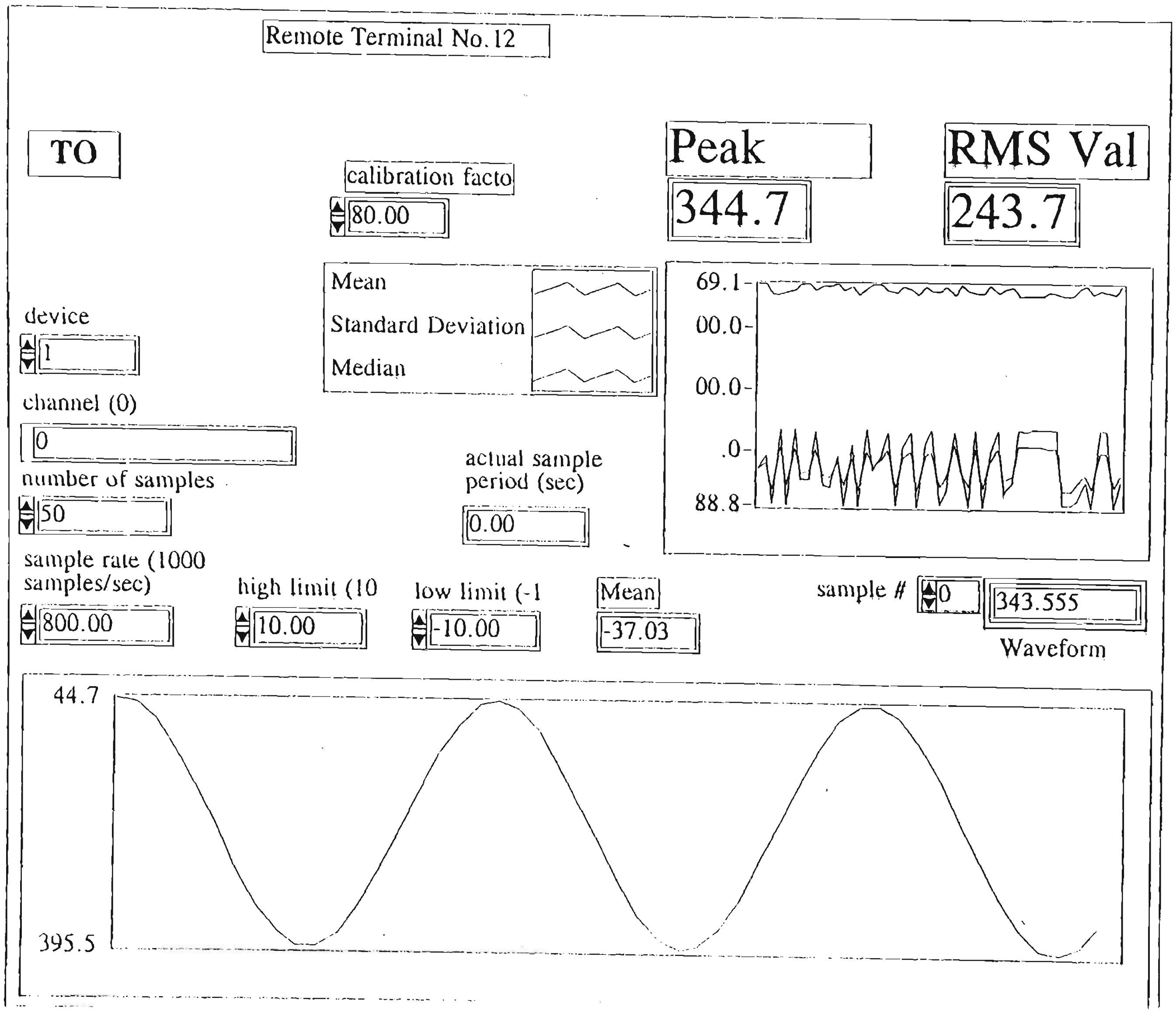
This field level vi acquires the specified number of scans at the specified scan rate and returns all the data acquired.

Use AI Waveform Scan to acquire a specified number of scans from a channel group at a specified scan rate. The VI stores the measurements in the buffer as they are acquired, and AI Read retrieves them from the buffer, scales them, and returns all the data as an array of voltages.

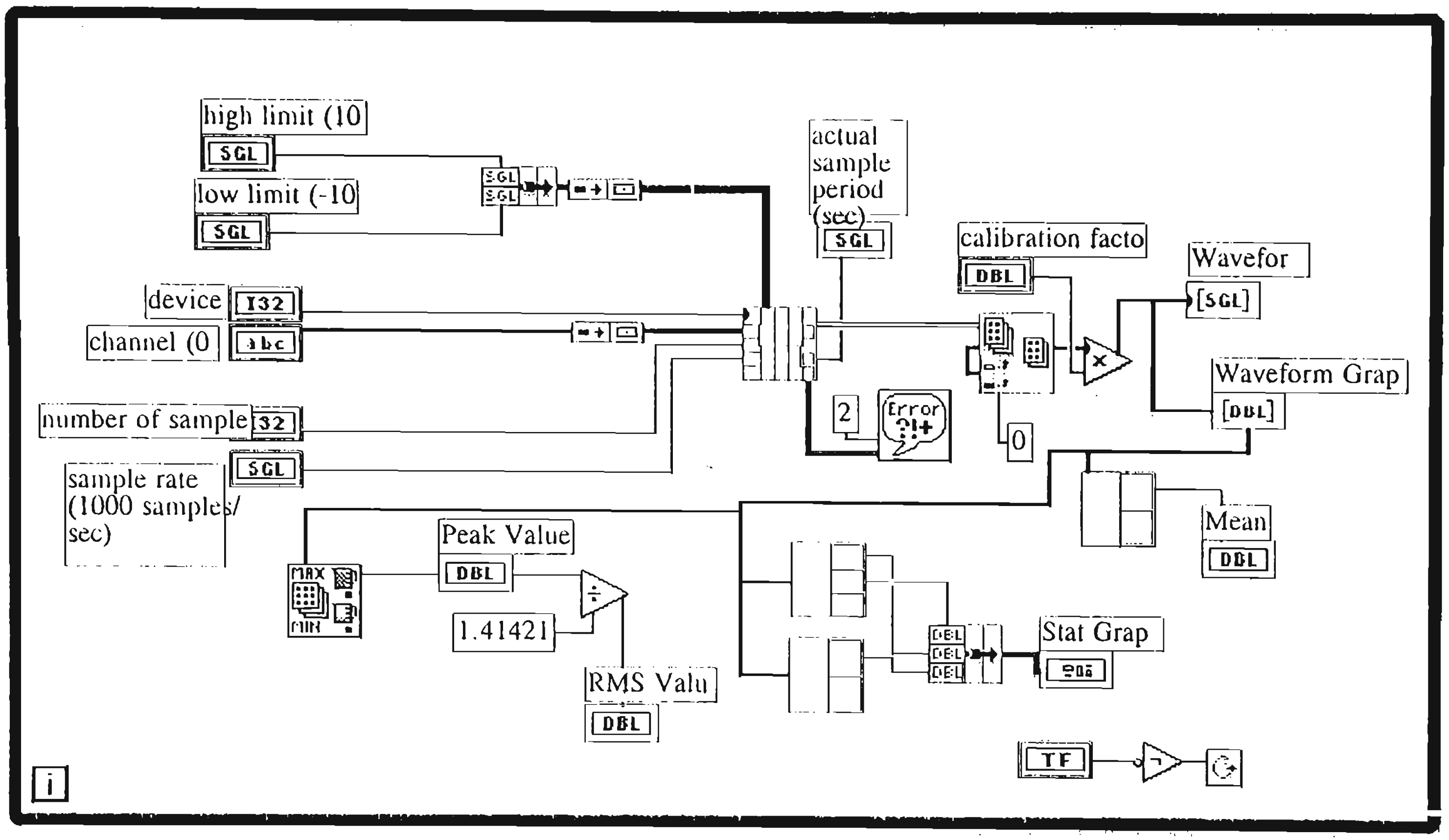
These voltage values are multiplied by the calibration factor of the instrument transformers or transducers used. Then the true RMS Value and Peak Value of the signal are computed and displayed.

These field level monitoring terminals, also provide inputs to the remote server vi which transfers data to other hierarchies.

Front Panel

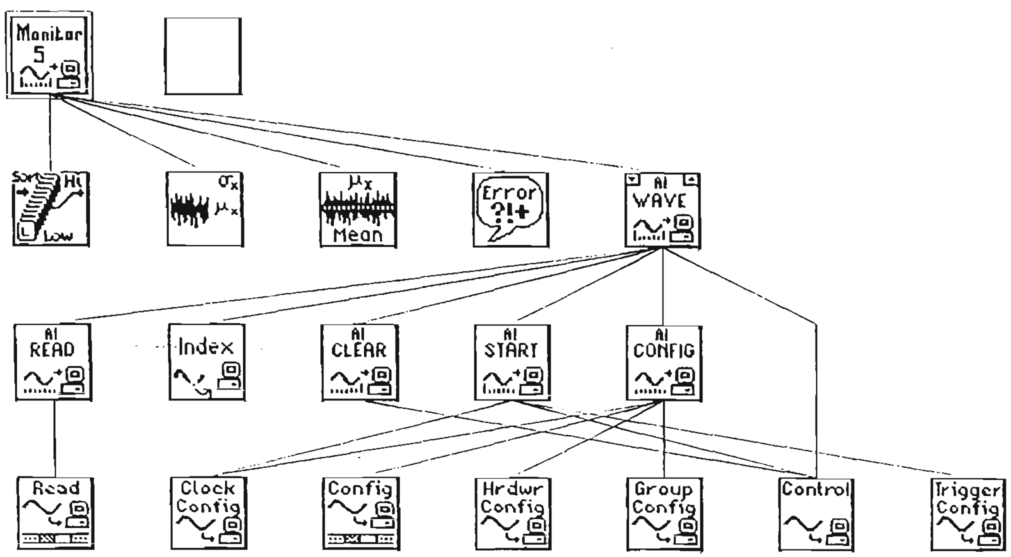

Remote Terminal No.12
TO
calibration facto
80.00
Peak
344.7
RMS Val
243.7
Mean
Standard Deviation
Median
69.1
00.0
00.0
.0
88.8
device
1
channel (0)
0
number of samples
50
actual sample period (sec)
0.00
sample rate (1000 samples/sec)
800.00
high limit (10
10.00
low limit (-1
-10.00
Mean
-37.03
sample #
0
343.555
Waveform
44.7
395.5

Block Diagram

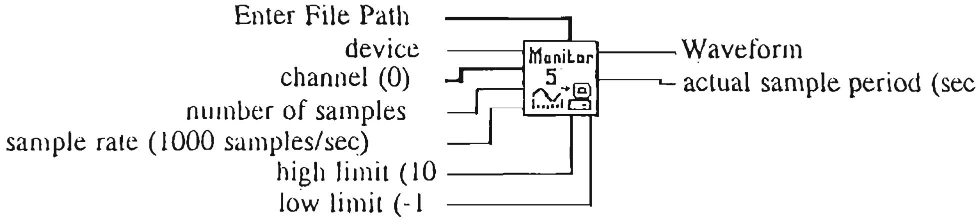


Monitoring Terminal 5.vi
12/01/94 02:52 AM

Position in Hierarchy



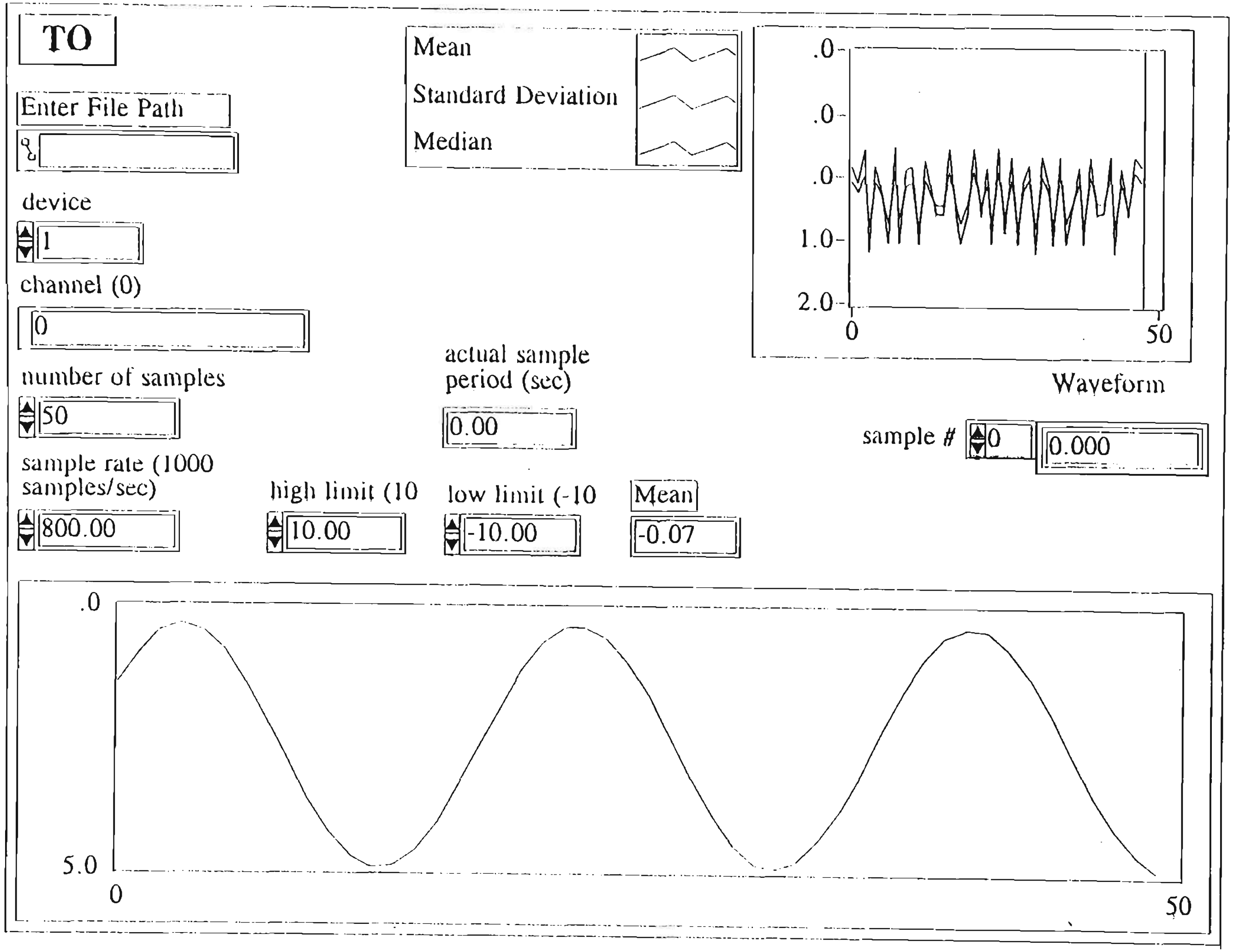
Connector Pane



Monitoring Terminal 5.vi

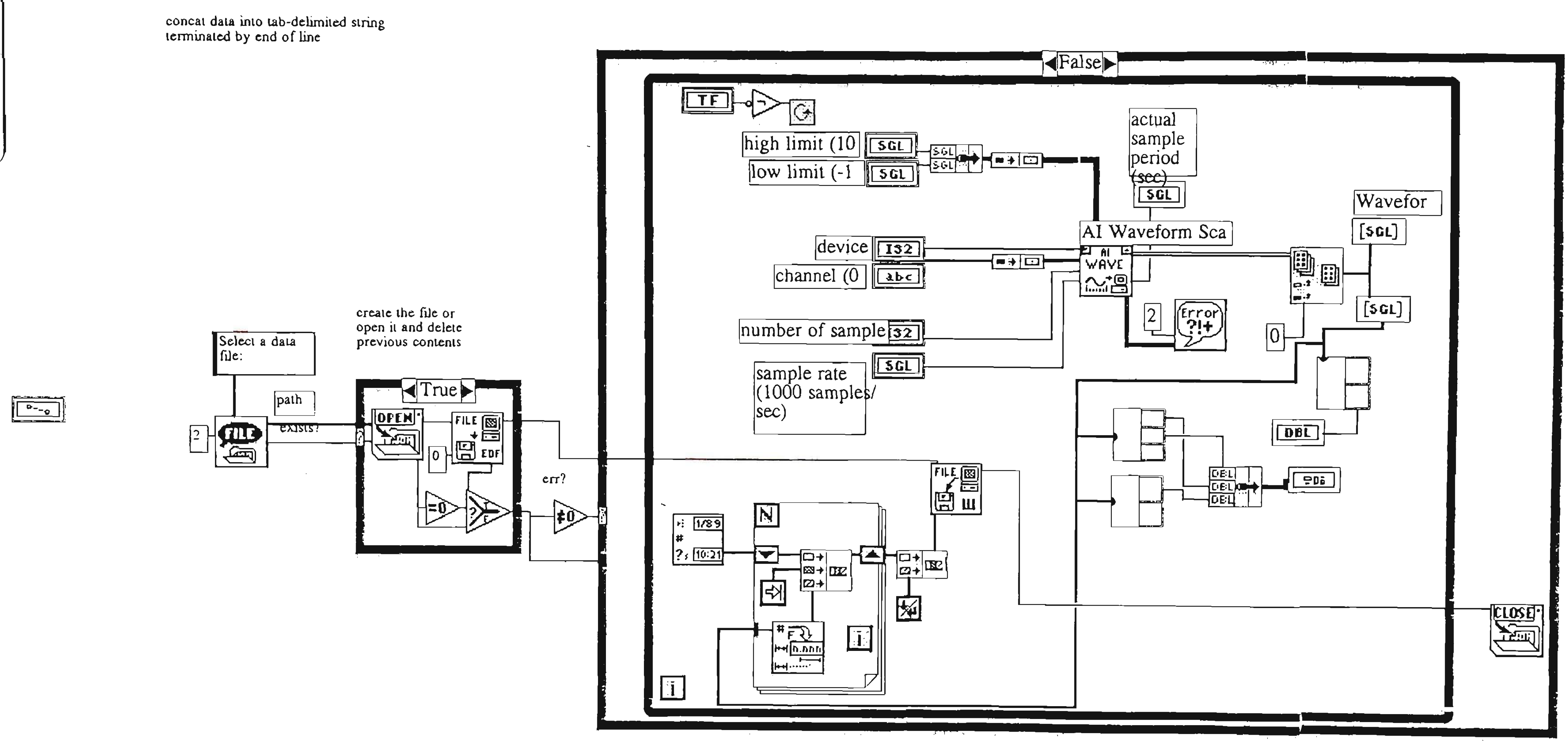
This field level instrument is capble of logging data into disk in addition to normal monitoring facility.

Front Panel

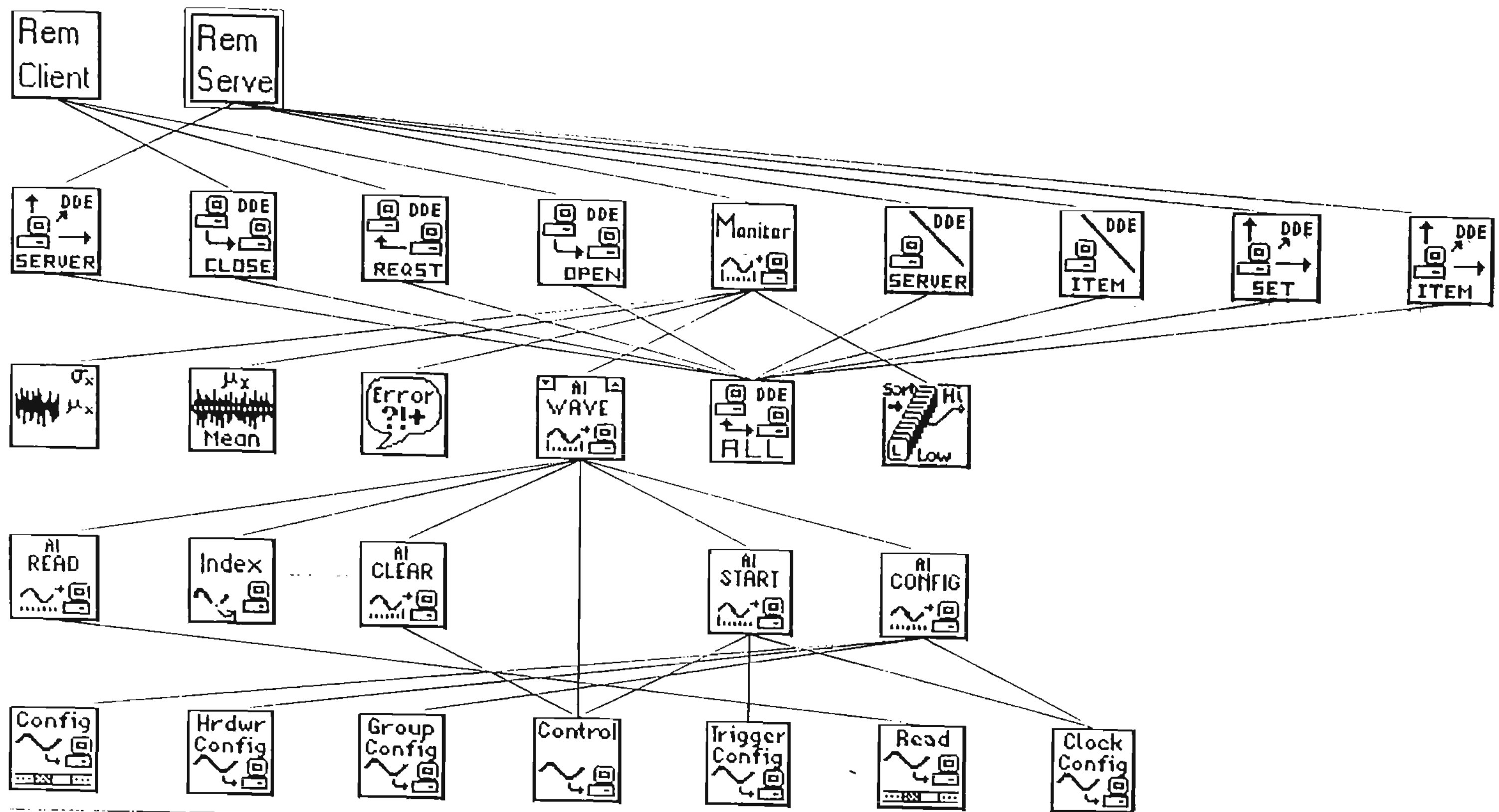

TO
Enter File Path
Mean
Standard Deviation
Median
.0
.0
.0
1.0
2.0
0
50
Waveform
device
1
channel (0)
0
number of samples
50
actual sample
period (sec)
0.00
sample #
0
0.000
sample rate (1000
samples/sec)
800.00
high limit (10
10.00
low limit (-10
-10.00
Mean
-0.07
.0
5.0
0
50

Monitoring Terminal 5.vi
12/01/94 02:52 AM

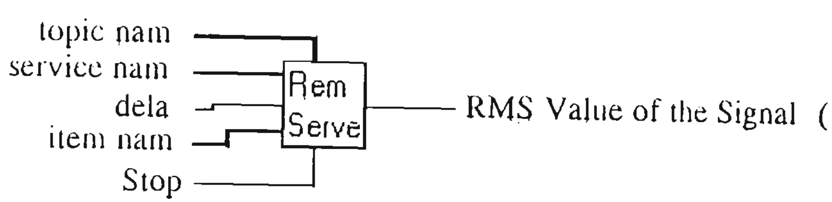
Block Diagram



Position in Hierarchy

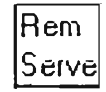


Connector Pane

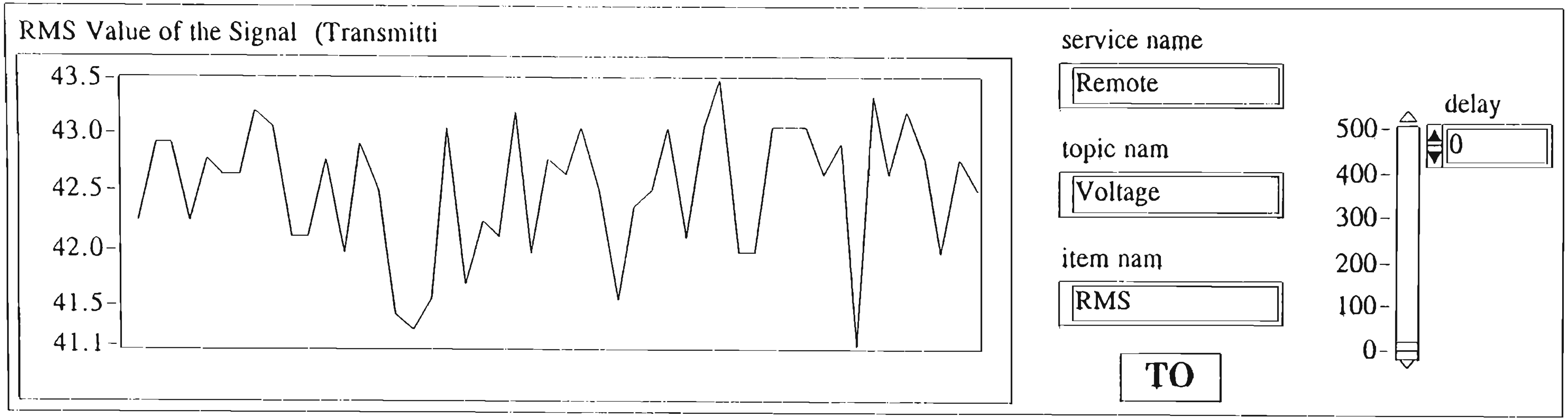


Remote Server3.vi

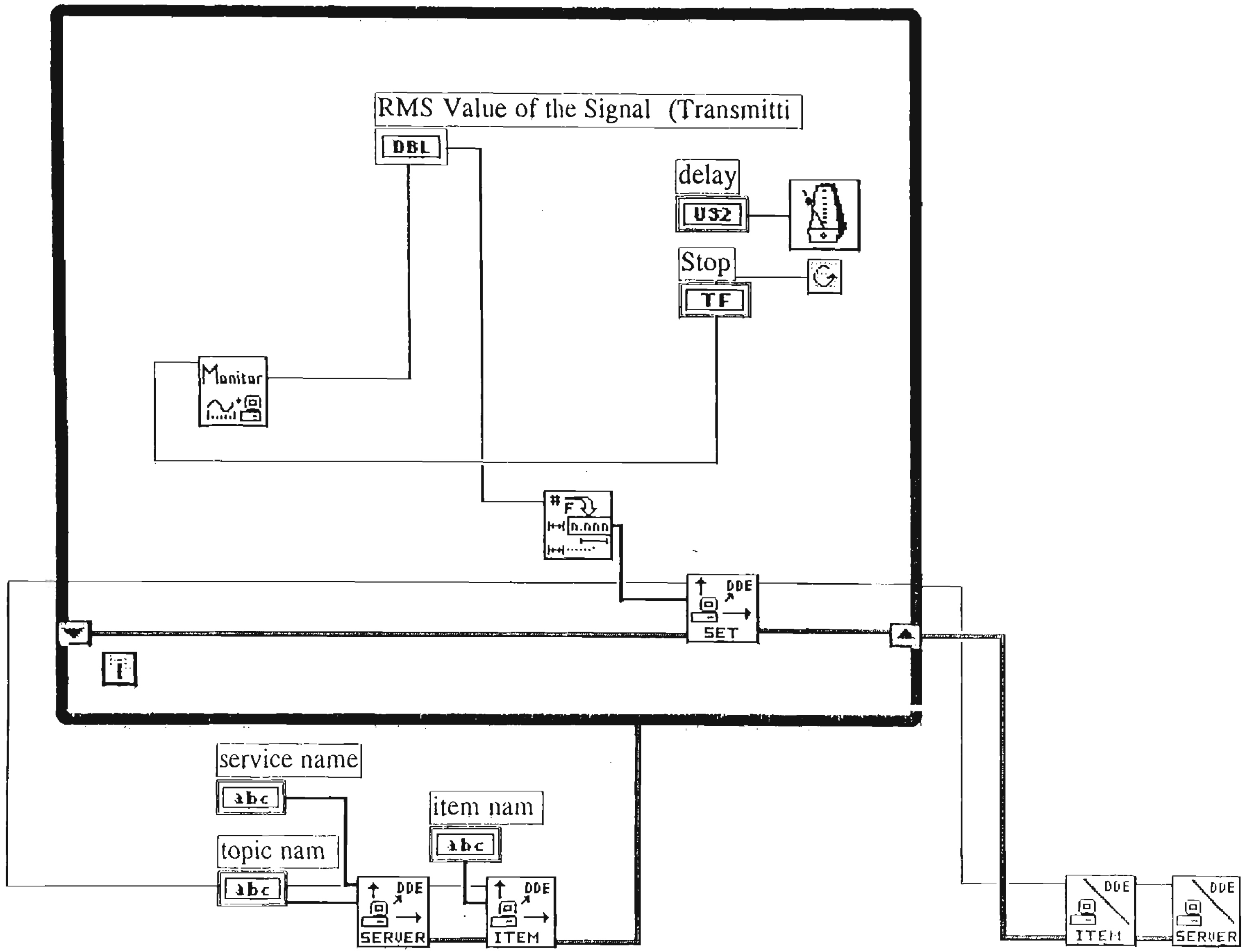
Remote Server.vi outputs a waveform via DDE to be read by Remote Client.vi. This field level vi acts as an input the to the signals read by the Remote Monitoring Terminals.


Rem
Serve

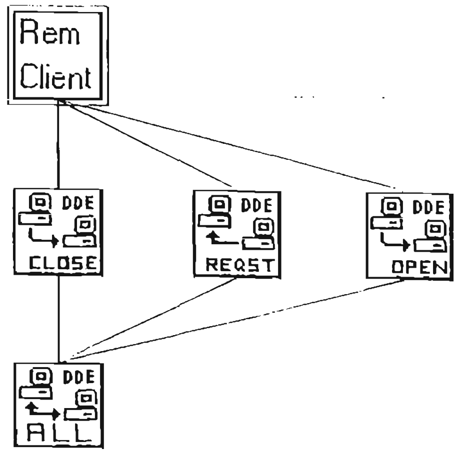
Front Panel


RMS Value of the Signal (Transmitti
43.5
43.0
42.5
42.0
41.5
41.1
service name
Remote
topic nam
Voltage
item nam
RMS
TO
delay
0
500
400
300
200
100
0

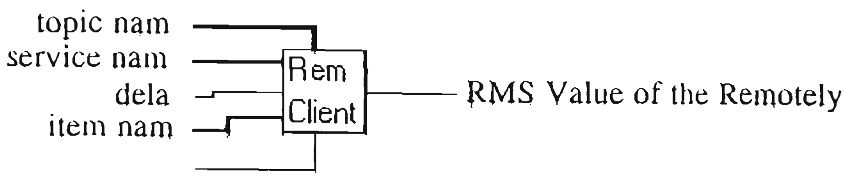
Block Diagram



Position in Hierarchy



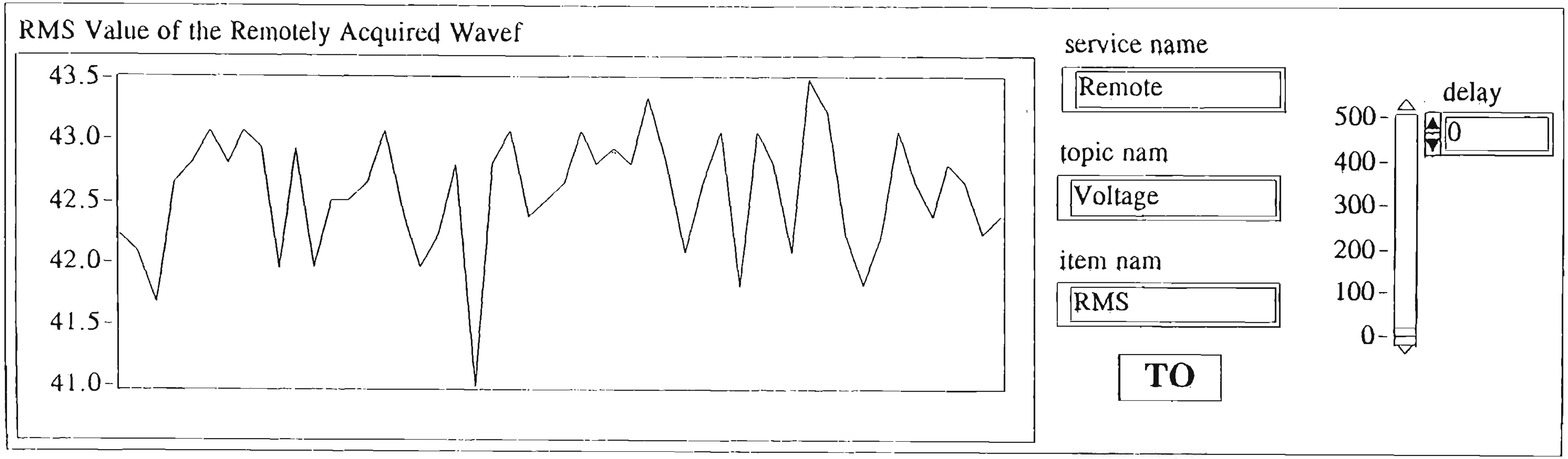
Connector Pane



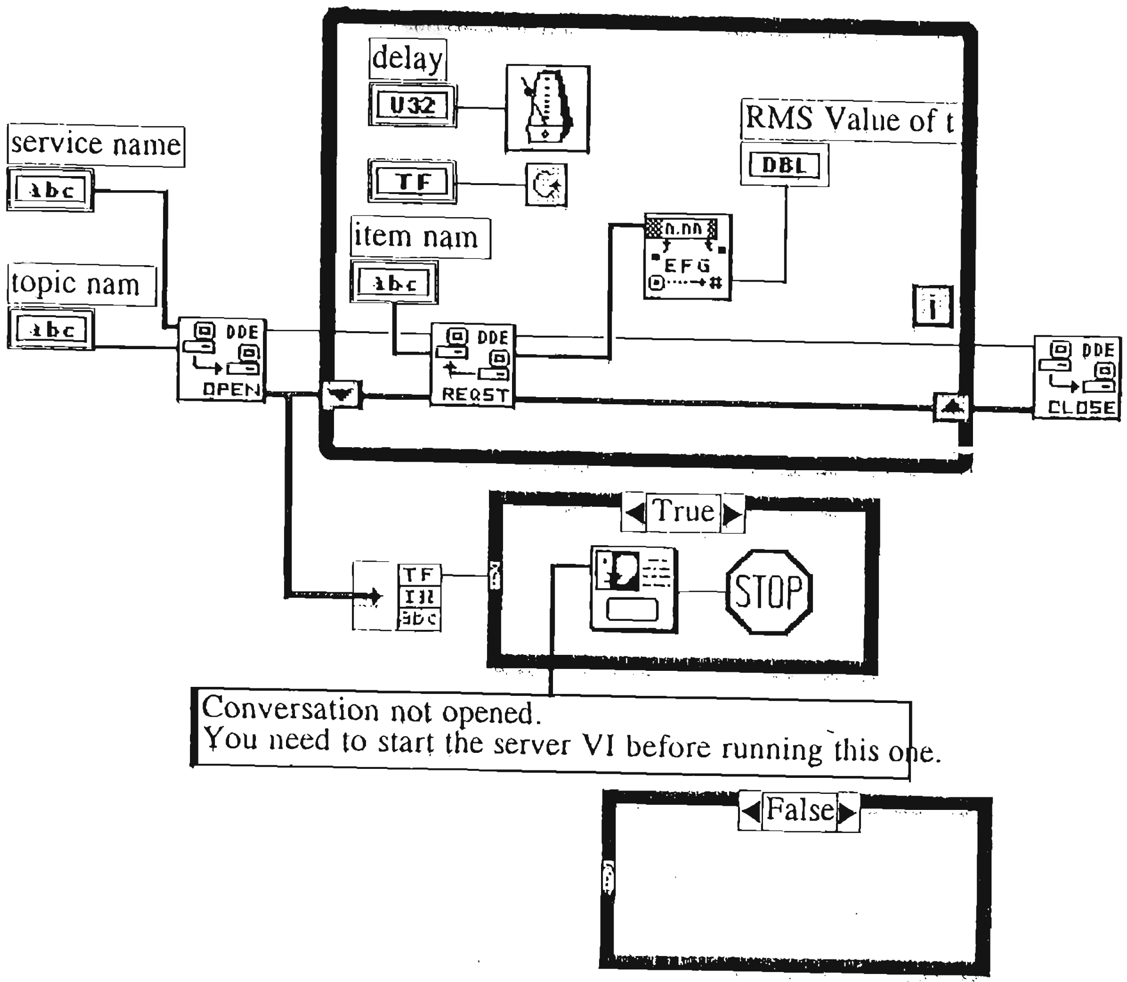
Remote Client.vi

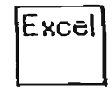
Remote client.vi requests information via DDE from Remote Server.vi. This vi is used by the coordination and management level processors to get information from field level processors.

Front Panel

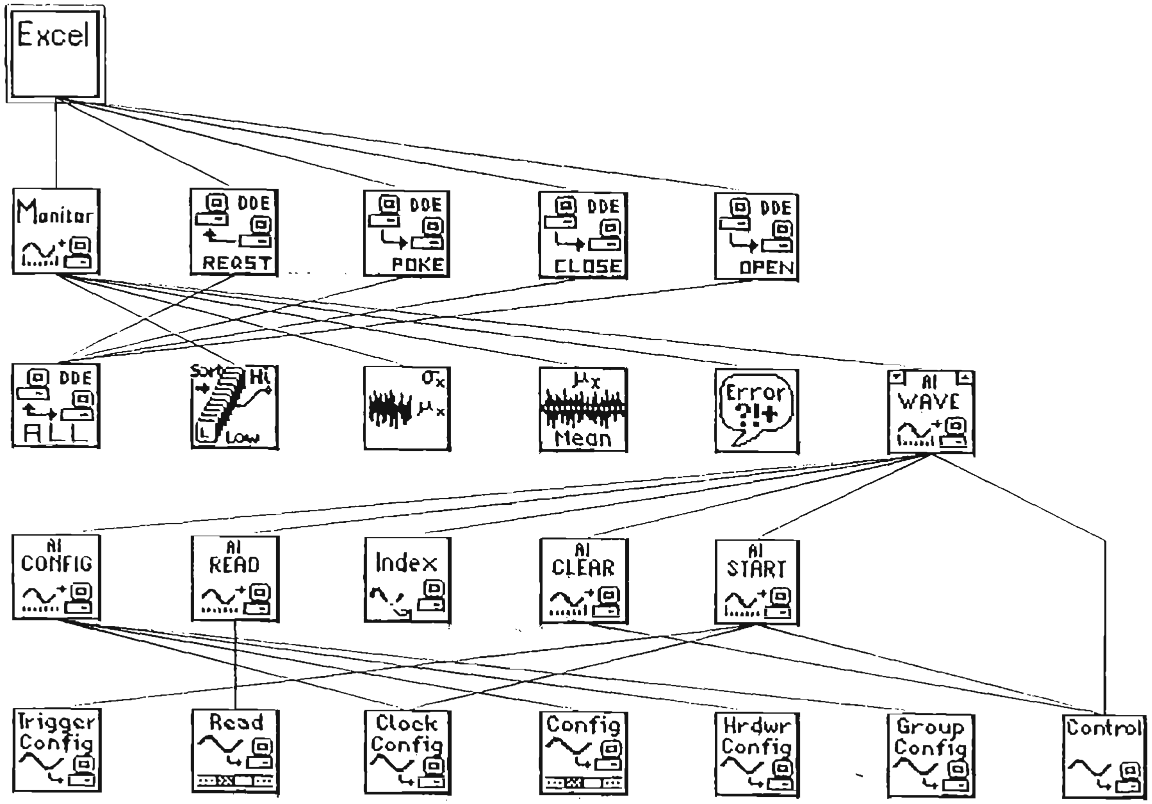

RMS Value of the Remotely Acquired Wavef
43.5
43.0
42.5
42.0
41.5
41.0
service name
Remote
topic nam
Voltage
item nam
RMS
TO
delay
500
400
300
200
100
0
0

Block Diagram

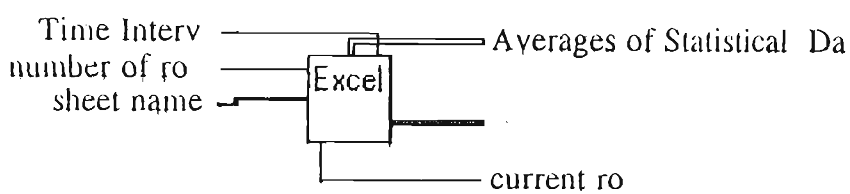




Position in Hierarchy



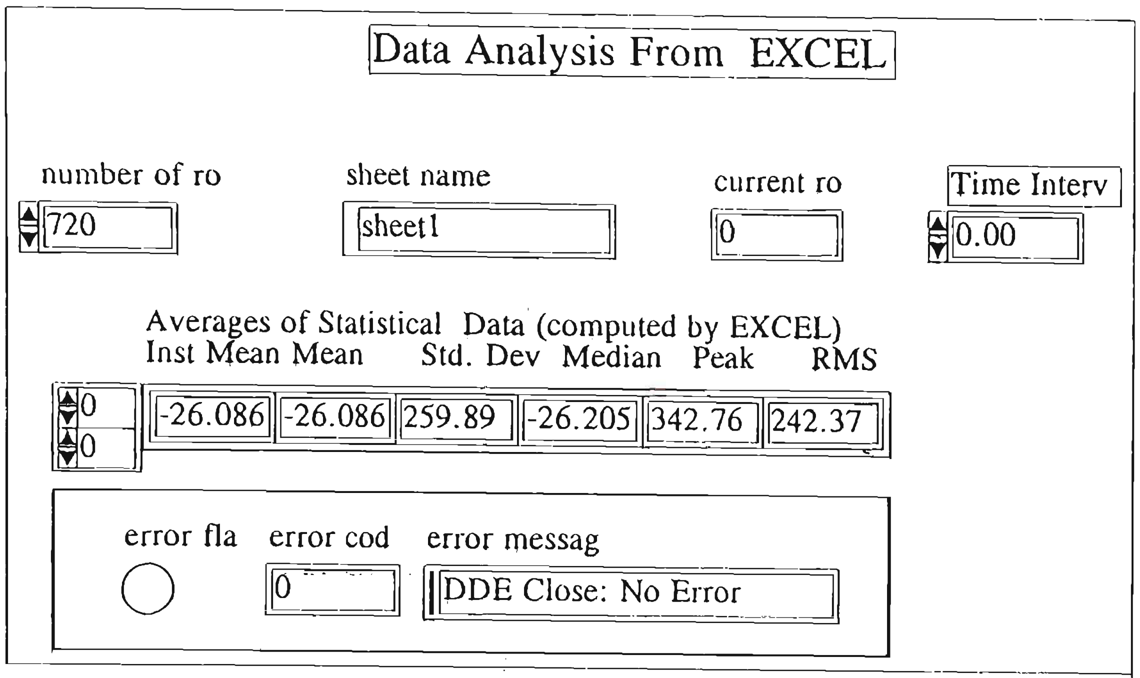
Connector Pane



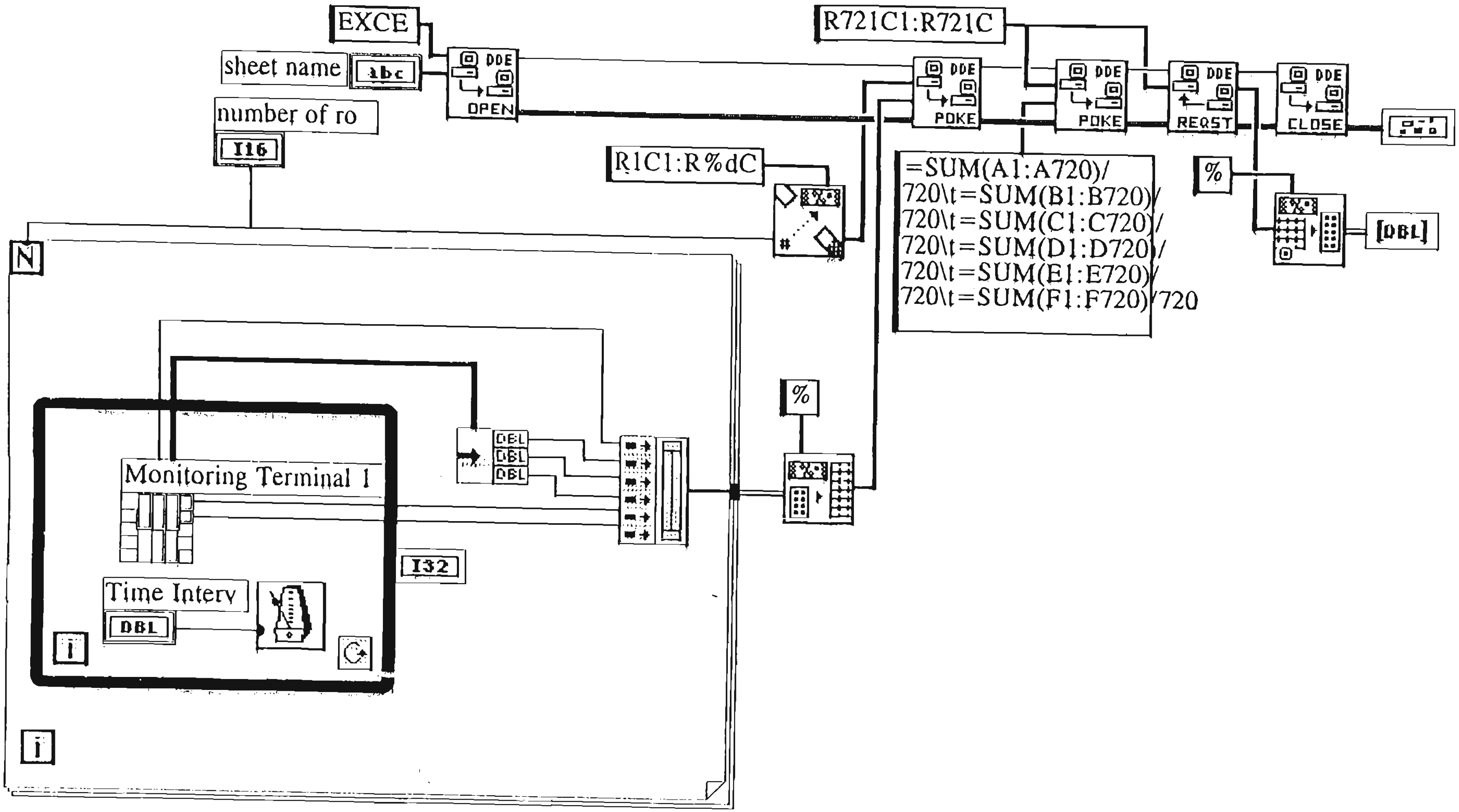
Send Data to EXCEL.vi

Data Analysis Using EXCEL vi is a Coordination and Managment level vi that sends data to EXCEL spreadsheets and calculates the average values. Any computation process could be done by changing appropriate EXCEL command. The data values could later be saved as EXCEL spreadsheets using EXCEL.
Time interval at which the data is acquired could be changed using the Time Interval input provided.

Front Panel



Block Diagram



APPENDIX C

Publications Related to the Work Presented

Proceedings, 2nd International Conference on "Modelling & Simulation," ~~Victoria University of~~ Technology, Melbourne, Australia, July 12-14, 1993, Vol.2

MODEL OF AN INTEGRATED SUBSTATION PROTECTION AND CONTROL SYSTEM

A. Zayegh, A. Kalam, C. Kannangara

Save Energy Research Group
Department of Electrical & Electronic Engineering
Victoria University of Technology
Melbourne, Australia

ABSTRACT

The recent advancements in the digital equipment associated with the power industry and the computer networks have opened a new era of the power system protection & control techniques. where the traditional power system control and protection could be superseded by integrated protection and control systems using computer networks.

This paper describes the development of the protection equipment needed and simulating the performance of the integrated substation protection and control system in an educational environment. using the commonly available IBM PC computers and highly reliable Local Area Networks (LAN) for the hierarchical system networking.

1. INTRODUCTION

The rapid development in digital technology has had a significant impact on power protection equipment and techniques. The common use of microprocessor based digital relaying paved the way for easy implementation of integrated substation protection and control systems.

1.1 Integrated Protection and Control Systems

Integration of control and protection of substation has been possible following the development of variety of digital equipment associated with the power industry. Substation protection, control and monitoring, traditionally includes a large number of equipment designed to perform specific tasks. Duplication of equipment, poor man-machine interface, high power consumption, high maintenance costs and lack of self monitoring and fault diagnosis are some of the other disadvantages associated with the traditional systems.

The advancement of multi tasking microprocessors and the availability of intelligent, easy to use standard interfaces, have made the development of customised computer networks a less exhaustive task. In order to integrate the protection and control system of a substation, these reliable, low cost computer networks offered an extremely feasible solution. As the hardware for these equipment has become relatively inexpensive compared to it's analogue counterparts, the initial fears of high costs involved in integrating protection and control systems using computers have diminished.

In an integrated protection and control system, the individual protection equipment are inter-connected via a communication link to form a Local Area Network (LAN). Each of these networks could be different from each other by their topology, media access control and the physical transmission media, depending on their application and the operating environment.

These networks normally have two levels of operation: Field Level and Coordination & Management Level. In the field level, analogue data usually from a current transformer or a voltage transformer is acquired and converted to a digital signal by a data acquisition unit. The same terminal equipment can deliver the control information received from the control station to the circuit breakers and switches. The field level of the network could either be a single processor or a low level LAN connecting processors with similar functions; ie. LAN connecting all bus protection units. Using the LAN all the field level processors are connected to a central computer. The coordination & management level computer possesses the intelligence to perform the analysis, supervision of archival data and coordination and reporting of short term data. Further it provides the synchronisation of the processors and maintains links with the outside world.

1.2 Current Developments

Many integrated systems are proposed and being tested currently in different parts of the world. Significant developments are made in Japan, China and in Europe. Most of these works are based on LAN architectures for integration.

In Japan a system is being tested using fibre optic media for physical transmission with IEEE 802.4 MAC (Media Access Control) protocol for communication between terminals[3]. In China there is a system using twisted pairs as communication media with RS485 interface along with Intel IPX344 intelligent BITBUS network transceiver[5]. Germany is proposing a second generation substation protection system that uses high level software tools to process the information[6]. This system using 32-bit microprocessors offers coordinated system structure with optical star configuration with built in comprehensive user software support packages. Data transmission rates in this system vary from 62 kbps to 6Mbps on higher levels. They have been able to demonstrate following facilities and advantages.

- alarm functions
- monitoring and accounting
- safety and reliability
- convenient operation and maintenance
- improved man machine interface
- self monitoring and fault recording
- comprehensive fault locating and recording
- interaction with external world

Further development is still emerging, and the integration of power system protection and control in the future, will be well established offering unlimited services. This type of integration was impossible a decade earlier.

This paper describes the design and implementation of an educational prototype integrated substation protection and control system using low cost, commonly available equipment to simulate an industrial model. The systems provide an interactive user interface and yet powerful enough to pursue further research activities.

2.0 SYSTEM DESIGN PHILOSOPHY

The main objective of this project is to design and implement an educational / research integrated substation protection control system, in order to demonstrate the advantages of using microprocessor based digital relaying techniques and LANs to build the required hierarchical networking architecture to achieve high reliability and new services in such environment.

2.1 Design Criteria

The following criteria were set for the design of an integrated substation protection and control system[1].

- Advanced relaying and control techniques ;

As the improved protection and control functions are necessary to meet the increasing demands of the power system security, the designed system must be able to provide intelligence to cope up with the requirements manifested by engineers. This implies the use of advanced microprocessor based digital relaying techniques.

- Centralised control and Distributed Processing ;

While offering distributed processing facilities to process short term data at local levels the system must be able to maintain centralised protection and control and monitoring functions. In other words the data acquired from the lower levels of the hierarchy are to be transferred to higher levels for further processing to influence the control decisions.

- Event Recording ;

Sophisticated monitoring system has to be provided in order to record the progress of the system. Archives have to be made and updated regularly. In addition to this, system must demonstrate higher degree of reliability and support unattended operation.

- Real Time Control ;

All control functions offered have to be in real time. Thus, the data acquisition, processing and transfer has to be done with minimum delay.

- Ability to perform Ad-Hoc Analysis on acquired Data ;

When there is a need, the system itself should be able to perform statistical analysis of the data and provide ad-hoc reports.

2.2 System Configuration

To satisfy the design criteria for the integrated substation protection and control system, the main elements are modelled in widely used IBM PC computers. Each of these computers are equipped with a Local Area network card and a Data acquisition card. A block diagram of the system configuration is shown in Figure 1.

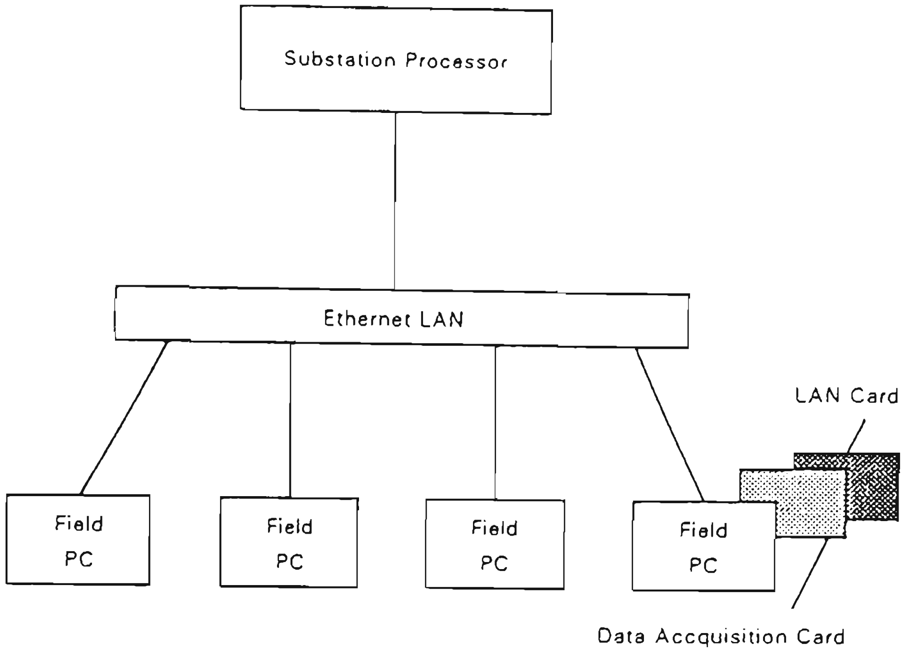


Figure 1. *System Configuration*

The main roles of each of these blocks are:

a. *The Local (Field) PC* : The local PC has the following functions.

- A local controller unit providing the digital relaying scheme required ; eg. Overcurrent Relay. Using a data acquisition unit it will continuously monitor the protected equipment in substation field; eg. Bus-bar, Transformer, etc., and provide the trip signal to the circuit breaker.

- Local monitor for specific terminal activity for the field operator.

- Member of low level network communicating with the central computer and the other computers in its level. (LAN card is installed in each PC).

b. *The Main Processor* : The main processor in this stage is based on IBM 486 machine. That will be replaced by a SUN - SPARK station later. The National Instruments Lab Window software package is used for the data analysis and presentation that provides us with the FFT, FHT, power spectrum, digital filters, interactive interface, multigraphs, strip charts, etc. as well as direct link with Lotus 1-2-3 or Symphony spreadsheet, ready for analysis.

3. SYSTEM FUNCTIONS

Individual PCs continually monitor the input through the Data acquisition card. In each of the PCs the memory is divided into two parts; Local memory and Common memory. Local memory contains the currently acquired data. If there is no abnormality in the power system operation, this data is expected to be the same over a long period of time. Common memory in each computer has copies of current status of all other computers in the network. If there is any change detected, the local processor immediately dumps a copy of the newly acquired data into the network bus. Using the network bus all the other PCs will update their common memory accordingly. This way all the computers in the cluster will have an understanding of the status of others at any given time. A dummy token is passed through the network in regular intervals to verify the alertness of each computer.

3.1 Media Access Control

For the media access control IEEE 802.3 *n*-persistent CSMA/CD (Carrier Sense Multiple Access / Collision Detection) standard is used with shielded twisted pairs as physical medium. *n* will be dependent on the number of the terminals in LAN. Interface board inside the computer contains a controller that is responsible for sending and receiving data in the proper format as well as computing checksums. The limitation of the cable length in this case is 500 metres maximum due to the restriction imposed by the medium used. This problem can be overcome to a certain extend by using repeaters[2].

3.2 Transmission Data Format

Transmission data format is expected to be in close relation to the IEEE 802.3 frame format that is a standard in many applications. The data field in the format is modified to cater the needs of the system. A presumed data format is shown in figure 2. [2]

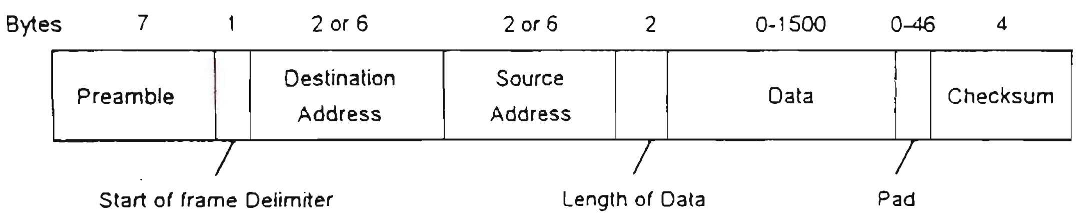


Figure.2. *Transmission format.*

4. FURTHER DEVELOPMENTS AND DISCUSSION

The integrated substation protection and control educational model is implemented. The system in it's early stage satisfies the basic design criteria and provides the basic requirement for educational purposes. The initial cost is very minimal because most of the system components are commonly used and already available in this department.

The system is tested under the following conditions to determine the main functionality.

a. The local PCs (controller) are sampling signal from dummy generators. and storing data in local and common memory.
b. The local controller is handling any abnormality without synchronisation (consulting) with main processor.
c. The main processor via an interactive user interface developed in this work, can ask each local controller for a copy of the actual status of the sampled data for further analysis and processing.

Currently the media used is shielded twisted pairs. This imposes a strict limitation on the data transfer rates. Yet it is economically feasible. In the future the medium might be changed to fibre optics which will offer enhanced data transfer rates and improved resistivity to electro magnetic interference.

As the number of terminal stations increases there will be increased attempts to get hold of the bus to transfer information. Due to this, collision rates may increase. To overcome this, a token bus is suggested in future. In a token bus architecture, it will be possible to assign priorities to the frames and since token is being held by one station at a time, collisions will not occur.

BIBLIOGRAPHY

[1] J. S. Deliyannides, E.A. Urden."Design Criteria for an Integrated Microprocessor-based Substation Protection and Control System." IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No.6 June 1982.

[2] A. S. Tanenbaum. "Computer Networks - second edition", Prentice-Hall, 1988.

[3] M. Suzuki, T. Matsuda, N. Ohashi, R. Tsukui, Y. Sano and T. Yoshida, " Development of a Substation Digital Protection and Control System Using Fibre-Optic Local Area Network" IEEE Transaction on Power Delivery, Vol. 4, No.3, July 1989, pp 1668-1674.

[4] A. Zayegh, A. Kalam and Z. Chen, " 32-bit Microprocessor Based Digital Relaying Techniques for Overcorrect and Differential Protection", International AMSE Conference. " Application of Signals, Data System Methodologies to Engineering Problems", Alexandria (Egypt), Dec 1992, AMSE Press, Vol.3, pp 81-87.

[5] Q. Yang, Y. Zhao, R. Watson, "Whole Transformer Station Protection and Automation - A Local Area Network Approach", First International Conference on Development in Power System Protection, University of York UK, Mar 1993, Proceedings pp 13-16.

[6] A. Inam , G. Ziegler, "Advanced Substation Protection and Control - Design and Introduction of the Second Generation", First International Conference on Development in Power System Protection, University of York UK, Mar 1993, Proceedings pp 38-41.

[7] L.G. Anderson, C. Ohlen, W. Wimmer, I. De Mesmaeker, T. Jones, "The Intelligent Protection, Control and Monitoring Terminal", First International Conference on Development in Power System Protection, University of York UK, Mar 1993, Proceedings pp 29-32.

DEVELOPMENT OF AN EDUCATIONAL INTEGRATED SUBSTATION PROTECTION AND CONTROL SYSTEM

A. Kalam C. Kannangara A. Zayegh

Save Energy Group
Department of Electrical and Electronic Engineering
Victoria University of Technology
PO Box 14428, MMC, Melbourne 3000
Tel : (03) 688 4000 , Fax : (03) 688 4908

Abstract: Following the rapid development of digital equipment used for the power industry, use of computer networks with digital relaying equipment to integrate substation protection and control became popular. In this paper we outline the implementation of such system for educational purposes which could be used for industrial purposes with minor modifications.

1.0 INTRODUCTION

The idea of integration of substation protection and control systems was first conceived in late seventies and early eighties with the advancements of digital electronic equipment specifically designed for power industry. Since Deliyanndes and Urden [1] outlined the design criteria for microprocessor based integrated substation protection and control system many developments have taken place in this particular area.

Traditional substation protection and control system has inherent disadvantages such as duplication of equipment, poor man-machine interface, high power consumption, high maintenance costs and lack of self monitoring and fault diagnostics etc.. Lately, with the availability of multi-tasking microprocessors and intelligent, easy to use standard interfaces, development of integrated protection systems to overcome these disadvantages has become a more feasible solution.

The control and protection functions of a transmission substation that can be integrated into a digital microprocessor based system will be less expensive, with lower operational and maintenance costs and possibly could achieve 10-20 % savings on the cost of relay and control equipment [2]. It is understood that this integrated method of fault diagnostics using substation computer, aids in making correct decisions during the fault diagnostics of a power system and enables faster restoration after any contingency.

By fair assessment of all the integrated substation protection and control systems developed so far, it is evident that these systems are complex and are very expensive to implement. These are some of the crucial factors that has hampered and delayed the application of this technology to the electrical supply industry. Therefore a low cost solution is in great need.

As power engineering and software development are too diverse areas in today's standards, research in this area, which involve system networking, interface modelling and complex software and hardware development are not widely carried out in traditional power engineering schools. In this project, we try to incorporate the expertise of the professional software developers to the power industry by making use of the already developed sophisticated, reliable but inexpensive high quality software packages to develop this versatile power engineering tool. Therefore, while achieving the requirements outlined by the power engineers, we can come up with a low cost solution, in which the expenditure on fundamental software development is minimal.

The system could initially be used as an educational aid to teach the power engineering concepts, but with some improvements mainly in physical transmission media it could be readily adaptable to the industrial environment. The feasibility of this project relied mainly on the following factors:

- advancements in digital electronic equipment associated with the power industry;
- availability of low cost multi-tasking computers with versatile interfaces;
- instrumentation that could be modelled in computers.

2.0 DESIGN STRATEGY

The main objective of this research was to design and implement a second generation integrated power system protection and control system for substations. It is referred to as a second generation system because it uses sophisticated computer software packages embedded in an integrated software environment to process data acquired by substation components, which was not available previously in such systems. Therefore the aim of the research was to develop such system to provide:

- advanced relaying and control techniques;
- centralised control and distributed processing;
- high quality man-machine interface (MMI);
- high reliability and unattended operation;
- integrated software environment with sophisticated packages;
- on line monitoring and event recording;
- low cost implementation;
- modular architecture for future developments.

3.0 SYSTEM DEVELOPMENT METHODOLOGY

In this project, integration of substation protection and control equipment was done using a Local Area Network (LAN). The type of the LAN selected depended on the topology, transmission media, media access control and the operating environment.

This network has two levels of operation: Field Level and Coordination & Management Level. In the field level, analogue data from a current transformer or a voltage transformer is acquired and converted to a digital signal by a data acquisition unit. The same terminal equipment can deliver the control information received from the control station to the circuit breakers and switches. The field level of the network could either be a single processor or a low level LAN connecting processors with similar functions; ie a LAN connecting all bus protection units. Using the LAN all the field level processors are connected to a central computer. The coordination & management level computer possesses the intelligence to perform the analysis, supervision of 2 archival data and coordination and reporting of short term data. Further it provides the

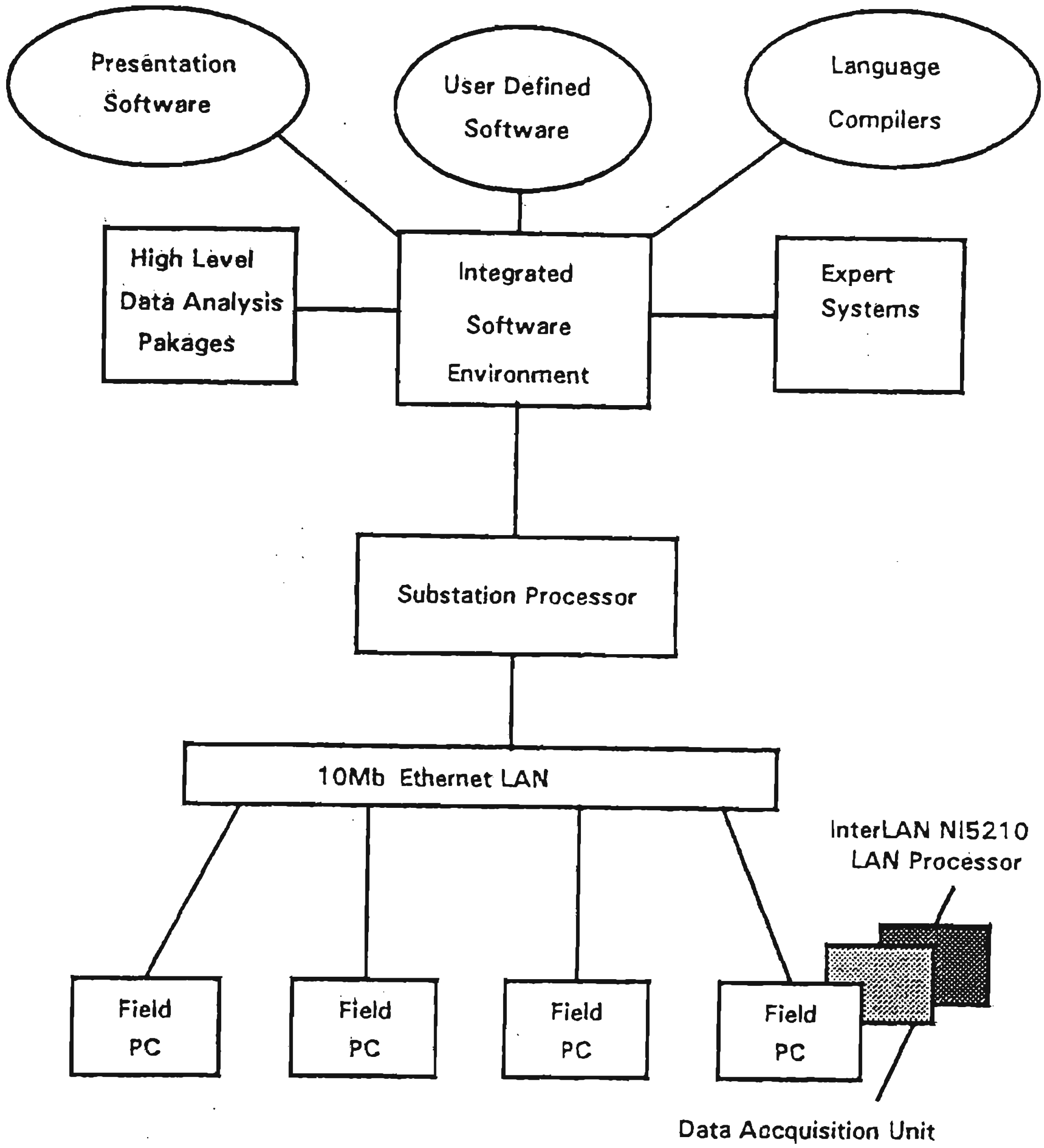


Figure 1. *Block Diagram Design of the System*

synchronisation of the processors and maintains links with the outside world.

As the will system eventually be operating in a highly electro-magnetically hostile environment the transmission media used in the LAN should be able to withstand electro-magnetic interference (EMI). Ideally fibre-optic cables be the best solution. Yet, due to cost constraints a double shielded coaxial cables are currently used.

For the media access control IEEE 802.3 Carrier Sense Multiple Access / Collision Detection (CSMA/CD) protocol is used. Networks using this protocol are usually referred to as Ethernet. Therefore a 10Mbytes Ethernet bus is used to interconnect system components. A block diagram of the design of the system is shown in Figure 1.

The main roles of each of the components are explained below.

a. *The Local (Field) PC ;* The local PC is a IBM 486/386 or compatible computer and has the following functions:

- a local controller unit providing the digital relaying scheme required; eg. Overcurrent Relay. Using a data acquisition unit it will continuously monitor the protected equipment in substation field; eg. Bus-bar, Transformer, etc., and provide the trip signal to the circuit breaker;
- a local monitor for specific terminal activity for the field operator;
- member of low level network communicating with the central computer and the other computers in its level. (LAN card is installed in each PC).

b. Substation Processor

Substation Processor is the centralised controller for the network. Additionally it hosts an integrated software environment. High level data acquisition and analysis packages, presentation programs, user defined software, expert systems and language compilers could be embedded to such environment to provide added versatility to the system. A redundant processor could be added in parallel to this processor to increase reliability of the overall system. The system console is equipped with user friendly interfaces, so that the operators may not need rigorous training to operate the system. This is achieved by setting up high quality graphics and icon based operations in the integrated software environment.

As the improved protection and control functions are necessary to meet the increasing demands of the power system security, the designed system will provide intelligence to cope up with the requirements manifested by engineers. This is achieved by using advanced microprocessor based digital relaying techniques.

While offering distributed processing facilities to process short term data at local levels the system will maintain centralised protection and control and monitoring functions. In other words the data acquired from the lower levels of the hierarchy is transferred to higher levels for further processing to influence the control decisions. All control functions offered are in real time; ie. data acquisition, processing and transfer is done with minimum delay.

4.0 FACILITIES AND EQUIPMENT

The system is implemented using IBM PC 486/386 or compatible computers. This is essential so as to satisfy the requirements of the software environment and the analysis packages that is used in the project. Further, higher processing speeds are necessary to comply with the power industry standards for protection and control. The computers are connected to form a LAN using thin Ethernet cable. InterLAN NI5210 High-level Data link layer controller card with "ENDIS" driver software are used to set up the communication interface. The system is developed as an application over a commercially available Ethernet based LAN. To be compatible with the software environment selected, Windows for Workgroups Local Area Network was used. Microsoft Windows 3.1 which is a widely used software environment for many applications is used as the base software environment for the project.

For data acquisition, analysis and presentation National Instruments' LABVIEW for Windows data analysis package is used. With this software it will be possible to provide the user with the FFT, DFT, power spectrum, digital filters, interactive interface, multigraphs, strip charts, etc. as well as direct link with Lotus 1-2-3 or Symphony spreadsheet, ready for analysis. National Instrument "LAB PC+" multi function I/O board with "NI-DAQ" software driver is used as the data acquisition unit in this application. This data acquisition unit which hosts a 12bit Analogue to Digital Converter (ADC), two 12-bit double buffered Digital to Analogue Converter (DAC), 24 digital I/O lines, three independent 16 bit counters and 8 bit Direct Memory Access (DMA) interface provides an excellent array of data acquisition utilities.

5.0 CONCLUSION

Although there are many integrated power system protection and control systems available worldwide, a low cost solution has not been proposed so far. In this project we make use of the currently available more sophisticated and reliable, developed yet inexpensive software to develop the application. Here neither low level software is designed to run a Local Area Network, nor attempt is made to design presentation software, or data acquisition software, but use is made of already available high quality software to develop a useful power engineering tool. Integrated substation protection systems available presently from the traditional power system equipment manufacturers are expensive, as they have to employ special group of software developers to design and build such systems from very fundamentals.

The project is still in the development phase. Initial tests has been done on each basic component of the system. The local data acquisition unit simulating the digital relaying has been tested with overcurrent protection scheme. Numerous data has been transferred between the local processor and the central processor. System shows promising capability to satisfy the needs of an integrated protection and control scheme for substations.

6.0 REFERENCES

[1] Deliyannides J. S., Urden E.A., "Design Criteria for an Integrated Microprocessor-based Substation Protection and Control System". IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No.6 June 1982.

[2] Nilsson S.L., Petrie H.R., Deliyannides J.S., Mankoff L.L., " New Digital Control and Protection System for Transmission Substations", International Conference on Large High Voltage Electric Systems, 1986.

[3] Lilley R.A., Seymour C., Bishop P.G., Pullen F. D., " Co-ordinated Substation Control and Monitoring ", International Conference on Large High Voltage Electric Systems, 1986.

[4] Douglas J., " Building the Smarter Substation ", EPRI Journal Vol.13 No. 4, Jun 1988, p 16-21.

[5] Bondia E., Suarez E., Cobelo F., " Integrated Protection and Control Digital System for Rural Substations ", IEE Conference Publication No. 302, 1989, p 113-115.

[6] Jeyasurya B., Venkata S.S., Vadari S. V., Postforoosh J., " Fault Diagnosis using Substation Computer ", Power Industry Computer Applications Conference, Seattle WA, USA, 1989.

[7] M. Suzuki, T. Matsuda, N. Ohashi, R. Tsukui, Y. Sano and T. Yoshida, " Development of a Substation Digital Protection and Control System Using Fibre-Optic Local Area Network" IEEE Transaction on Power Delivery, Vol. 4, No.3, July 1989, pp 1668-1674.

[8] Kwon W.H., Chung B. J., Park J. W., Lee G. W., Yoon M. C., " Real-Time Fibre-Optic Network for an Integrated Digital Protection and Control Sysyem ", IEEE Transactions on Power Delivery Vol.7, No. 1, Jan 1992, p 160-166.

[9]Zayegh A., Kalam A., Kannangara C., " Model of an Integrated Substation and Protection and Control System", Proceedings of International Conference on Modelling and Simulation '93 Conference, Victoria University of Technology, Melbourne, Australia,12-14 July 1993,p 735-740.

THIRD GENERATION GENERAL PURPOSE DATA ACQUISITION & CONTROL SYSTEM BASED SUBSTATION PROTECTION & CONTROL SYSTEM

C. Kannangara, A. Zayegh, A. Kalam
Save Energy Group
Victoria University of Technology
PO Box 14428 MMC
Melbourne Victoria

Summary Latest developments in software for instrumentation are now capable of providing combined data acquisition, control and graphical presentations features built into them. Careful use of these available software with selected operating system interfaces and networking software, developers are now able to design and implement various complex engineering applications which has been very expensive and exhaustive to be built in the past with relatively less effort and minimum costs. The idea of this paper to illustrate one such application in which standard instrumentation software was used in conjunction with the right networking tools to develop a cost effective substation protection and control system.

1.0 INTRODUCTION

With the development of instrumentation software the traditional monitoring and control systems are at the verge of being revolutionised. More and more software based control is taking over the control and monitoring functions of many equipment. They are widely sought and appreciated for their accuracy, ease of calibration, versatility and many other features. This is having an impact on the power engineering area too. Currently there are digital relays, controllers and protective gear based on microprocessors available in the market and many are being added. Integration of substation protection and control system is an idea resulted from this ever increasing options available through the digital equipment associated with the power industry. By integrating substation monitoring, control and protective gear it is possible to replace the traditional protective and control gear which are cumbersome, inefficient in terms of power consumption and need large space and cabling requirements with a local area network (LAN) of computers performing similar duties while overcoming most of the disadvantages associated with the traditional systems.

2.0 SYSTEM ARCHITECTURE

This system was developed on three key standard software products

- Integrated software environment for the operating system interface, graphic user interface and multitasking capability
- Third generation instrument software for instrumentation, data acquisition and analysis and presentation
- Local Area Network software for control and the management of the LAN.

These three software products are selected carefully to have full compatibility with each other with no hassle in data exchange or control. This makes the implementation of the integrated substation protection and control system a manageable task with relatively less software development and cost because in this case any software for direct hardware interface, software to run a local area network or presentation software are not developed from very fundamentals. However the quality of the graphic user interface, reliability of the network operation, and the accuracy of the instrumentation and control and the speed considerations of data acquisition and dispatch is implemented to a very high standard.

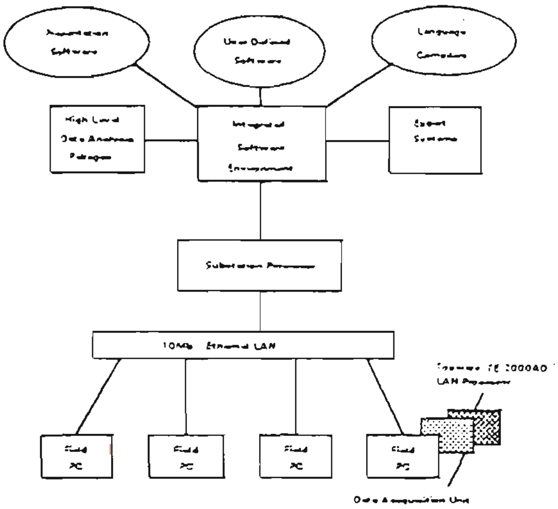


Figure 1. System Architecture

The protection and control architecture for the substation was developed in a two tier configuration. The low level or the field level computers were positioned to acquire data through a current or voltage transformer. This could be processed locally for or could be transferred to the central substation computer for further processing. Local processing include alarm processing, transient analysis, metering, fault identification and rectification. At the substation level the central processor will monitor the low level processors and process the central information such as maintaining alarm summaries, remote monitoring and control of substation equipment, accounting etc.. Further central computer which hosts the integrated software environment offers the user to directly interact with spreadsheets, language compilers, presentation software to process the information gathered from lower levels. The abovemwntioned architecture is shown in Figure 1.

3.0 SYSTEM DEVELOPMENT

3.1 LAN Topology

To implement the integrated substation protection and control system based on a LAN it was very important to determine the appropriate LAN topology to increase the reliability factors as well to minimise the costs involved. Therefore an evaluation and a feasibility study was done on different LAN tropologies to determine the relative advantages and disadvantages of a particular topology in relation to this application. The local bus topology was selected as the best solution for its network reliability in terms of the ability to function even when a single workstation breakdown, ease in cable connections, flexibility, low cost cables and connectors and ease of adding new workstations.

3.2 Transmission Media

Due to the high electromagnetic interference that exist in the substation environment the transmission media that is used in the integrated protection and control system has to have a high noise immunity. Ideally the fibre optic media is the best solution. But due to factors such as high cost, cabling inflexibility, lack of standard components and high installation costs involved, double shielded coaxial cables were used for this application. The software developed for the integrated protection and control system is however capable of operating over a fibre optic link with minimum modifications. Coaxial cables were used as the next best solution fir their low maintenance costs and relatively better signal to noise resistance over the long distances.

3.3 Media Access Protocol

The integrated substation protection and control system does not depend on any manufacturers protocol but uses the standard IEEE 802.3 protocol for media access. This protocol widely known as Ethernet. Use of this protocol makes this system an open architecture and any other standard software or hardware may be added to the system in future. This Ethernet can be wired with different types of cable. In this project Ethernet baseband LAN that uses Thinnet cabling was used. This network is capable of carrying signals upto 185 metres without a regenerative repeater. This is quite adequate in the case of substation environment. LAN specification and material used is listed in Table 1.

Topology	Local Bus
Cable Type	RG-58
Impedance	50Ω
Terminator Resistance	50Ω+ - 2Ω
Minimum length between Terminals	0.5m
Maximum cable segment	185m
Maximum connected segments	5
Maximum units per segment	30

Table 1. LAN specification

4.0 SOFTWARE

In the process of development of this low cost integrated substation protection and control system, emphasis was given to use standard software products wherever possible. This was done purposely to:

- support an open system architecture where software and hardware from many different manufacturers could be integrated
- make provisions for further improvements with the advancement in technology
- minimise the costs associated with the development

4.1 Instrumentation Software

To take measurements, data acquisition and provide the control signals to protective gear Labview instrumentation software developed by the National Instruments was used. Labview like any other programming tool is equipped with extensive range of libraries of functions and subroutines for general and specific instrumentation software development. Further it provides with an easy to use graphical interface which could be customised. With Labview it is possible to simulate a range of equipment from a simple voltmeter to fully integrated control system in a single computer. Application specific libraries for data acquisition, GPIB and serial instrument control, data analysis, data storage and data presentation is very helpful in developing high quality instrumentation software with low costs in a short period of time. Due to the fact that the instruments simulated by Labview, perform and look like the original equipment they often referred to as virtual instruments. In the substation protection and control system developed to simulate various equipment and functions. Labview was used extensively.

4.2 Integrated Software Environment

Software developed for the integrated protection and control system is hosted by Microsoft Windows environment. Windows was sought as it is the most widely used icon based user friendly graphical interface for the MS-DOS (Microsoft Disk Operating System) operating system. By selecting Windows platform, it was possible for the integrated protection and control software to make permanent or ad-hoc data links with other Windows applications easily. Therefore it was possible to make the data acquired by the integrated protection and control system to be made available for Windows oriented spreadsheet such as Microsoft Excel, or for a language compiler such as C++, or a word processing package through data links or through object linking and embedding.

Windows architecture usually consists of three main components: Windows Application Programming Interface (API) , the Windows core and Windows extensions and drivers. The way these components are developed, it is possible for the developer to use Windows API to write Windows-based applications without knowing the details about how Windows core routines work internally, or how Windows device drivers communicate with hardware. This makes the development of large software projects easy. In developing the integrated protection and control system the software development was based on the Windows environment and therefore managed to save significant amount of programming effort.

4.3 Local Area Network Software

Another advantage with Windows is that it offers a variety of software applications based on it. This includes various spreadsheets, word processors, language compilers, presentation software and most importantly software to run local area networks. There are two Windows networking software: Windows NT and Windows for Workgroups. In this project Windows for Workgroups was used as the supporting networking software for the system. Windows for Workgroups builds

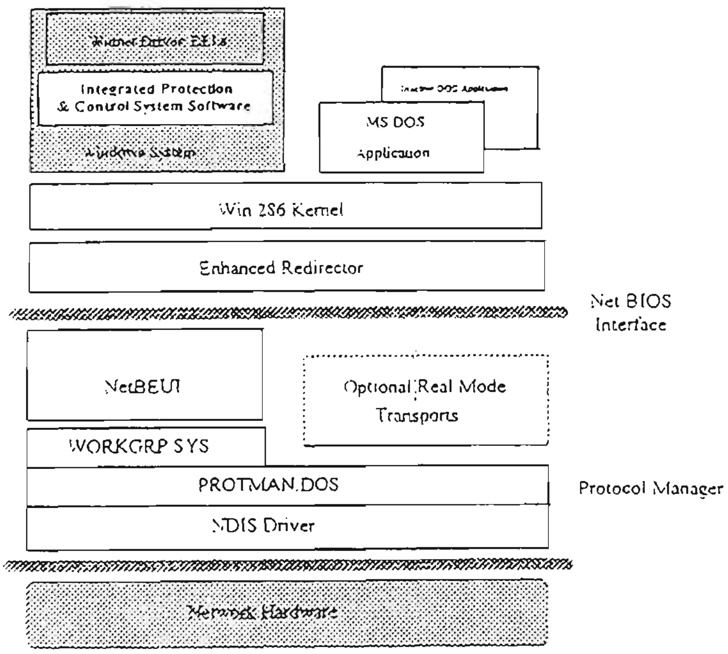


Figure 2. How the system software fits into network hardware

on the Windows 3.1 architecture by providing integrated network functionality in the base operating system. The incorporation of networking components in Windows for Workgroups helps the developer to define a standard platform for network units to communicate and exchange information. MS-DOS device driver is loaded during MS-DOS system initialisation process and the Protocol Manager in Windows will bind the network transport protocols to NDIS-complaint (Network Device Interface Specification) network adaptor card MAC (Media Access Control) driver. The NDIS network adaptor card driver is used to define how the network protocol will communicate with a network adaptor card. The network adaptor card used in this project was Topware TE 2000AD card. This card is fully compatible with IEEE 802.3 10Base2 and 10BaseT standards and has 10MB/s data transfer rate which is typical for Ethernet. The way the integrated protection and control system software implemented in Windows platform and is connected to network hardware through Windows for workgroups is shown in the Figure 2.

5.0 SYSTEM FUNCTIONS

Developed system has been able to demonstrate following capabilities

- online remote monitoring and control
- high quality graphic user interface
- high reliability and unattended operation
- data logging functions
- integrated software environment with embedded software applications
- some statistical analysis
- processing alarms and maintaining summaries
- metering and accounting
- centralised control and distributed processing
- low cost implementation

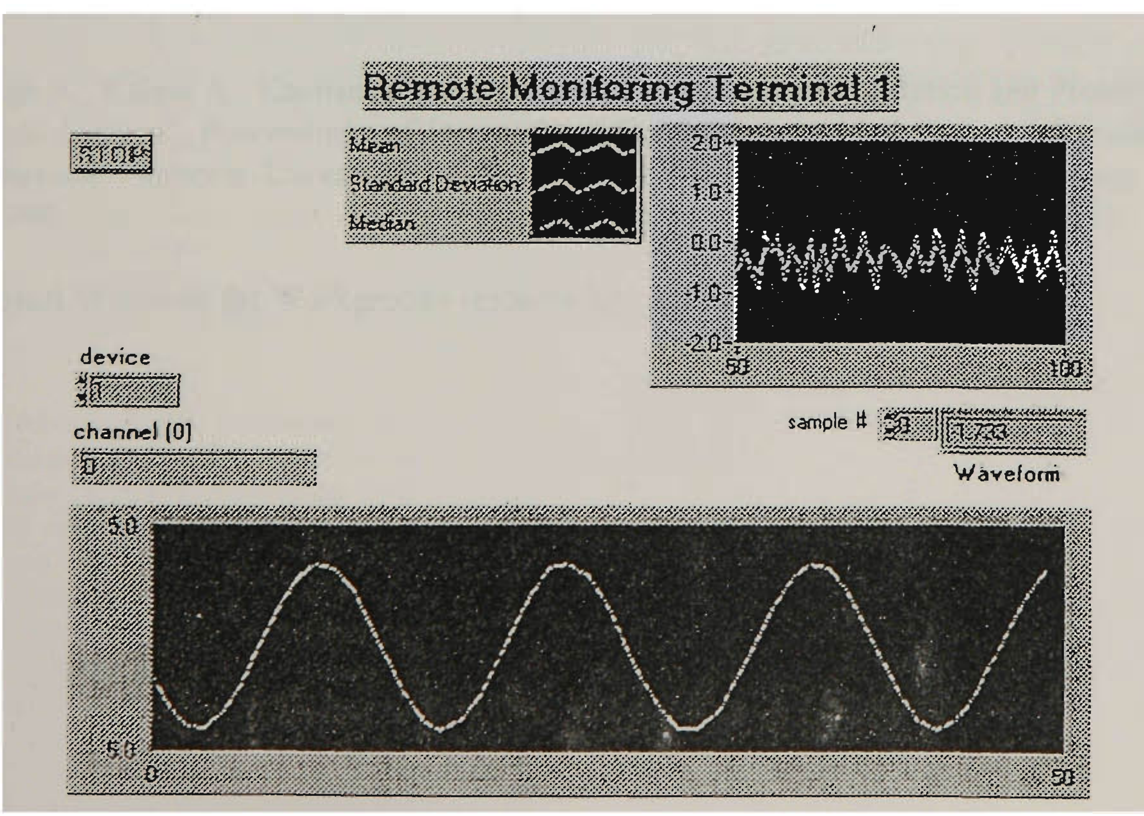


Figure 3. Remote terminal capturing waveforms and performing statistical analysis on-line

The system is developed in a modular architecture so that any future development is easy. High quality graphic interface is very user friendly and menu based system operation needs minimum training to operate the system. Fast data acquisition and network data transfer rate guarantees the updating is done on time in the central station. In Figure 3. a sample screen of remote monitoring terminal is shown.

6.0 CONCLUSION

The ability to use standard widely available software to develop a useful power engineering application was illustrated in this project. Using the standard software and protocols lead to an open system architecture where any other software or hardware could be added to improve the application performances at later stages. Further it was possible to achieve considerable savings on cost of implementation and in programming effort and time.

REFERENCES

[1] Deliyannides J. S., Urden E.A., "Design Criteria for an Integrated Microprocessor-based Substation Protection and Control System". IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No.6 June 1982.

[2] M. Suzuki, T. Matsuda, N. Ohashi, R. Tsukui, Y. Sano and T. Yoshida, "Development of a Substation Digital Protection and Control System Using Fibre-Optic Local Area Network" IEEE Transaction on Power Delivery, Vol. 4, No.3, July 1989, pp 1668-1674.

[3] Kwon W.H., Chung B. J., Park J. W., Lee G. W., Yoon M. C., "Real-Time Fibre-Optic Network for an Integrated Digital Protection and Control System", IEEE Transactions on Power Delivery Vol.7, No. 1, Jan 1992, p 160-166.

[4] Zayegh A., Kalam A., Kannangara C., "Model of an Integrated Substation and Protection and Control System", Proceedings of International Conference on Modelling and Simulation '93 Conference, Victoria University of Technology, Melbourne, Australia, 12-14 July 1993, p 735-740.

[5] Microsoft Windows for Workgroups resource kit, Microsoft Corporation

Electrical Engineering Congress
Sydney, Australia, 24-30 November 1994

Local Area Network Based Low Cost Integrated Substation Protection and Control System

C. Kannangara, A. Zayegh, A. Kalam
Save Energy Group
Victoria University of Technology
PO Box 14428 MMC Melbourne 3000
Ph (03) 688 5047 Fax (03) 688 4908
Email Chanaka@cabsav.vut.edu.au

Summary With the recent developments in the digital equipment associated with the power system such as digital relays and transducers the development of integrated substation protection and control systems is possible. Although there are many integrated power system protection and control systems available worldwide, a low cost solution has not been proposed so far. In this paper, the use of the currently available very sophisticated and reliable, yet inexpensive high level third generation software to develop such application is discussed. Here, neither the low level software to run a Local Area Network, nor the Presentation or Data acquisition software is designed from fundamentals, but use is made of already available high quality software to develop a useful power engineering tool. Integrated substation protection systems available presently from the traditional power system equipment manufacturers are expensive as they have to employ special group of software developers to design and build such systems from very fundamentals.

The developed system offers at the moment high quality Man Machine Interface (MMI), and remote monitoring and control facilities. Further developments are under way and this could lead to a prototype for a low cost integrated system as it does not depend on any particular power protection or control manufacturers protocol but uses standard IEEE 802.3 Carrier Sense Multiple Accesses / Collision Detection (CSMA/CD) protocol (Ethernet). Data acquisition and control is done directly so that it could be used on a range of different manufacturer's equipment. These capabilities make this development to act as a system integrator for substation protection and control and will overcome many disadvantages associated with the traditional protection and control systems.

1.0 INTRODUCTION

In protection and control of the power systems as in any other control system, the information generated in the plant should be communicated to a central control area. In order to support the ever growing quality of the electricity supply, the electric power transmission and distribution systems increase in complexity. This means more reliable monitoring and control systems are needed. Further to support such system, reliable communication systems with higher level of security and the ability to transfer data in larger volumes are necessary.

Traditional substation protection and control systems have inherent disadvantages such as duplication of equipment, poor man-machine interface, high power consumption, high maintenance costs and lack of self monitoring and fault diagnostics etc.. Lately, with the rapid development of microprocessor technology and the availability of multi-tasking microprocessors and intelligent, easy to use standard interfaces, development of integrated protection systems to overcome these disadvantages has become a more feasible solution.

The control and protection functions of a transmission substation that can be integrated into a digital microprocessor based system will be less expensive, with lower operational and maintenance costs and possibly could achieve 10-20% savings on the cost of relay and control equipment [2]. It is understood that this integrated method of fault diagnostics using substation computer, aids in making correct decisions during the fault diagnostics of a power system and enables faster restoration after any contingency.

2.0 BACKGROUND AND CURRENT DEVELOPMENTS

Many integrated systems are proposed and being tested currently in different parts of the world. Significant developments are made in Japan, China and in Europe. Most of these works are based on LAN architectures for integration.

In Japan, a system is being tested using fibre optic media for physical transmission with IEEE 802.4 MAC (Media Access Control) protocol for communication between terminals[3]. In China, there is a system using twisted pairs as communication media with RS485 interface along with Intel IPX344 intelligent BITBUS network transceiver [5]. Germany is proposing a second generation substation protection system that uses high level software tools to process the information [6]. This system using 32-bit microprocessors offers coordinated system structure with optical star configuration with built-in comprehensive user software support packages. Data transmission rates in this system vary from 62 kbps to 6Mbps on higher levels.

By fair assessment of all the integrated substation protection and control systems developed so far, it is evident that these systems are complex and are very expensive to implement. These are some of the crucial factors that has hampered and delayed the application of this technology to the electrical supply industry (ESI). Therefore a simple and low cost solution may have better impact on the ESI.

As power engineering and software development are too diverse areas in today's standards, research in this area, which involve system networking, interface modelling and complex software and hardware development are not widely carried out in traditional power engineering schools. In this project, we try to incorporate the expertise of the professional software developers to the power industry by making use of the already developed sophisticated, reliable but inexpensive high quality software packages to develop this versatile power engineering tool. Therefore, while achieving the requirements outlined by the power engineers, it is possible to come up with a low cost solution, in which the expenditure on fundamental software development is minimal.

3.0 AIMS AND FUNCTIONS OFFERED

Main objective of this exercise was to use commonly used efficient and reliable computers along with the standard sophisticated software to come up with a low cost solution for substation monitoring and control. In addition to that, efforts are endeavoured to provide following requirements:

- reliability - system monitors the respective protection or control units continuously. Any failure is promptly signalled to all the stations currently engaged by special message window prompting on the user interface.
- Real time operation - the designed system is based on fastest available personal computers and provides adequate speed of operation for power system monitoring and control functions.
- Capacity - Data handling, processing and communication capacities of the computers are enough to report and process faults within one half of the cycle
- Low Cost Implementation - hardware and software used by the system are most standard products in the industry. By using such products it was possible to achieve the best possible quality in terms of speed, reliability, graphic user interface and modularity with other standard software.
- Open system architecture - use of standard software and hardware, and standard protocols means the system is open and provisions are made to be compatible with future developments and modifications.

The functions offered by the system is therefore to provide:

- on line control and monitoring.
- high quality man-machine interface
- high reliability and unattended operation
- integrated software environment with sophisticated packages
- centralised control and distributed processing
- low cost implementation
- modular architecture for future developments

3.0 SYSTEM DEVELOPMENT

The system developed in this project, uses a Local Area Network (LAN) to connect various substation protection and control units. Special attention was paid to select the transmission media, media access protocol and the topology of the LAN in order to customise its operation to suit the needs of the task. Further, this network had two levels of operation as shown in Figure 1, to facilitate the handling of layer specific data. By having this two tier operation it was possible to minimise the processing overheads and maximise the efficiency of the overall system.

Two layers in this case are the Field Level and Coordination & Management Level. In the field level, analogue data from a current transformer or a voltage transformer is acquired and converted to a digital signal by a data acquisition unit. The same terminal equipment can deliver the control information received from the control station to the circuit breakers and switches. The field level of the network could either be a single processor or a low level LAN connecting processors with similar functions; ie a LAN connecting all bus protection units. Using the LAN all the field level processors are connected to a central computer. The coordination & management level computer possesses the intelligence to perform the analysis, supervision of archival data and coordination and reporting of short term data. Further, it provides the synchronisation of the processors and maintains links with the outside world.

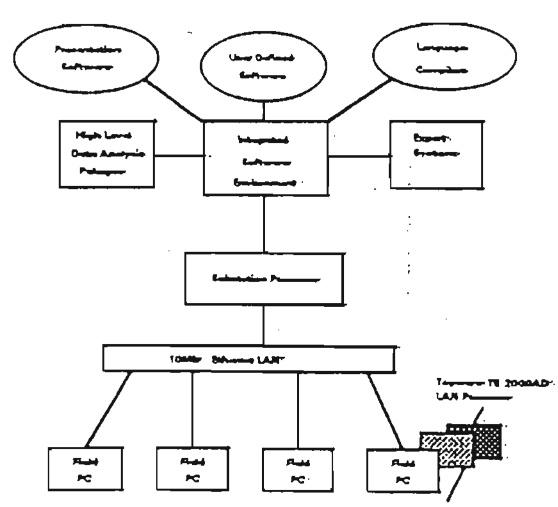


Figure. 1 Two level structure of the system

3.1 LAN Topology

When considering a desired network topology for this project, first an evaluation of the standard network topologies was conducted and the advantages and disadvantages associated with each topology in general and in relation to the project was determined. Particular attention was given to the factors such as reliability of the network operation, how a single cable malfunction would affect the whole LAN operation, ease in cable connections, cost of components and connectors, maintenance costs, security, resistance to signal noise over distances were looked into in assessing the suitability. By considering all the above criteria a bus type topology was selected as it offered most of the desired characteristics associated with respect to the developed system.

3.2 Transmission Media

Substation environment usually has a high degree of electromagnetic noise associated with it. This will affect the data signals transmitted over the transmission media. Therefore the transmission media must be able to withstand this high electromagnetic noise. Fibre optic cables are the most desired medium. But due to cost constraints double shielded coaxial cables are used. Nevertheless the software used is capable of operating over the fibre optic media if the required hardware is made available.

3.3 LAN protocol and controller.

The LAN protocol used for this system is IEEE 802.3 Carrier Sense Multiple Access / Collision Detection (CSMA/CD). This protocol is widely known as Ethernet. Ethernet networks could be wired with different types of cable and in this case an Ethernet baseband LAN that uses Thinnet cabling was used. Thinnet coaxial cable can carry a signal up to approximately 185 meters without a repeater. This is quite sufficient in a substation environment. Specification of the network are shown in Table 1.

Topology	Local Bus
Cable Type	RG-58
Impedance	50Ω
Terminator Resistance	50Ω+/- 2Ω
Max Cable Segment	185m
Min length between terminals	0.5m
Maximum connected segments	5
Maximum computers per segment	30

Table 1. LAN Specification

Topware NE2000E type High Level Data Link Controller was used to connect the computers to LAN.

3.4 Base LAN Software

The software used to run the LAN was Windows for Workgroup 3.11. Microsoft Windows 3.11 was used as the base software environment for the system. This was used mainly due to its multi-tasking capability and the user friendliness. Further by far this is the most popular icon based graphic interface for the personal computer operating system. The Windows for Workgroup builds on the architecture implemented in Windows 3.11 by providing integrated network functionality in the base operating system. The incorporation of networking components to Windows helps to define a standard platform to communicate and exchange information between Windows based applications. The software used to develop the integrated protection and control system uses Windows functionality extensively. Therefore, by using a Windows compatible networking software development of communication links between protection and control units has been less exhaustive.

4.0 SOFTWARE DEVELOPMENT

4.1 Integrated Software Environment

The integrated substation protection and control system was built on the Microsoft Windows platform. Windows offer an easy to use icon based user friendly interface to the operating system. By developing the system as a Windows application it was possible to incorporate all the features of Windows to the integrated protection and control system.

In general, Windows architecture consist of three main components: the Windows Application Programming Interface (API), the Windows core and Windows extensions, and the Windows drivers. Customised software applications could be developed through Windows API without knowing the details about how the Windows core routines work internally. The developer also doesn't need to know the implementation details of how Windows device drivers communicate with the hardware. This saves a lot of

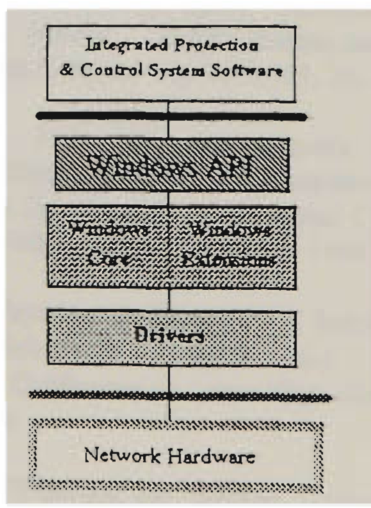


Figure 2. How software is implemented in Windows platform

programming effort and provides the opportunity to develop high quality software with multi-tasking capabilities and user friendly graphic interfaces in a relatively short period of time with low costs.

4.2 Network Dynamic Data Exchange

Windows Dynamic Data Exchange (DDE) facility is a standard Windows protocol and enables the Windows based applications to exchange data and carry out remote commands by means of Windows messages. In Windows for Workgroups this facility is extended over the network and provisions are made to exchange data with remote computers over the network. DDE is most appropriate to exchange data when there is no need for continuous user interaction. First, a link is established between the remote protection or control unit which is going to exchange data with the central computer. Once the link is established, however, the application can exchange data over the network in real time without further user intervention. This network DDE facility was used as the basis for remote monitoring and control of the integrated protection control system.

4.3 Virtual Instruments

Using computers to simulate instruments is nowadays a common practise. With this instrumentation software a single computer can take the role of a simple current meter to a very complex spectrum analyser. Labview, developed by National Instrument Corporation is one such programming tool. Labview like any other general purpose programming language is equipped with extensive libraries of functions and subroutines for any programming task. It also contains application specific libraries for data acquisition. GPIB and serial instrument control. data analysis. data presentation and data storage.

Labview was used to develop the instrumentation software for this smarter substation protection and control system. Labview programs are called virtual instruments because their appearance and operation resemble actual instruments.

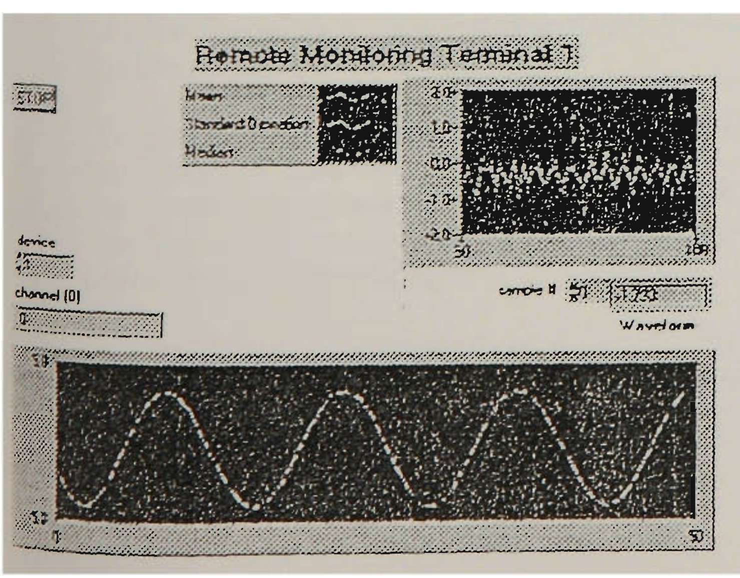


figure 3. a virtual instrument for remote monitoring

4.4 Data Acquisition Unit

To gather data from the Voltage or Current transformers, National Instruments LAB PC+ multi-function input /output board was used. This unit consist of 12 bit analogue to digital converter, two double buffered digital to analogue converters, 24 digital input/output lines, three independent 16 bit counters, and an 8 bit direct memory access (DMA) interface. These input/output lines are used in the substation for the measurement and monitoring of equipment and to convey control and protection signals.

5.0 SYSTEM PERFORMANCE

The developed system is at the moment offering remote monitoring and control, data analysis and data logging functions. Remote monitoring include metering and accounting alarm monitoring. Further, it can monitor a waveform from a remote station and show it on the user screen in time domain and frequency domain. This helps the user to analyse the harmonic distortion and diagnose harmonic problems. Automatic monitoring helps to plot the demand against time and predict peak demand values. Further data could be imported to a spreadsheet (EXCEL) for other calculations and accounting purposes. Protection algorithms could be included in the substation level computers to determine the fault occurrence.

6.0 CONCLUSION

An integrated substation protection and control system was developed using standard software products. Use of standard products enabled this system to adapt any standard hardware or software in later stages. Further the use of high quality products ensured the reliability of the system and in economic terms the project was very cost effective.

References

[1] Delivannides J. S., Urden E.A., "Design Criteria for an Integrated Microprocessor-based Substation Protection and Control System". IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No.6 June 1982.

[2] Nilsson S.L., Petrie H.R., Delivannides J.S., Mankoff L.L., "New Digital Control and Protection System for Transmission Substations", International Conference on Large High Voltage Electric Systems, 1986.

[3] Lilley R.A., Seymour C., Bishop P.G., Pullen F. D., "Co-ordinated Substation Control and Monitoring", International Conference on Large High Voltage Electric Systems, 1986.

[4] Douglas J., "Building the Smarter Substation", EPRI Journal Vol.13 No. 4, Jun 1988.

[5] Bondia E., Suarez E., Cobelo F., "Integrated Protection and Control Digital System for Rural Substations", IEE Conference Publication No. 302, 1989.

[6] Jeyasurya B., Venkata S.S., Vadari S. V., Postforoosh J., "Fault Diagnosis using Substation Computer", Power Industry Computer Applications Conference, Seattle WA, USA, 1989.

[7] M. Suzuki, T. Matsuda, N. Ohashi, R. Tsukui, Y. Sano and T. Yoshida, "Development of a Substation Digital Protection and Control System Using Fibre-Optic Local Area Network",IEEE Transaction on Power Delivery, Vol. 4, No.3, July 1989.

[8] Kwon W.H., Chung B. J., Park J. W., Lee G. W., Yoon M. C., "Real-Time Fibre-Optic Network for an Integrated Digital Protection and Control System". IEEE Transactions on Power Delivery Vol.7, No. 1, Jan 1992.

[9] Zayegh A., Kalam A., Kannangara C., "Model of an Integrated Substation and Protection and Control System", Proceedings of International Conference on Modelling and Simulation '93 Conference, Victoria University of Technology, Melbourne, Australia, 12-14 July 1993.

INTEGRATED SUBSTATION DIGITAL PROTECTION AND CONTROL - A GENERAL PURPOSE LOW COST SOLUTION

C. Kannangara, A. Kalam, A. Zayegh
Victoria University of Technology
Australia

Abstract

The recent developments in the software applications provide extremely advanced functions for instrumentation and control. Some of these products offer combined data acquisition, control and graphical presentations features which are built into them. Carefully using these available software with selected operating system interfaces and networking software, developers are now able to design and implement various complex engineering applications which has been very expensive and exhaustive to be built in the past. This paper illustrates one such application in which standard instrumentation software was used in conjunction with the right networking tools to develop a cost effective substation protection and control system.

Keywords
Integration, Protection, Local Area Networks, substation

1 INTRODUCTION

In order to support the ever growing quality of the electric supply, the electric power transmission and distribution systems increase in complexity. This means more reliable monitoring and control systems are needed. Further to support such system, reliable communication systems with higher level of security and with the ability to transfer data in larger volumes are necessary.

Traditional substation protection and control systems have inherent disadvantages such as duplication of equipment, poor man-machine interface, high power consumption, high maintenance costs and lack of self monitoring and fault diagnostics etc..

The control and protection functions of a transmission substation that can be integrated into a digital microprocessor based system will be less expensive, with lower operational and maintenance costs and possibly could achieve 10-20% savings on the cost of relay and control equipment [2]. It is understood that this integrated method of fault diagnostics using substation computer, aids in making correct decisions during the fault diagnostics of a power system and enables faster restoration after any contingency.

With the development of instrumentation software the traditional monitoring and control systems are at the verge of being revolutionised. More and more software based control is taking over the control and monitoring functions of many equipment. They are widely sought and appreciated for their accuracy, ease of calibration, versatility and many other features. This is having an impact on the power engineering area too. Currently there are digital relays, controllers and protective gear based on microprocessors available in the market and many other are being added. Integration of substation protection and control system is an idea resulted from this ever increasing options available through the digital equipment associated with the power industry. By integrating substation monitoring, control and protective gear it is possible to replace the traditional protective and control gear which are cumbersome, inefficient in terms of power consumption and need large space and cabling requirements with a local area network (LAN) of computers performing similar duties.

In protection and control of the power systems as in any other control system, the information generated in the plant should be communicated to a central control area. Lately, with the rapid development of microprocessor technology and the availability of multi- tasking microprocessors and intelligent, easy to use standard interfaces, development of integrated protection systems to overcome these disadvantages has become a more feasible solution.

2.0 OBJECTIVES

Main objective of this exercise was to use commonly used efficient and reliable computers along with the standard sophisticated software to come up with a low cost solution for substation monitoring and control. In

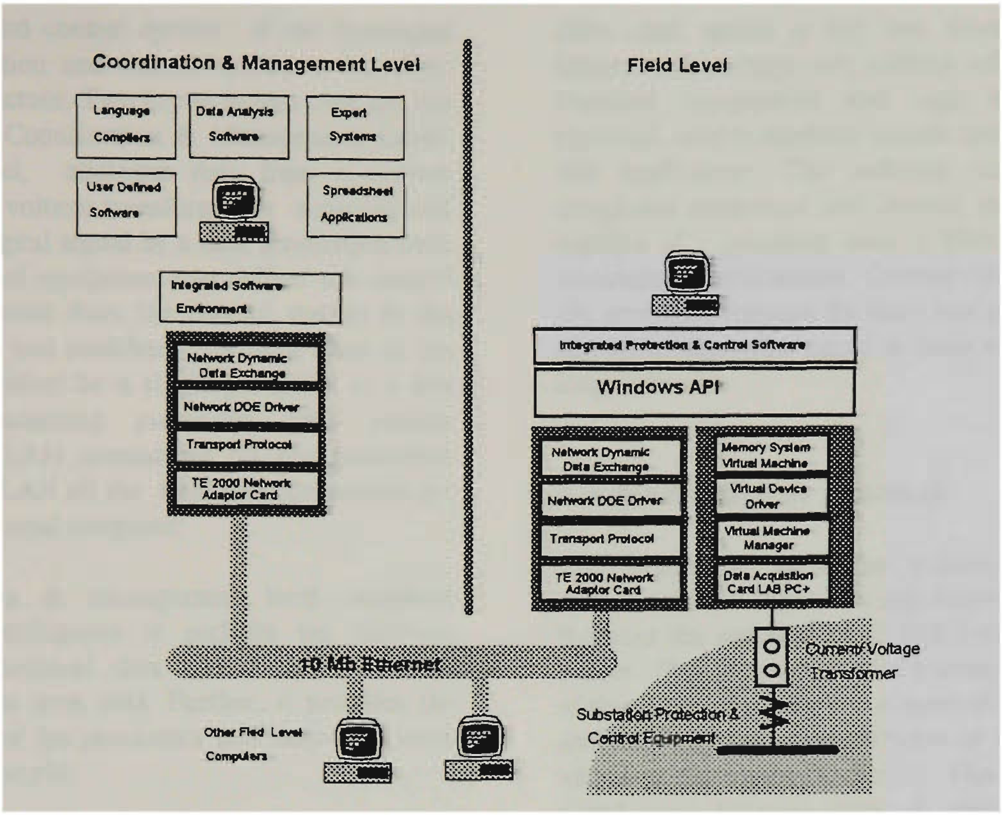


Figure 1. Development Architecture of the Integrated Substation Protection System

addition to that, efforts are endeavoured to provide following requirements:

- reliability - system monitors the respective protection or control units continuously. Any failure is promptly signalled to all the stations currently engaged by special message window prompting on the user interface.
- Real time operation - the designed system is based on fastest available personal computers and provide adequate speed of operation for power system monitoring and control functions
- Capacity - Data handling, processing and communication capacities of the computers are enough to report and process faults within one half of the cycle
- Low Cost Implementation - hardware and software used by the system are most standard products in the industry. By using such products it was possible to achieve the best possible quality in terms of speed, reliability, graphic user interface and modularity with other standard software.
- Open system architecture - use of standard software and hardware, and standard protocols means the system is open and provisions are made to be compatible with future developments and modifications.

The designed system managed to offer following functions and services.

- on line control and monitoring
- high quality man-machine interface
- high reliability and unattended operation
- integrated software environment with sophisticated packages
- centralised control and distributed processing
- low cost implementation
- modular architecture for future developments

3.0 SYSTEM ARCHITECTURE

Low cost integrated substation protection and control system is based on three standard software products

- An integrated software environment for the operating system interface, graphic user interface and multitasking capability
- Third generation instrument software for instrumentation, data acquisition and analysis and presentation
- Local Area Network software for control and the management of the LAN.

These products were selected carefully to have the full compatibility with each other in terms of data exchange, usage of common library functions and graphical interface. These products are available off the shelf from software dealers and it is possible to minimise the fundamental software development costs.

The protection and control system of the developed substation protection and control system is based on the two level structure. Two layers in this case are the Field Level and Coordination & Management Level. In the field level, analogue data from a current transformer or a voltage transformer is acquired and converted to a digital signal by a data acquisition unit. The same terminal equipment can deliver the control information received from the control station to the circuit breakers and switches. The field level of the network could either be a single processor or a low level LAN connecting processors with similar functions; ie a LAN connecting all bus protection units. Using the LAN all the field level processors are connected to a central computer.

The coordination & management level computer possesses the intelligence to perform the analysis, supervision of archival data and coordination and reporting of short term data. Further, it provides the synchronisation of the processors and maintains links with the outside world.

In addition to all these the central computer which hosts the integrated software environment offers the user direct interact with spreadsheets, language compilers, presentation software to process the information gathered from lower levels. The above mentioned architecture is shown in Figure 1.

4.0 HARDWARE CONSIDERATIONS

4.1 LAN Topology

To implement the integrated substation protection and control system based on a LAN it was very important to determine the appropriate LAN topology to increase the reliability factors as well to minimise the costs involved. Therefore an evaluation and a feasibility study was done on different LAN tropologies to determine the relative advantages and disadvantages of a particular topology in relation to this application. The local bus topology was selected as the best solution for its network reliability in terms of the ability to function even when a single workstation breakdown, ease in cable connections, flexibility, low cost cables and connectors and ease of adding new workstations.

4.2 Transmission Media

Due to the high electromagnetic interference that exist in the substation environment the transmission media that is used in the integrated protection and control system has to have a high noise immunity. Ideally the fibre optic media is the best solution. But due to factors such as high cost, cabling inflexibility, lack of standard components and high installation costs involved, double shielded coaxial cables were used for this application. The software developed for the integrated protection and control system is however capable of operating over a fibre optic link with minimum modifications. Coaxial cables were used as the next best solution fir their low maintenance costs and relatively better signal to noise resistance over the long distances.

4.3 Media Access Protocol

The integrated substation protection and control system does not depend on any manufacturers protocol but uses the standard IEEE 802.3 protocol for media access. This protocol widely known as Ethernet. Use of this protocol makes this system an open architecture and any other standard software or hardware may be added to the system in future. This Ethernet can be wired with different types of cable. In this project Ethernet baseband LAN that uses Thinnet cabling was used. This network is capable of carrying signals upto 185 metres without a regenerative repeater. This is quite adequate in the case of substation environment. LAN specification and material used is listed in Table 1.

Topology	Local Bus
Cable Type	RG-58
Impedance	50Ω
Terminator Resistance	$50\Omega+-2\Omega$
Minimum length between Terminals	0.5m
Maximum cable segment	185m
Maximum connected segments	5
Maximum units per segment	30

Table 1. LAN specification

At the field level there are low level computers which will acquire data and perform local protection and control functions and normal supervisory functions. At the higher level, which is the substation level the processing of central data or archival data takes place.

5.0 SOFTWARE CONSIDERATIONS

In the process of development of this low cost integrated substation protection and control system,

emphasis was given to use standard software products wherever possible.
This was done purposely to:

- support an open system architecture where software and hardware from many different manufacturers could be integrated
- make provisions for further improvements with the advancement in technology
- minimise the costs associated with the development

5.1 Integrated Software Environment

Software developed for the integrated protection and control system is hosted by Microsoft Windows environment. Windows was sought as it is the most widely used icon based user friendly graphical interface for the MS-DOS (Microsoft Disk Operating System) operating system. By selecting Windows platform, it was possible for the integrated protection and control software to make permanent or ad-hoc data links with other Windows applications easily. Therefore it was possible to make the data acquired by the integrated protection and control system to be made available for Windows oriented spreadsheet such as Microsoft Excel, or for a language compiler such as C++, or a word processing package through data links or through object linking and embedding.

Windows architecture usually consists of three main components: Windows Application Programming Interface (API) , the Windows core and Windows extensions and drivers. The way these components are developed, it is possible for the developer to use Windows API to write Windows-based applications without knowing the details about how Windows core routines work internally, or how Windows device drivers communicate with hardware. This makes the development of large software projects easy. In developing the integrated protection and control system the software development was based on the Windows environment and therefore managed to save significant amount of programming effort.

5.2 Local Area Network Software

Another advantage with Windows is that it offers a variety of software applications based on it. This includes various spreadsheets, word processors, language compilers, presentation software and most importantly software to run local area networks. There are two Windows networking software: Windows NT and Windows for Workgroups. In this project Windows for Workgroups was used as the supporting networking software for the system.

Windows for Workgroups builds on the Windows 3.1 architecture by providing integrated network functionality in the base operating system. The incorporation of networking components in Windows for Workgroups helps the developer to define a standard platform for network units to communicate and exchange information. MS-DOS device driver is loaded during MS-DOS system initialisation process and the Protocol Manager in Windows will bind the network transport protocols to NDIS-complaint (Network Device Interface Specification) network adaptor card MAC (Media Access Control) driver. The NDIS network adaptor card driver is used to define how the network protocol will communicate with a network adaptor card. The network adaptor card used in this project was Topware TE 2000AD card. This card is fully compatible with IEEE 802.3 10Base2 and 10BaseT standards and has 10MB/s data transfer rate which is typical for Ethernet. The way the integrated protection and control system software implemented in Windows platform and is connected to network hardware through Windows for Workgroups is shown in the Figure 2.

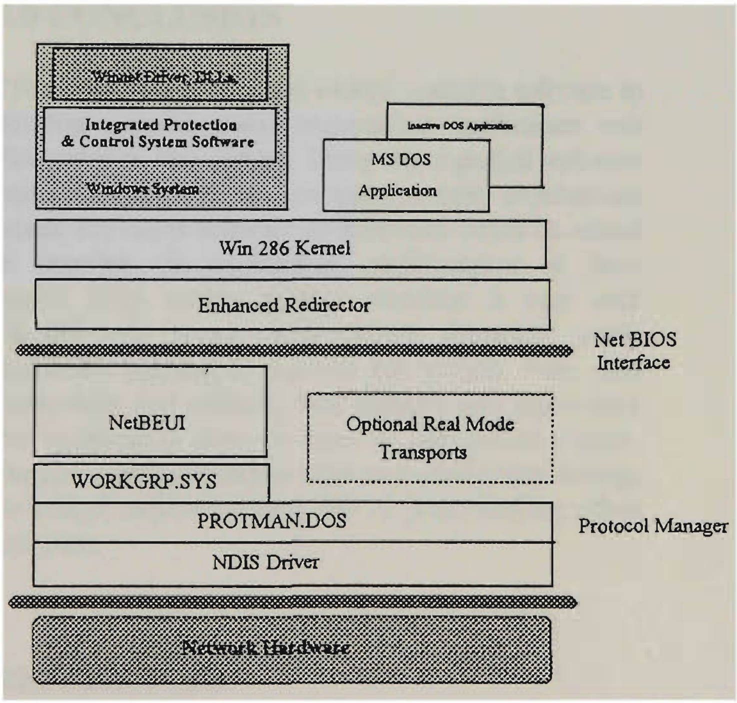


Figure 2. How the system software fits into network hardware

5.3 Network Dynamic Data Exchange

Windows Dynamic Data Exchange (DDE) facility is a standard Windows protocol and enables the Windows based applications to exchange data and carry out remote commands by means of Windows messages. In the Windows for Workgroups this facility is extended over the network and provisions are made to exchange data with remote computers over the network. DDE is most appropriate to exchange data when there is no need for continuous user interaction. First, a link is established between the remote protection or control unit which is going to exchange data with the central computer. Once the link is established, however, the application can exchange data over the network in real time without further user intervention. This network DDE facility was used as the basis for remote monitoring and control of the integrated protection control system.

5.4 Instrumentation Software

To take measurements, data acquisition and provide the control signals to protective gear Labview instrumentation software developed by the National Instruments was used. Labview like any other programming tool is equipped with extensive range of libraries of functions and subroutines for general and specific instrumentation software development. Further it provides with an easy to use graphical interface which could be customised. With Labview it is possible to simulate a range of equipment from a simple voltmeter to fully integrated control system in a single computer. Application specific libraries for data acquisition, GPIB and serial instrument control, data analysis, data storage and data presentation is very helpful in developing high quality instrumentation software with low costs in a short period of time. Due to the fact that the instruments simulated by Labview, perform and look like the original equipment they often referred to as virtual instruments. In the substation protection and control system developed to simulate various equipment and functions, Labview was used extensively. A remote monitoring panel shown in figure 3 uses this software to capture waveforms.

6.0 PERFORMANCE

The developed system is at the moment offering remote monitoring and control, data analysis and data logging functions. Remote monitoring include metering and accounting alarm monitoring. Further, it can monitor a waveform from a remote station and show it on the user screen in time domain and frequency domain. This helps the user to analyse the harmonic distortion and diagnose harmonic problems. Automatic monitoring helps to plot the demand against time and predict peak demand values. Further data could be imported to a spreadsheet (EXCEL) for other calculations and accounting purposes. Protection algorithms could be included in the substation level computers to determine the fault occurrence.

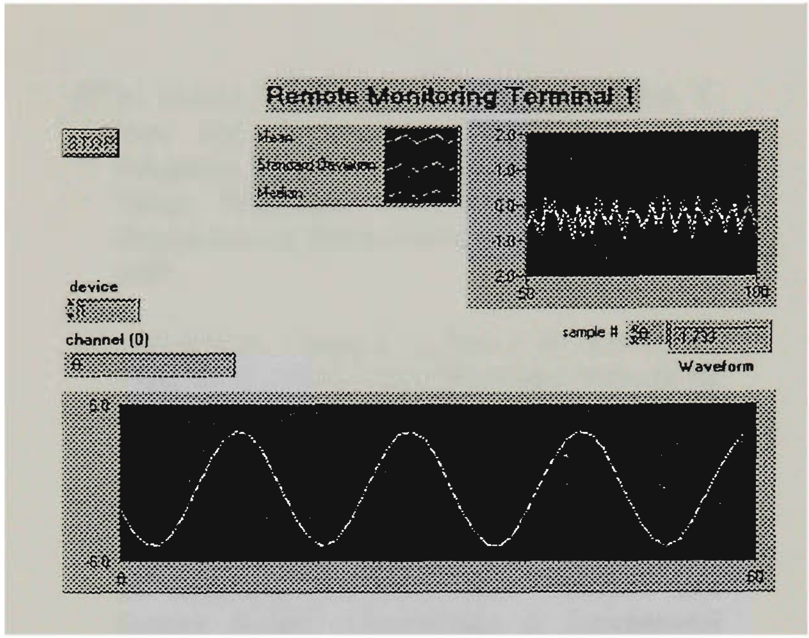


Figure 3. Remote Monitoring of Waveforms

7.0 CONCLUSION

The ability to use standard widely available software to develop a useful power engineering application was illustrated in this project. Using the standard software and protocols lead to an open system architecture where any other software or hardware could be added to improve the application performances at later stages. High quality graphic interface is very user friendly and menu based system operation needs minimum training to operate the system. Fast data acquisition and network data transfer rate guarantees the updating is done on time in the central station. Further it was possible to achieve considerable savings on cost of implementation and in programming effort and time.

REFERENCES

[1] Deliyannides J. S., Urden E.A., "Design Criteria for an Integrated Microprocessor-based Substation Protection and Control System". IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No.6 June 1982.

[2] Nilsson S.L., Petrie H.R., Deliyannides J.S., Mankoff L.L., "New Digital Control and Protection System for Transmission Substations", International Conference on Large High Voltage Electric Systems, 1986.

[3] Lilley R.A., Seymour C., Bishop P.G., Pullen F. D., "Co-ordinated Substation Control and Monitoring", International Conference on Large High Voltage Electric Systems, 1986.

[4] Douglas J., "Building the Smarter Substation", EPRI Journal Vol.13 No. 4, Jun 1988.

[5] Bondia E., Suarez E., Cobelo F., "Integrated Protection and Control Digital System for Rural Substations", IEE Conference Publication No. 302, 1989.

[6] Jeyasurya B., Venkata S.S., Vadari S. V., Postforoosh J., "Fault Diagnosis using Substation Computer", Power Industry Computer Applications Conference, Seattle WA, USA, 1989.

[7] M. Suzuki, T. Matsuda, N. Ohashi, R. Tsukui, Y. Sano and T. Yoshida, "Development of a Substation Digital Protection and Control System Using Fibre-Optic Local Area Network",IEEE Transaction on Power Delivery, Vol. 4, No.3, July 1989.

[8] Kwon W.H., Chung B. J., Park J. W., Lee G. W., Yoon M. C., "Real-Time Fibre-Optic Network for an Integrated Digital Protection and Control System", IEEE Transactions on Power Delivery Vol.7, No. 1, Jan 1992.

[9] Zayegh A., Kalam A., Kannangara C., "Model of an Integrated Substation and Protection and Control System", Proceedings of International Conference on Modelling and Simulation '93 Conference, Victoria University of Technology, Melbourne, Australia,12-14 July 1993.