POWER SYSTEM SIMULATION:
A HIGH POWER AMPLIFIER APPROACH

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Presented to the
Nineteenth Annual
Western Protective Relay Conference
Spokane, Washington
October 20-22, 1992

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INTRODUCTION

Before the advent of Model Power System testing of protective relay systems, relay transient performance had to be judged on the basis of performance on actual power system applications. Early relay designs were functionally tested on simple fault simulations as provided by combinations of resistance, inductance, and capacitance. Signal sources were developed that could simulate the secondary voltage and current levels as would be found in a substation during a fault. The longer a relay design remained in existence, the more live fault testing the relay would undergo. Improvements in relay design would be made based on field experience.

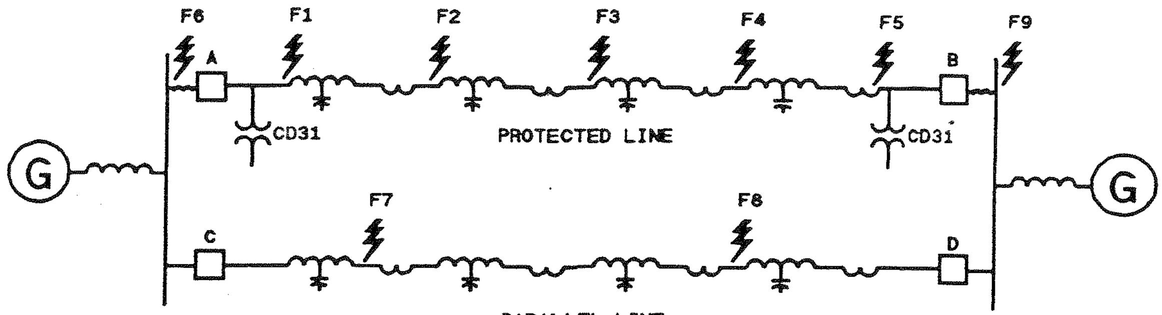
The introduction of high speed solid state relay systems in the early 1960's introduced a new concern with relay testing. The faster operating times of these relays caused them to respond to transient signals that did not affect the slower electromechanical designs. Power systems were becoming more heavily loaded and "field testing" of these relays would have been disruptive and a compromise to the security and reliability of the power system. The Model Power System (MPS) was born out of the necessity to test these relays under more realistic power system conditions.

As the name implies, the MPS is a scale model of a small portion of a power system with line, bus, circuit breaker, CT and CCVT models. Figure 1 shows a typical configuration of the GE MPS. The design is flexible to allow different line configurations, line angles, and line lengths to be modeled as well as providing various source impedances and mutual conditions. Since the desired output level was 5 Amp nominal, components had to be designed to accommodate the high currents and voltages that would be required to simulate the substation environment. Size and economic considerations were often the limiting factors in the development plans of the overall model. Testing was of course limited to the configurations that could be realized with the existing line sections and sources. Although a system could contain a generator, internal voltage and current signals were typically not available and thus provided insufficient data for detailed generator relay testing.

For those situations where larger system representation was required, low power MPS's were developed. These systems operated on lower voltages and currents and as such, the line models were relatively less expensive to build and more line models could be physically located in an equivalent space. Some of these simulators were equipped with large water cooled amplifiers in order to provide the high voltage and current signals still required for relay testing. Although more of the power system could now be modeled, special situations would require special models to be built which still required extensive time and money to implement.

112 MILE LINE MPS SYSTEM

WITH ZERO SEQUENCE MUTUAL



SECONDARY IMPEDANCE

LEFT SOURCE	LINE	RIGHT SOURCE
Z1 : 1.5 at 88 deg	Z1 : 6 at 88 deg	Z1 : 1.5 at 88 deg
Z0 : 1.5 at 88 deg	Z0 : 18.5 at 76 deg	Z0 : 1.5 at 88 deg
	Z0M : 7.5 at 53 deg	
	XC1 : 110	
	XC0 : 167	

Figure 1
Typical Analog Model Power System Configuration

Today's power systems are becoming even more complex with new configurations such as 6 Phase lines and dynamic equipment such as Thyristor Controlled Series Capacitors. Addition of this equipment to the power system often calls into question the performance of existing relay schemes not only on the line section being modified, but also on many adjacent line sections. In conjunction with growing complexity in power systems, microprocessor based relays utilize tens of thousands of lines of code to provide as many as 6 different relay schemes as well as a host of peripheral functions in one programmable package. A change in functionality in these devices is most often effected via new software. The effects of a software change are much harder to evaluate than a change in a piece of hardware. A change in one module of the program may cause problems in a functionally unrelated section of the program. As such, the manufacturer must re-evaluate the complete performance of the relay for each software change. With a general push for speed, quality, and service, the relay manufacturer is challenged to find new ways of testing his product to insure closer coordination between the relay system and the power system over today's broader range of operating conditions.

In response to the challenges presented above and to augment its existing Analog MPS, GE Protection and Control has implemented in its Malvern, PA Technology Center a new Digitally Sourced Model Power System (DSMPS) that combines Digital Simulation technology with new High Power Amplifier technology. With digital simulation, existing system configurations can be modeled in greater detail over a larger portion of the power system. Technology concepts can be validated, new ideas tested, and relay performance evaluated. Digital controls can provide automatic operation and data analysis. New High Power Amplifier technology provides more versatility and dynamic range to cover the wide diversity of relay test environments. This paper describes the DSMPS design and presents some examples of simulations performed.

SYSTEM DESCRIPTION

The simulator can be functionally broken down into three primary blocks as shown in Figure 2.

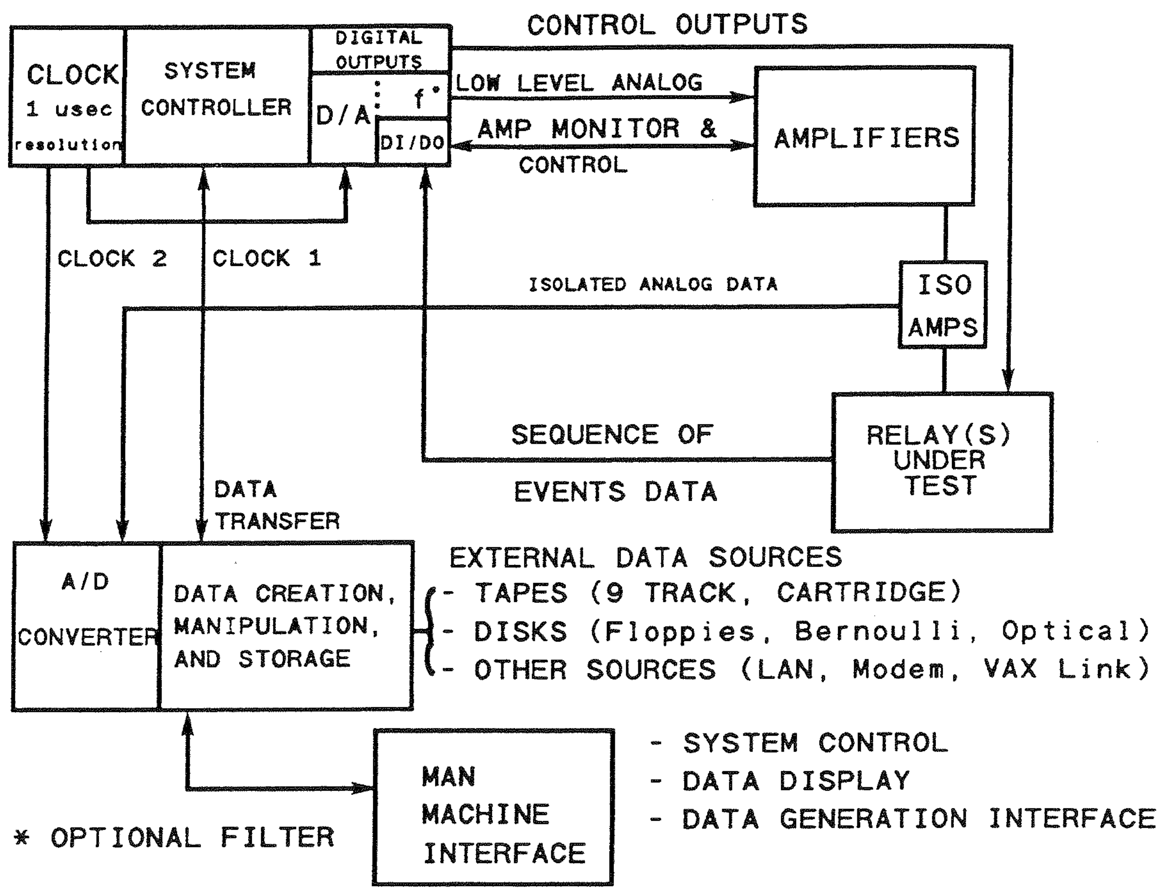


Figure 2
DIGITALLY SOURCED MODEL POWER SYSTEM

DATA CREATION (BLOCK 1)

The first block, labeled "Data Creation, Manipulation, and Storage" is the digital data source for the system. The function is implemented via a 33 MHz 486 PC with 16 Mbyte DRAM, 1 Giga-byte Hard drive, and a 640 MByte Re-writable optical disk drive.

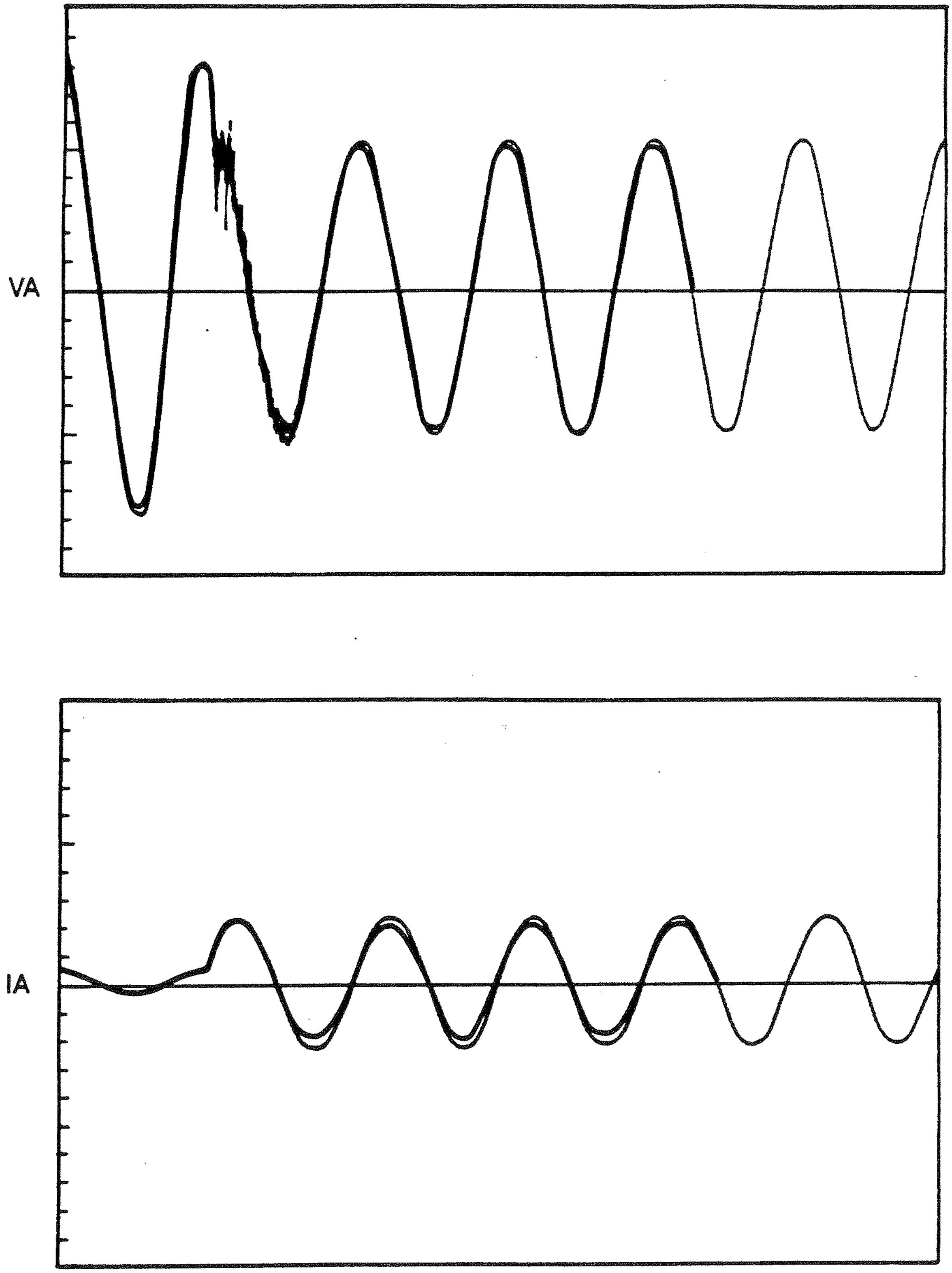


Figure 3
EMTP - MPS Waveform Comparisons
Thick Line - MPS   Thin Line - EMTP

- EMTP DATA GENERATION

The primary digital data source for the simulator is a PC version of the Electro Magnetic Transients Program (EMTP) known as the Alternate Transients Program (ATP). EMTP inputs system impedances, equipment, and signal sources and solves the wave equations to obtain simulation results. One issue in using EMTP is in validation of the input system model. To gain some insight as to how close EMTP simulations are compared to outputs from GE's Analog MPS, a study was performed in conjunction with GE's Power System Engineering Department and the results published [1]. Overall registration was fairly good as can be seen in figure 3, however, EMTP outputs were observed to be "less lossy" as compared to the analog simulator and there was some difference in response of CCVT models. Clearly, EMTP model validation will necessarily become a critical step is the overall digital simulation process.

In type testing of a relay system, conditions such as fault location, fault type, fault initiation angle, fault impedance, pre-fault load, evolving faults, system and source configuration, off frequency, out of step blocking, and CT/CCVT transient response are varied. Over 200,000 fault cases will result given all the permutations and combinations.

In order to generate this mass of fault cases, a front end processor to ATP was developed that can automatically vary the fault parameters. The ATP file processor works with a special input set-up as illustrated in Figure 4. Fault type is selected via switches S1 to S6. By varying the operate time of the

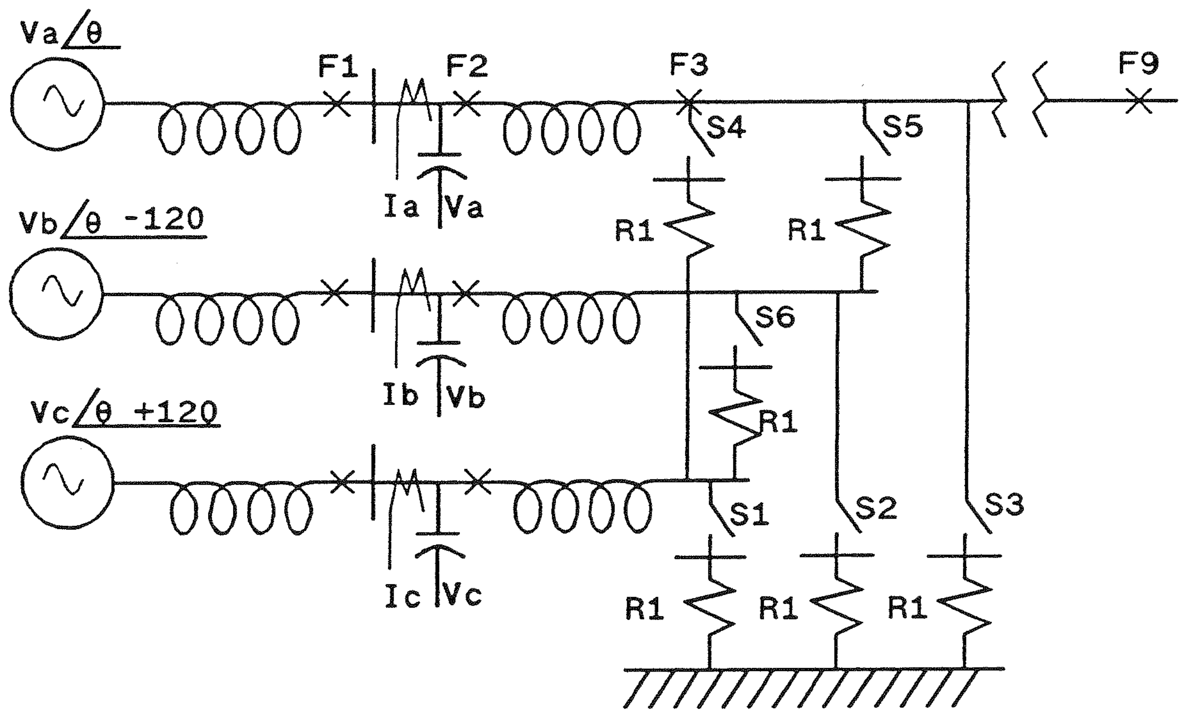


Figure 4
EMTP Input Format for Pre-Processor Application

fault switches, the fault initiation angle can be adjusted. Fault resistance is modified by proper selection of R1. Pre-fault load is adjusted by choice of the source angle - THETA. Each resultant file is automatically named based upon its parameter setup then run through ATP. Resultant output data files will be stored per the new IEEE STANDARD COMMON FORMAT FOR TRANSIENT DATA EXCHANGE - COMTRADE [2]. Due to the volume of cases to be saved, data storage will be formatted per the BINARY storage option as defined in section 6.5 of the COMTRADE document. To permit rapid loading of libraries of fault cases, data files will be stored on removable optical disk platters. Given data files of 3 voltages and 3 currents sampled at a rate of 10,000 samples per second for a 15 cycle fault duration, a total of 12,800 fault cases can be stored on a single platter.

- SYNTHETIC DATA

Short circuit programs such as ASPEN provide steady state phasors in the solution of a fault case. A program has been developed that takes these steady state phasors and samples them to create transient data files. DC offset is added to the current waveforms based on a user input fault initiation angle and system DC time constant. This is only a first approximation of an actual system fault, but does supply idealized waveforms to the relay.

- ANALYTIC DATA

A third data source used with the simulator is analytic data generated per the equation:

$$Y_i[nT] = \sum_{m_i} M * SIN(\frac{2\pi}{N} nm_i + \phi_{m_i})$$

where:

Y_i = RESULTANT OUTPUT DATA FOR CHANNEL i

n = OUTPUT SAMPLE NUMBER

N = # OF SAMPLES IN A 1 SECOND PERIOD

$m_i = 0, 1, 2, \ldots \frac{N}{2} - 1$ = FREQUENCIES INCLUDED OF THE i_{th} OUTPUT

$T = \frac{1}{N}$ = SAMPLE PERIOD

i = 1 to 24 = CHANNEL NUMBER FOR OUTPUT DATA

M_{m_i} = MAGNITUDE OF THE m_{th} HARMONIC ON CHANNEL i

ϕ_{m_i} = PHASE ANGLE OF M HARMONIC ON CHANNEL i

This equation sums together up to N/2 harmonic signals, including DC, for up to 24 output channels and when implemented with timers, can yield a programmable output duration with microsecond accuracy.

Alternately, analog data sources such as Analog Model Power System Simulators and tape decks can be sampled by the internal A/D converter. The A/D chosen can sample 16 analog channels at 12 bit resolution with an aggregate throughput of 250,000 samples per second continuous to disk. The A/D converter plays another crucial role in the validation of the amplifier output. As the amplifiers do have voltage and current limits, it is possible to have a test setup where the amplifiers are pushed into saturation. Although the amplifiers have a overload output, comparison of the amplifier output signals with the D/A input provides a needed monitoring function.

The other primary data source for the simulator is Digital Fault Recorder (DFR) and Digital Relay oscillograph data. Typically, files received from this source contain a limited number of pre-fault cycles. Since many relays (both analog and digital) require a certain amount of pre-fault data to establish memory and polarizing quantities, a feature has been added on the playback unit to repeat the first cycle of data a user-programmed number of cycles. As these digitizing devices proliferate in the power system, this "real life" data will become readily available and will prove to be extremely valuable in relay performance analysis. It is intended to interface with this data via the COMTRADE file format either in its ASCII or BINARY formats.

- DATA MANIPULATION

The second function of this block, listed as "Manipulation" provides any needed massaging of the data. Massaging can include operations such as interpolation, decimation, digital filtering, amplifier compensation, and data scaling. Interpolation is the operation of fitting extra data points between existing ones or in a more complex operation, exchanging one set of sample points and times for a new expanded set. Although more data points are added, frequency content remains the same. The process of decimation, on the other hand, deletes data points and necessarily reduces frequency content in a sample set. When deleting sample points, if the data was captured with a wide band anti-aliasing filter, it will be necessary to digitally filter the data through the appropriate low pass digital filter. The interpolation/decimation function will be implemented via the guidelines set up in the ANSI C37.111-1991 COMTRADE standard [2]. The other manipulation function of note is that of amplifier compensation. The amplifiers have a dynamic response that is a function of frequency, magnitude, and relay burden. As this response is analytically predictable, signals can be compensated before being played through the amplifiers resulting in a linear amplifier response over a wide dynamic range.

As a side function to the Data Creation block is the Man Machine Interface (MMI). The MMI provides an intelligent interface to the control, data generation, and data display functions of the system. Date viewing is facilitated via a 33 inch VGA auxiliary monitor that operates in parallel with the primary 16 inch display. Plots of data files and relay operations can be made either on dot matrix or laser-jet printers.

SYSTEM CONTROLLER (BLOCK 2)

The second major block of the simulator is the System Controller (SC). The major function of the SC is to provide the Digital to Analog conversion function to source the amplifiers. The SC contains 24 channels of synchronized, 16 bit D/A conversion. Output of the D/A is a +/- 10 v signal. The 16 bit converter provides 80 dB of dynamic range with data rates up to 50,000 samples per second. The D/A boards reside in a VME chassis and are driven by a 25 MHz Motorola 68040 CPU with 4 Mbyte (expandable to 32 Mbytes) of on board dual port RAM. Sample data is loaded from the PC to the Motorola board via a parallel 16 bit bus to bus interface. This parallel interface is capable of bidirectional communication at 1 Mbyte per second. At an output rate of 10,000 samples per second, over 16 seconds of 24 channel data can be loaded into the playback memory and over a minute's worth of data can be loaded if only 6 channels are required.

The D/A and A/D converters are clocked from internal counters on the 68040 board. These counters are 32 bits wide with a resolution of 1 microsecond. As such, a wide range of sample rates can be accommodated.

The VME system also houses digital outputs and inputs to effect simulation of control signals to the relay or device under test, monitoring of relay performance, and amplifier monitoring and control. In particular, digital inputs and outputs are time synchronized with the analog output waveform. Digital inputs are returned to the PC where they are recorded on disk for analysis.

AMPLIFIERS (BLOCK 3)

The last block in the system is the amplifier block. This block is comprised of 24 current amplifiers and 10 voltage amplifiers manufactured by Doble Engineering. Both the current and voltage amplifiers are configurable to optimize the voltage current output ratio. As such a high compliance voltage/low current output or a low compliance voltage/high current output can be selected for each test data case. The amplifiers passes a wide band width that is a function of burden, but as noted earlier, can be compensated via software. Peak amplifier output (1 cycle - inductive burden) of 36,000 VA for a 3 phase event is possible. If higher currents are required, two three phase banks can be combined to output nearly 400 Amps peak. The units are equipped with alarms to detect over-drive, over-temperature, and sustained output error. Operation of any of these alarms will cause the amplifiers to trip off line.

AUTOMATIC TESTING

As pointed out earlier, the number of fault and disturbance data cases required for type testing a relay is enormous. In view of the fact that a software change in a digital relay will require re-type testing, some sort of automatic test feature is desirable. As such, the DSMPS is designed for automatic playback and data recording. Having previously created a large number of EMTP data files, the tester would load into the control program the name of a file which contains the names of all the date files to load and play for a particular test sequence. The system will automatically retrieve each file, load the data into the 68040 board, play the data through the amplifiers and relays, record the results via digital inputs, and save the results on the PC for computerized report generation. As an estimate, running a fault case every 5 seconds allows 12 cases per minute, 720 cases per hour, and up to 17,280 cases per day.

TEST EXAMPLES

- EMTP DATA SOURCE

A number of unique power system configurations have been tested on the simulator. Two cases of interest are presented here as examples. The first example is that of a Controlled Series Capacitor (CSC) as pictured in Figure 5. The CSC can be a combination of a traditional switched series bank and a Thyristor Controlled Series Capacitor (TCSC). Although conventional series capacitor models exist on the analog model power system, the components and switching arrangement are sufficiently unique to have required building of new components. As such, a TCSC model was implemented on EMTP. Figure 6 shows the resultant waveforms as developed by EMTP and played through the amplifiers and relays under test. Results of this test program are reported in [3].

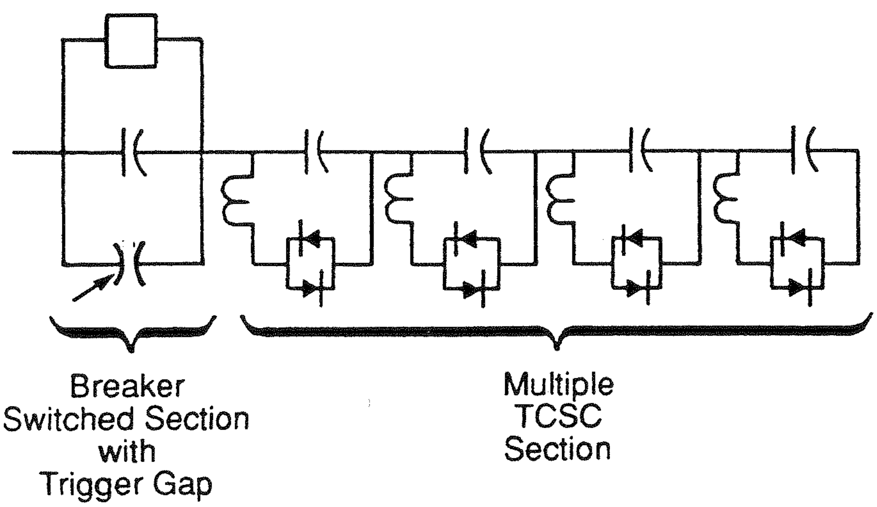


Figure 5
Controlled Series Capacitor Configuration

- DIGITAL FAULT RECORDER DATA SOURCE

DFR data from a fault on a series compensated line was obtained from a utility customer. A program was supplied by the manufacturer to convert the data from their proprietary format to the COMTRADE format which was readable by the amplifier playback program. The currents and voltages shown in Figure 7. As can be seen, the DFR data contained approximately 3 cycles of prefault information which was considered insufficient to allow the polarizing voltage circuits of the distance relay achieve full steady state value. Subsequently, the prefault period was extended by repeating the first cycle

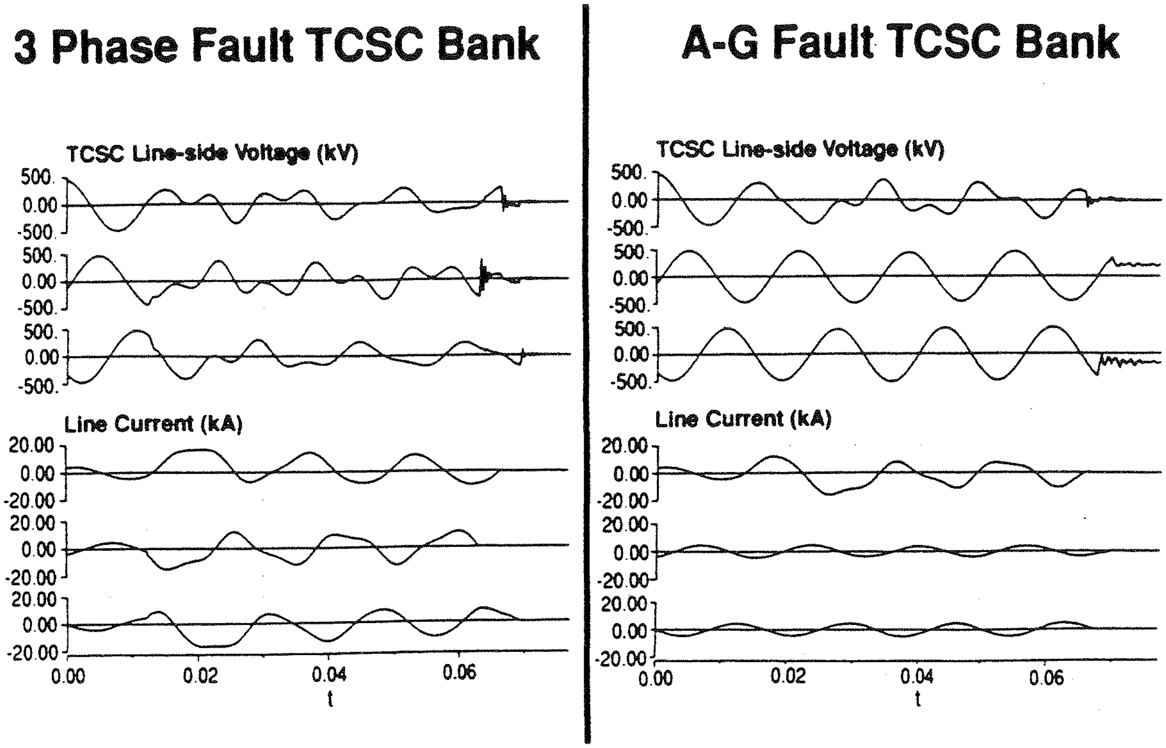


Figure 6
EMTP Simulation of Faults on a TCSC

of data in the DFR record. The resultant data file was loaded into the system, run through the amplifiers, and relay response verified.

CONCLUSIONS

Model Power System testing of new relay designs must be an integral part of the development cycle of a protective relay system to insure that the final design will perform as expected on the power system. This is much more critical with digital relay designs than it was with electromechanical or solid state designs. An Amplifier based Digitally Sourced Model Power System was introduced to augment existing Analog Model Power System capability. The Digitally Sourced Simulator can be fed any digital data, however, facilities have been developed to focus on EMTP as a data source. Continuing development is required on CT and CCVT models to accurately represent the real world signal conditions. Automatic simulator operation and data analysis is possible and necessary to re-type test a relay after a software change. The benefits of the DSMPS have been demonstrated in real world applications.

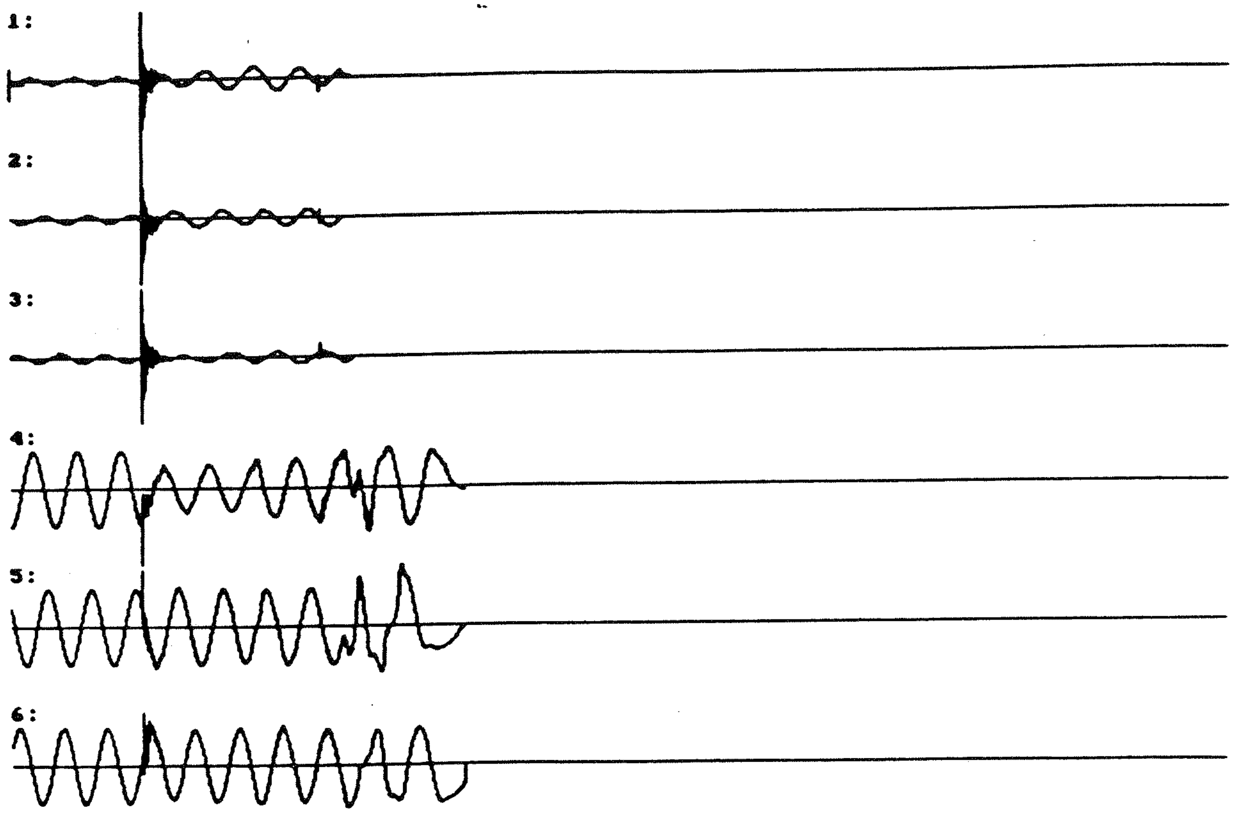


Figure 7
DFR Data from Fault on a Series Compensated Line

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MANAGING MULTIPLE INTELLIGENT DEVICES AND CONTROL TASKS IN THE SUBSTATION ENVIRONMENT USING A PERSONAL COMPUTER BASED DATA ACQUISITION AND CONTROL SYSTEM

Presented to the 19th Annual
Western Protective Relay Conference
Spokane, Washington
October 20-22, 1992

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INTRODUCTION

The world of protective relaying has become computer oriented over the past several years. Due to this microprocessor revolution in relaying, the protective specialist has had to become more in tune with computer programming and computer communications. Complications facing the protection engineer when programming and gathering information from these devices are:

* Differences in communications (RS232 vs RS422/485) and protocols between devices manufactured by different vendors makes it difficult or impossible to network devices.

* Implementing a means for the timely gathering and analyzing the vast amount of data available from these devices.

* Interfacing the intelligent devices with existing substation control systems, i.e., SCADA (supervisory control and data acquisition).

There are many devices in today's substation that communicate serially with a personal computer. It can be advantageous in some circumstances to make these devices communicate with each other or to manipulate data from multiple devices on a real time basis. Unfortunately this can not be done directly because of communication protocol differences and differences in hardware, i.e., RS232 vs RS485. Fortunately the personal computer (PC) has no trouble interfacing with either of these communication standards.

Microprocessor controlled protective relays gather and store large amounts of system operating and fault data. This information allows the protection engineer to do many new and exciting things. As the number of intelligent devices in the substation grows, it becomes more complex and time consuming to program and gather data from each device. The challenge is to retrieve this information from many relays at different stations in a timely manner so that it can be used in determining the cause of outages and facilitate a quick restoration of the system.

There are programs available on the market the protective engineer can utilize that handle the basic transferring of files to a PC and analyzing of the data. These programs are not designed with the sophistication to do such tasks as transmit data from multiple devices on a real time basis to a host or process the relay data in ways that satisfy specific customer needs.

Many customers today are interested in interfacing their protective devices with their SCADA system. At the present time, there are no off-the-shelf products that make this possible. The protection engineer who would like to automatically extract and process data from microprocessor relays or interface the relays with SCADA must look beyond the standard relay software to solutions provided by industrial data acquisition and control techniques.

Herein described is how to build a PC based Data Acquisition and Control system (DA&C) to network all substation devices to a SCADA system. The PC based system gathers information from protective devices as events occur and processes that information. It then reports the information to the SCADA master on a real time basis. Also described are some ideas on how to manage other substation monitoring and control tasks utilizing PC based distributed automated control.

NETWORKING MULTIPLE INTELLIGENT DEVICES

It can be advantageous to network all intelligent substation devices to a dedicated PC in the substation. This allows communication to take place with any or all of the devices virtually instantaneously and without human intervention. Special hardware and software is needed to create more than four serial ports on the PC, which is the maximum that DOS can handle. Once the information is brought into the host PC, a program executing on the PC can manipulate the information and recommunicate it back to any device on the network in the proper protocol for that device. The following is a discussion of the different types of communications that are most common for microprocessor based relays and other equipment.

RS422/485

This type of communication is full duplex over a two pair wire network which can be up to 4000 feet long. RS422 will allow multiple addressable devices to be controlled by one host. The RS485 will allow multiple hosts and slave devices all on the same two pair wire network. The real advantage of the RS422/485 is that all devices are addressable and that they all are connected to a common two pair wire network which can go long distances.

RS232

This type of communication is full duplex over a single pair with ground. A separate channel is required for the host computer to communicate with each device. RS232 devices typically are not addressable and the maximum distance of the network is approximately 100 feet.

Communications Protocols for Microprocessor Relays

Most microprocessor based relays' protocol is ASCII oriented and uses a combination of software handshaking called X-ON/X-OFF and modem handshaking.

INFORMATION TRANSFER

Software packages which access microprocessor based relays and other devices through a modem and dial up phone line are the most common way to interface with microprocessor relays at the present time. Unfortunately, the substation phone is an already overworked commodity as it is also being used to call up such devices as solid state meters. As the number of devices to call up increases, it becomes increasingly difficult to efficiently and productively retrieve information through this medium. Moreover, the phone is needed for voice communications during a system outage which is precisely when information from the microprocessor relays are needed for fault diagnosis.

With these things in mind, it becomes apparent that a more sophisticated means to retrieve and process the vast amount of information available from these devices is needed. At first thought, it seems it would be advantageous if these intelligent devices could be connected directly to the existing SCADA RTU (remote terminal unit). Most RTU's however, cannot handle multiple communication channels and even if it were possible, there would be a point where the processing of information would bottleneck at the RTU or overload the master station. It seems that something more is needed to accomplish the task of bringing information to a central location.

ACHIEVING DISTRIBUTED DATA ACQUISITION AND CONTROL THROUGH THE SCADA SYSTEM

A typical SCADA system is intended to acquire discrete and analog indication points and provide discrete open/close control of field devices on request of the operator. The master station provides the decision making for the entire system. The RTU acts as a slave device, gathering information and reporting that information, or opening or closing contacts when told to by the master. The RTU is not designed as an intelligent control system to interface with and supervise multiple intelligent devices such as the microprocessor based protective relay. The task of communicating with these multiple intelligent devices, gathering information and processing that information requires more processing power than the traditional RTU can provide. In addition, the RTU must be selective in reporting back to the master so that it will not overwhelm it with information, delay other RTU polling, and slow the entire SCADA system down. The SCADA master does not perform automatic control efficiently and cannot provide high speed closed loop control.

If the traditional SCADA RTU is replaced or paralleled with a high powered industrialized PC these tasks can be performed. Installing a PC as an interface between the microprocessor based relays and SCADA master provides an intermediate level of distributed control which will increase the power and capability of any SCADA system. There are two different ways to connect a PC to a SCADA system.

1. The PC can be connected the same as an existing RTU but as a separate unit, and be programmed to emulate the RTU protocol for the system. Thus the master station cannot differentiate between the PC and a standard system RTU. Emulating an RTU restricts the user to handling information in a fixed protocol and format but requires no modification to the SCADA system.

2. Interface with SCADA by connecting the PC on a separate link to the master. This separate link could be programmed to handle information as the user dictates, allowing the user to specify the information transfer protocol and other aspects of the system. Doing this allows more flexibility for the user but requires a second communication channel and may require SCADA programming modifications.

BUILDING THE SYSTEM

Our latest substation upgrade project at Longmont is a lineup of 15kv switchgear containing nineteen SEL-251 relays. I decided to purchase a rack-mount industrial PC to link the relays to our SCADA system rather than trying to utilize a RS232 dataswitch and dial up phone line. Using a dataswitch would have burdened an already overworked phone line, as other agencies are using the phone line to gather data from electronic meters. The PC has the capability to communicate with 16 different RS232 devices at this time and is expandable to 64 RS232 communication ports. One port is connected to the microwave system and communicates directly with the SCADA master by calling a Quick Basic program which emulates a standard Landis and Gyr RTU using Telgyr 6000 protocol. Fourteen of the ports are connected to the SEL-251 feeder relays. The last port is connected to a dial up modem as a non-critical communication path to the dispatch center which is used for transferring bulk information such as metering information or long event reports. The following gives the rational for implementing the system and describes in detail how the system functions. Considerations when building and programming the system are also discussed.

Fault locating on a distribution system is a time consuming task of sectionalizing and retesting of the feeder until the fault is isolated. Many lineman man-hours and customer outage hours could be saved if the lineman could get a head start on locating the fault. The lineman needs a simplified report giving the location of the fault in terms he is familiar with. It is much more straightforward to give the lineman a feeder section number than several short relay event reports--long event reports are out of the question. Moreover this information must be arrived at automatically as there are no engineers available to read and interpret an event report during off hours, when most outages occur.

A computer program linking an event report from the relay on the faulted feeder with data from a computer fault analysis modeling program and other information such as distance to each fuse and available fault current range on each feeder section can predict the location of a fault minutes after inception. This program resides on the PC DA&C system in the substation. The PC gathers information from the SEL relays immediately after the fault, writes it to files on the hard drive, calls the fault analysis program, then transmits the fault location to the SCADA master in the form of an analogue indication point. The lineman checks SCADA for the line section number before leaving the line center or it can be relayed to him via the dispatcher.

Hardware

An industrial rack mount PC can be obtained from several vendors. It is best to purchase a true industrial hardened PC, but depending on the environment the unit is to operate in, a desk top model may be sufficient. An Intel 486 based PC is preferred for its speed of operation. PC selection is based on how much needs to be done in a given time period. A flat screen monitor is desirable for locating in panels where space is limited. A conventional monitor is more cost effective and can be located at a desk remote from the computer which should be located as close to the RS232 devices as practicable. Be warned though that boosters are needed to locate a conventional VGA monitor more than 20 feet from the computer.

RS232 or RS422/485 communications can be interfaced to the PC through the many PC bus expansion cards available on the market. The most powerful is a card manufactured by Industrial Computer Source which interfaces 16 RS232 ports to the PC. There are eight UARTS and two 80186 microprocessors which handle the task of polling the ports and bringing the data into buffers. These microprocessors handling the communications tasks off load the host processor so that it can perform higher level tasks such as manipulation of the data to put it in the form that is acceptable for the SCADA system. There are two versions of the serial card partial handshake and full handshake. The full handshake card which uses hardware handshaking signals is required for modem communications.

Analog and Digital I/O Cards

These PC expansion cards are used to provide monitoring of analog voltages, currents and dry output contacts. They also provide ON/OFF control of devices such as breakers, reclosure switches, etc. Many vendors offer analog and digital input/output cards for interface with PC's. Some plug directly into the PC expansion chassis to interface directly to the data bus and are connected to termination panels at the source of the input signals. Some cards write information directly into the memory of the PC (DMA) which allows very high throughput rates. Other systems communicate to the host PC over an RS422/485 twisted pair network. Things to consider when making a selection are sampling speed desired, noise in the environment, and physical distances between all points on the network.

Programming

Most all data acquisition and control cards come with software drivers for high level languages such as Basic, Quick Basic, and C. A compiled programming language is preferred for its speed of operation. Programming experts can write their code in assembly language which is the most efficient, but protection engineers will find Quick Basic the easiest to use. Those engineers who have neither the time or inclination to write their own programs can design a program flowchart and leave the programming to the experts.

The following is a discussion of the program that runs on our PC based data acquisition and control system. The main functioning of the program is to interface fourteen SEL-251 feeder relays to a Landis and Gyr SCADA master station--refer to Figure 1. The program is written in Quick Basic and calls drivers to accomplish communications tasks. The program functions as follows. After the relay detects a fault, it will immediately send a short fault report to the communications port. Activity is sensed on the port and immediately written to a unique file on the hard drive of the PC. The Quick Basic program then requests a long event report from the relay and writes it to a unique file. The program then calls a subroutine which reads the event report, calculates the fault currents and compares them with calculated fault values for that particular feeder derived from a fault analysis program. The calculated fault values reside in files on the PC hard drive and are correlated to line sections for the faulted feeder. The derived line section number is then stored in a unique variable and control is then transferred back to the main program. The program then calls a SCADA communications subroutine which puts the line section number in the form of the proper protocol, calculates a CRC-16 error check and stores the information in bytes which will be transmitted out of the SCADA port when the next poll occurs. Most of the time the PC system has nothing to report to the master as data is reported only if a change occurs. In this case the PC returns an exception response after the poll occurs.

CONSIDERATIONS WHEN INTERFACING TO YOUR SCADA SYSTEM

The simplest way to interface your PC based DA&C system to SCADA is to program it to emulate an RTU on the SCADA network. The communication protocol for the SCADA system is needed to write the program. If the protocol is not available, it can be determined by utilizing a serial analyzer program, see Figure 2. This program gives the byte codes in ASCII, hex, decimal, octal, and binary. The user must correlate the RTU response to master commands and master responses to RTU data by monitoring the communications from both ends simultaneously while known commands are executing.

Protocol determines the rules for how computers communicate with each other. There are many standard protocols that can be used. The user must decide what data needs to be transferred before deciding on a protocol to use. If the protocol is already established, the user must figure out how to best utilize the protocol for transferring the required information. The following describes a typical SCADA protocol and how to utilize it to transfer information to the master station.

Each byte or character of information consists of 10 bits, 1 start bit, 8 data bytes and 1 stop bit. The message can be of variable length and consists of three parts, the header, contents and trailer. The header and trailer are always present. The contents portion will be present only if there is data to be transferred. The message will begin with a break character which is a string of ones or zeros. The second character is the RTU address. The next bytes are data bytes which can be in different formats, depending on whether the data is analog, indication status, pulse accumulator counts, etc. The last 2 bytes (trailer portion) is a CRC-16 error check code.

The PC must have a program continuously running to collect data from all microprocessor relays and transmit it to the SCADA master station. The PC is programmed to communicate with the master using the SCADA system protocol. The following is an explanation of how the program executes. First, an interrupt is generated by data entering the buffer on the serial port assigned to the SCADA master. The computer looks at the data to see if the SCADA master is requiring an action. This is as simple as looking for its unique address. An error check is performed to determine validity of data. If the address is not correct, it ignores the message; if the address is proper, the scan code is looked up to determine what action is required of the computer by the master. The computer then performs the required duty and reports back to the master. An error check is then generated and added to the outgoing data.

<u>CRC-16 Cyclic Redundancy Code</u>
CRC-16 is a method of performing error checks on a serial data line. It calculates a 16 bit number based on every bit of data being transferred using the standard generator polynomial (X**16+X**15+X**2+1). There are two ways to implement the CRC-16 code:

1. Purchase standard hardware that performs the routine.

2. Program the code in the computer. A paper by Aram Perez in the June 1983 issue of IEEE MICRO explains CRC-16 in detail

and gives an algorithm for calculating the routine based on data bytes.

Special user application programs can be written for the SCADA master to perform user specific tasks such as receiving of event reports or other data in ASCII format. In some cases the manufacturer can reprogram the protocol to suit the needs of the customer. This allows the user to set up the PC to communicate in the protocol that is most efficient for the application.

OTHER APPLICATIONS WE ARE WORKING ON

Load-Tap-Changer (LTC)

LTC control can be accomplished more effectively using digital computer technology. LTC control bandwidth and other parameters can be adjusted as loading and time of day dictates.

On-the-fly Relay Setting Changes

The distribution system is switched in many different configurations due to system maintenance, outages etc. It is useful to customize settings for each feeder to maximize protection and security. For example an all underground circuit would not need reclosing or instantaneous overcurrent relays or industrial customers on dedicated circuits may require special settings to coordinate with plant protection. But when the system is switched in an abnormal configuration different settings may be required. The DA&C system can make these changes automatically by sensing system status or loading.

Peak Shaving Using Supply and Demand Side Management Techniques.

The PC control system can calculate total integrated load at the substation for the purpose of peak shaving. The PC can take control of the transformer LTC to reduce voltage to the load, thus reducing the power required in a resistive load. This method of supply side load management is very effective for residential loads. A demand side technique is to take direct control of the load during peak times. The PC could send radio signals or communicate over dial up modems to turn off non critical loads during peak periods.

Distribution Automation Applications.

The DA&C system is an integral part of distribution system automation. If the system is equipped with a fault locating system as described previously, the system could take automatic action to switch the faulted portion of the system out and then restore the rest of the feeder. If automatic switching is not desirable the system could give the lineworker a report with suggested switching. System efficiency or reliability can be maximized by having the automation system switch automatically as a response to any monitored parameters.

Full Time Power Quality Monitoring on Each Distribution Bus
There are PC expansion cards on the market that sample at high rates, trigger and store information similar to a digital storage oscilloscope. The phase voltages on a distribution bus can be monitored with this type of PC expansion card to detect any voltage fluctuations or harmonics and alarm SCADA. Sampling is continuous and a report is triggered only when user defined parameters are exceeded. The report is written to the PC hard drive for future retrieval.

Hydro Plant Automation
I installed and programmed an Opto 22 single board industrial computer to control all operational functions at Longmont Hydro Plant. The computer is interfaced to our SCADA system.

NETWORKING DEDICATED PC's

There are many things that can be performed by the PC. There comes a point where the PC is doing as much as the CPU can handle. At this point the DA&C system tasks should be split among several PC's each being dedicated to its own special task. The PC's could then be linked together with a Local Area Network (LAN) system. This forms a comprehensive computer network with dedicated distributed control--Figure 3.

CONCLUSION

Control of the electrical system should not be undertaken without exhaustive testing and proving of the system before it is placed into service. Every safety consideration must be evaluated and fail safe devices installed. With sound engineering practices to implement advanced data acquisition and control principles the automated electrical system can be the best operating and most efficient in the world.

References:

1. McNamara, John E., Technical Aspects of Data Communication, Third Edition, 1988, Digital Equipment Corporation

2. Perez, Aram, "Byte-wise CRC Calculations", IEEE Micro, June 1983

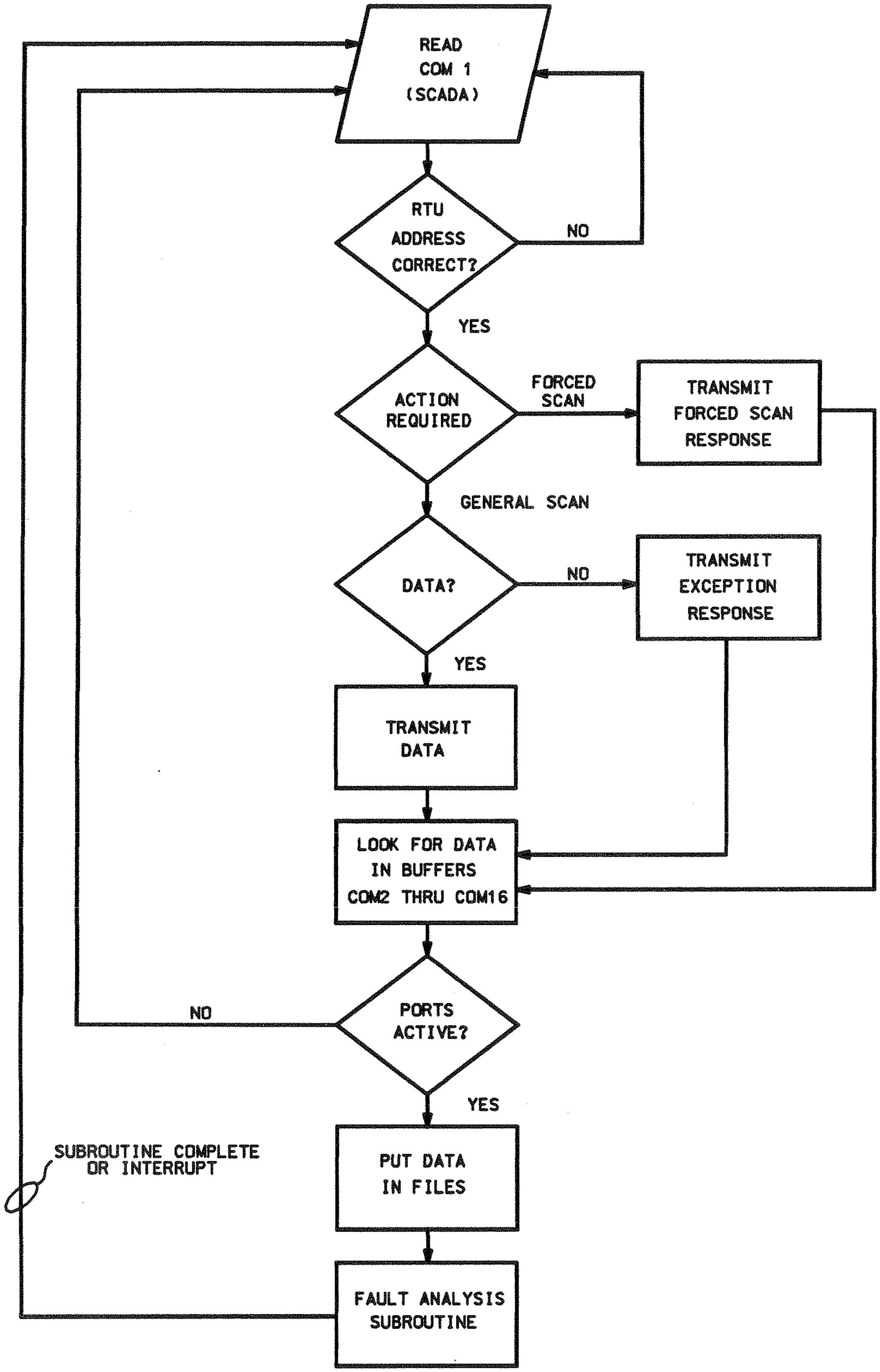

FIGURE 1

FLOWCHART OF SEL-SCADA INTERFACE PROGRAM

```
R. .ew Data    Current Configuration: master                       Serialtest V 3.0
 ┌Hexadecimal Data─────────────────────────────────────────┐  ┌ASCII Data─────────┐
 │ FF 82 03 A0 66 46 D2 2A FF 44 00 33 FF 04 01 C3 │  │ é♥áfF╥* D 3 ♦├ │
 │ FF 01 C1 C0 FF 01 C1 C0 FF 02 81 C1 FF 82 03 A8 │  │ ┴└ ┴└ ü┴ é♥¿  │
 │ 56 EF 87 96 FF 04 01 C3 FF 84 03 A8 04 29 B2 A4 │  │ V∩çû ♦├ ä♥¿♦)▓ñ │
 │ FF 41 C0 30 FF 81 03 B0 A4 EA C6 F2 FF 42 80 31 │  │ A└0 ü♥░ñΩ╞≥ BÇ1 │
 │ FF 82 03 A8 46 C4 CA 49 FF 44 00 33 FF 84 03 A0 │  │ é♥¿F─╩I D 3 ä♥á │
 │ D6 FC AE 59 FF 01 C1 C0 FF 81 03 A8 16 CF F3 8E │  │ ╓ⁿ«Y ┴└ ü♥¿╧≤Ä │
 │ FF 02 81 C1 FF 82 03 A8 16 7F B6 3A FF 04 01 C3 │  │ ü┴ é♥¿╢: ♦├ │
 │ FF 04 01 C3 FF 41 C0 30 FF 81 03 A8 A6 45 07 E9 │  │ ♦├ A└0 ü♥¿ªEΘ │
 │ FF 42 80 31 FF 02 81 C1 FF 44 00 33 FF 84 06 A0 │  │ BÇ1 ü┴ D 3 ä♠á │
 │ A4 00 B0 41 E0 36 D5 FF 01 C1 C0 FF 81 03 A8 66 │  │ ñ ░Aα6╒ ┴└ ü♥¿f │
 └─────────────────────────────────────────────────┘  └───────────────────┘
search by Port     Mark      Go to            Error scan      heX
Search             Delta     Crc/checksum     Rate            cHaracter
 ┌Byte Information──────────────────────────────────────┐
 │Byte        1 of    153222   Source DCE               │ Reviewing:
 │   ASCII   Binary   Oct   Dec   Hex       Timestamp   │   master
 │  80H+DEL 11111111 377   255   FF                     │ Mark:
 │Signals: RTS  CTS  DSR  CD  DTR  RI                  │ End Mark:
 │Errors: -- None --                                     │
 └───────────────────────────────────────────────────────┘
```

Serialtest monitors both DCE (data communication equipment) and DTE (data terminal equipment) at the same time. DTE transmissions are underlined (SCADA master end) DCE transmissions are RTU response. Note that all data is shown in HEX, ASCII, BINARY, OCTAL, and DECIMAL

In this example the master is sending a general scan to RTUs 1, 2, and 4 - the RTU response immediately follows.

FIGURE 2
SERIAL ANALYZER PROGRAM

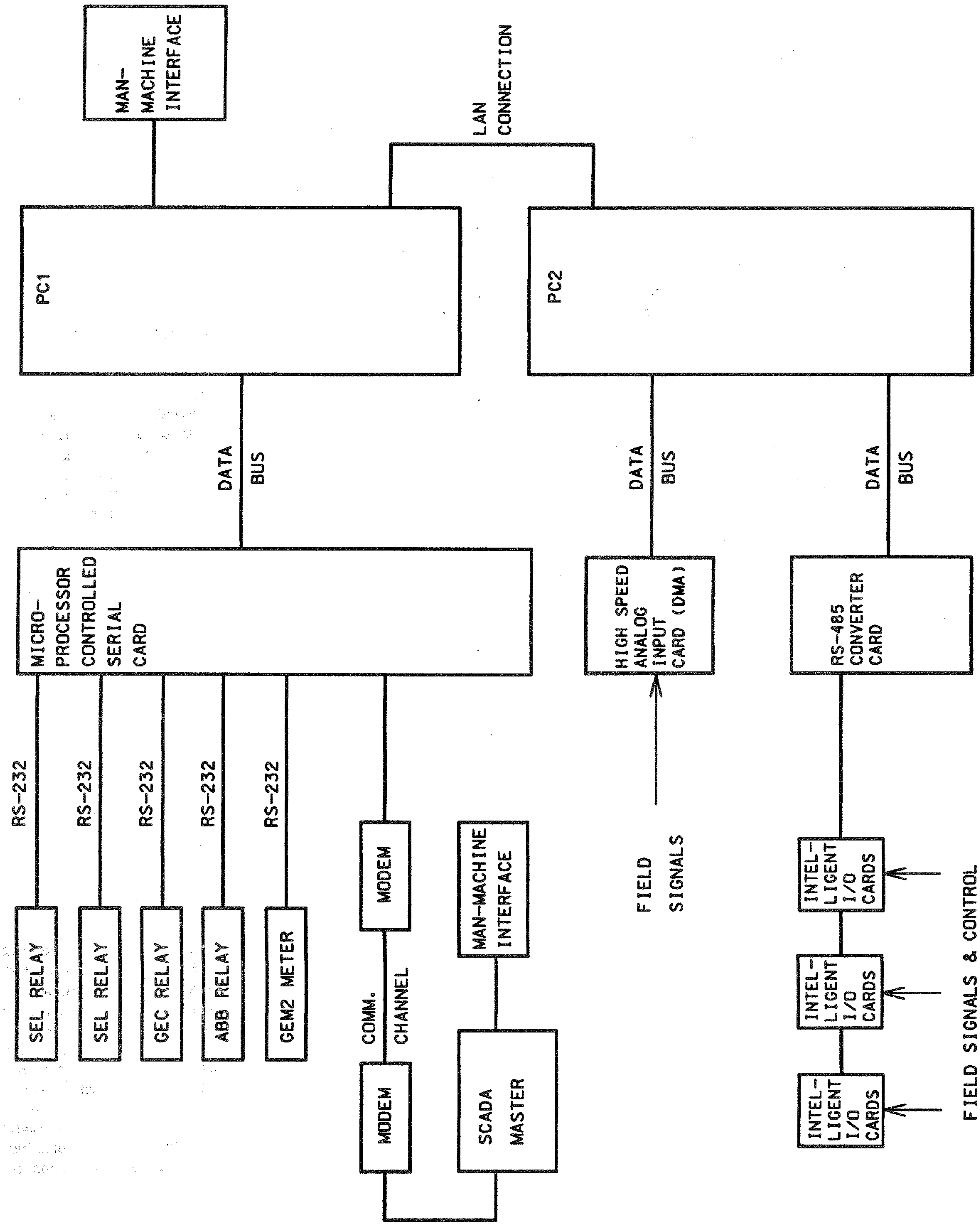

FIGURE 3

SCHEMATIC OF PC BASED DATA ACQUISITION AND CONTROL SYSTEM