A GENERAL PURPOSE HARDWARE FOR MICROPROCESSOR BASED RELAYS

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Abstract: The use of microprocessor technology for power system relaying was first introduced in the early 1970's. Since this time, many microprocessor based relays have become commercially available. However, in most cases, the hardware used is specially designed for each relay. The functions of a microprocessor based relay are software controlled, so it should be possible to design a general purpose hardware that can be used to build microprocessor based relays for different functions. This paper describes the design of such a general purpose hardware. The designed hardware has been used in two microprocessor based relays for three-phase transformer protection, and for three-phase inverse time overcurrent protection. These applications are also briefly described in the paper.

Introduction

Power systems are, generally, protected by using combinations of relays and circuit breakers. Relays detect the onset of faults and, if necessary, initiate the opening of circuit breakers to isolate faulty equipment. Electric utilities traditionally use electromechanical and solid state relays. Modern power systems are complex networks. The complexity of these networks demands that relays used for protection be reliable, accurate and take a short time to make decisions. In order to implement these characteristics on electromechanical and solid-state relays, high-precision analog devices and accurate tuning are required. However, recent advances in the field of microprocessors have made available microprocessor based relays as a viable alternative to electromechanical and static relays. These relays take advantage of the high reliability that has been achieved in VLSI fabrication and the expanded flexibility and information handling compatibilities of microprocessors. In microprocessor based relays, high-precision components and their fine tunings are replaced by software manipulations. Memory storage capabilities of these relays can be used to furnish useful information on pre-fault and post-fault signals which upon investigation might lead to improved operating practices and relay designs.

The development of microprocessor based relays has received considerable attention since early 1970's [1, 2]. Rockefeller [3] examined the feasibility of using a digital computer for protecting the equipment of a major substation and transmission lines emanating from it. Since then, the use of microprocessors in power system relaying applications has been an active area of research.

The functions of a microprocessor based relay are software controlled. The basic functions can be identified as: data acquisition, signal processing and decision making. A microprocessor based relay acquires samples of voltages and currents. It then uses signal processing techniques to calculate the estimates of the operating parameters of the power system. These techniques use a set of mathematical equations implemented on a microprocessor that provides numerical estimates of voltage and current phasors, and frequency. These estimates are used to calculate other derived quantities, such as, impedance, power, and volt-per-Hertz. An appropriate relay logic compares the derived parameters with desired relay characteristics for making decisions.

Because a microprocessor based relay is a software controlled device it is conceivable to design a general purpose hardware for microprocessor based relays. This hardware will function as one of several relays depending on the software modules used. The relay built using such a hardware would have lower production costs. This will also lead to a smaller inventory of spares for maintenance. Such a relay would be more versatile and flexible. Revisions and modifications necessitated by changes in operating conditions can be incorporated in the software without hardware changes. Also, input signals to most relays are identical, comprising of either voltages or currents or both. The general purpose hardware can be designed to accept several of these input signals. The input paths can be selected by software depending upon the application. Also, in some cases, the unused paths can be used as alternate paths. Whenever trouble develops in a normal input path, software control can activate the alternate route. Therefore, general purpose hardware design would offer more flexibility in routing of input data which leads to higher levels of reliability.

This paper describes a general purpose hardware that can be used to build microprocessor based relays for different functions. The hardware uses commercially available integrated circuits and other components. The design of the hardware is described in the paper. The designed hardware was used for a microprocessor based relay for detecting faults involving windings of transformers. It was also used for a three-phase inverse time overcurrent relay. These applications are briefly described in the paper.

A Typical Digital Relay

The hardware block diagram of a stand alone microprocessor based relay is shown in Figure 1. The relay includes analog and digital input subsystems, microcomputer, power supplies and digital output subsystems. The analog subsystem receives low level signals that represent power system voltages and currents. It uses low pass filters to band limit the signals. The subsystem reduces the levels of signals to avoid saturation of analog to digital (A/D) converters. The processed time-continues signals are converted to time-discrete signals using sample and hold amplifiers. A multiplexer applies each signal in turn to an A/D converter that converts the sampled values (time-discrete signals) to equivalent digital numbers. The digital input subsystem conveys the status of the power

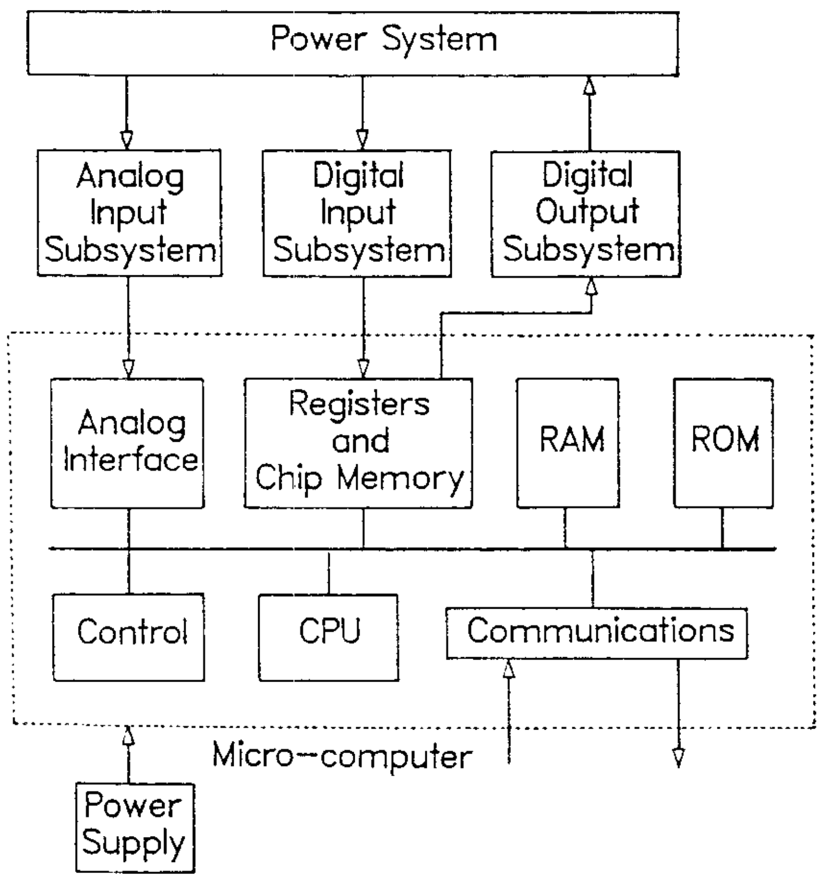

Figure 1: A Functional Block Diagram of a Digital Relay

system circuit breakers and switches to the relay. The processor reads the converted data and contact input data, and performs protective relay functions and calculations. Finally the decisions of the relay are conveyed to the power system through the digital output subsystem. A record of significant events are saved in Random Access Memory (RAM) as historical files. These may be later transferred to tape or disk for permanent storage.

Power supply to the relay must be independent of the station ac supply to ensure that the relay performs properly under all operating conditions. A dc-dc converter is generally used to provide energy to the relay from a substation storage battery.

Requirements of a General Purpose Hardware

The general purpose hardware should be designed such that it can be used to build relays for most protection applications. Such a hardware is expected to have the following features:

- Data acquisition system hardware should be designed in a modular form. Each module should have multiple input paths suitable for voltage and current signals. It should be possible to select one or more modules and the input paths inside the module under software control.

- Analog inputs must be conditioned using low-pass filters before they are sampled. This is necessary to limit the effects of noise and unwanted high frequency components. The particular protective relaying task dictates the total amount of filtering required. For example, distance protection requires fundamental frequency components only. For this task, it is possible to use analog low-pass filters having a cut off of about 90 Hz. A transformer differential relay uses second harmonic to detect the inrush current and fifth harmonic for detecting the overfluxing, so a cut-off frequency of 350 Hz is practical. Also, it is required to have different type of filters (e.g. Butterworth, Bessel, Chebychev etc.) depending upon the requirements of the digital filter used in the relay design. Thus, the hardware in the data acquisition system should be selected to allow a change in low-pass filter design without physically replacing the filter.

- Since the sampling period must be at least twice the cut-off frequency of low-pass filter, it also depends on the relaying application. The sampling interval may typically vary from 4 samples to 20 samples or more in a power frequency cycle depending on the technique used for estimating the system parameters in the relay design. It will be desirable for the general purpose hardware to be able to control the sampling rates through a software function.

- The number of bits in an A/D converter should be selected to meet the accuracy requirements of the most sensitive relaying applications.

- No microprocessor has yet been specifically designed for power system relaying applications. Relays so far designed are implemented on general purpose microprocessors. The choice of the microprocessor depends on the sampling rate and the amount of processing required in a sampling interval. The transformer protection scheme described later in this paper requires simultaneous processing of 12 signals in one sampling interval. This indicates that some of the relaying applications require implementation of time-critical computations. Therefore, the general purpose hardware should be such that it is suitable for digital signal processing applications involving time-critical computation.

Proposed General Purpose Hardware

The requirements of a general purpose hardware for microprocessor based relays have been described in the previous section. A hardware has been designed to meet these requirements. Figure 2 shows the block diagram of the hardware designed. It can be divided into three blocks.

- Isolation and analog scaling
- Data acquisition system
- Microcomputer

Isolation and Analog Scaling

The isolation and analog scaling block has been designed to accept the voltage and current signals from power system transducers. It provides electrical isolation from the power system and scales down the inputs from the system to levels suitable for data acquisition system. Since A/D converters accept only voltage signals, it also converts currents to equivalent voltages.

Figure 3 shows a schematic diagram of the hardware used for isolation and analog scaling of a voltage signal. A voltage from a potential transformer is supplied to an auxiliary potential transformer that reduces the voltage level and provides electrical isolation. The voltage is further reduced by a potentiometer to a level suitable for the data acquisition system. The metal oxide varistor (MOV) is used at the input of the auxiliary transformer that protects the data acquisition system against transients in the input signals.

Figure 4 shows the circuit diagram and the hardware used for processing current signals before they are used in the data acquisition system. A current from a current transformer is reduced to a lower level by an auxiliary current transformer. The secondary of the auxiliary current transformer is connected to a resistor that converts the current signal to an equivalent voltage signal. A metal oxide varistor

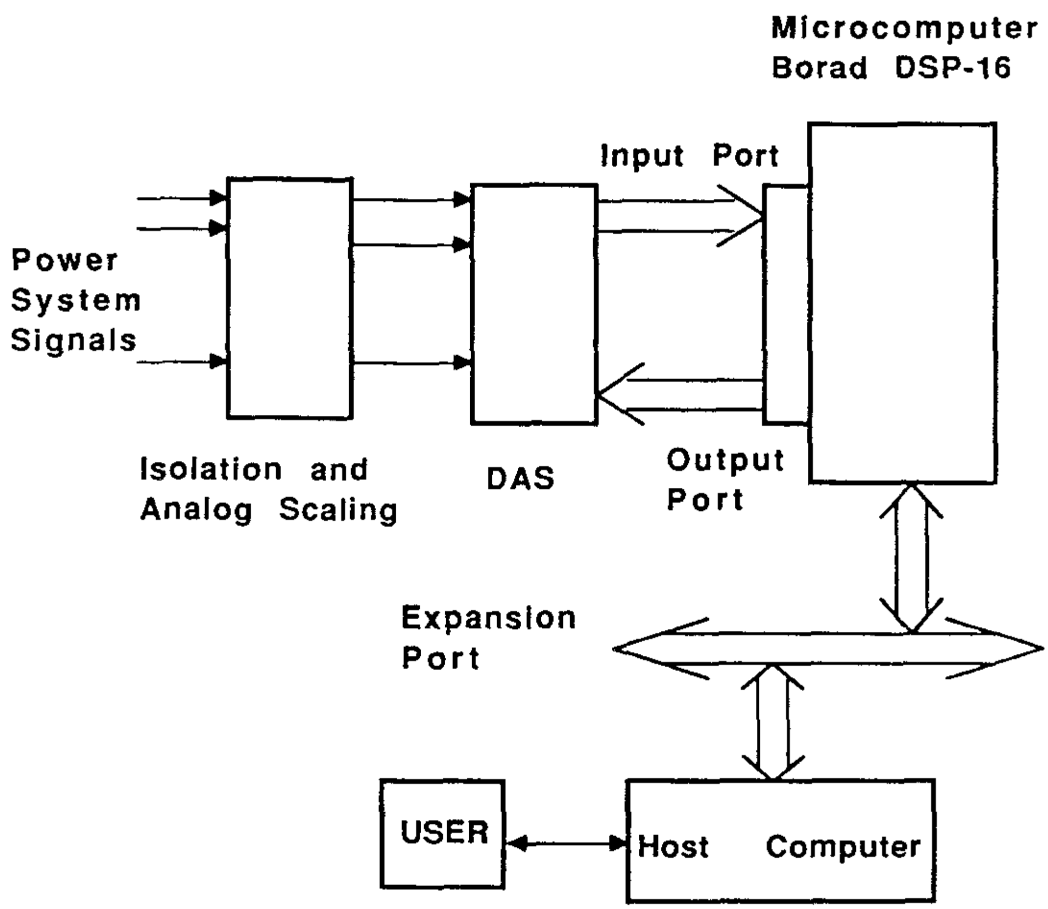

Figure 2: A Block Diagram of General Purpose Hardware

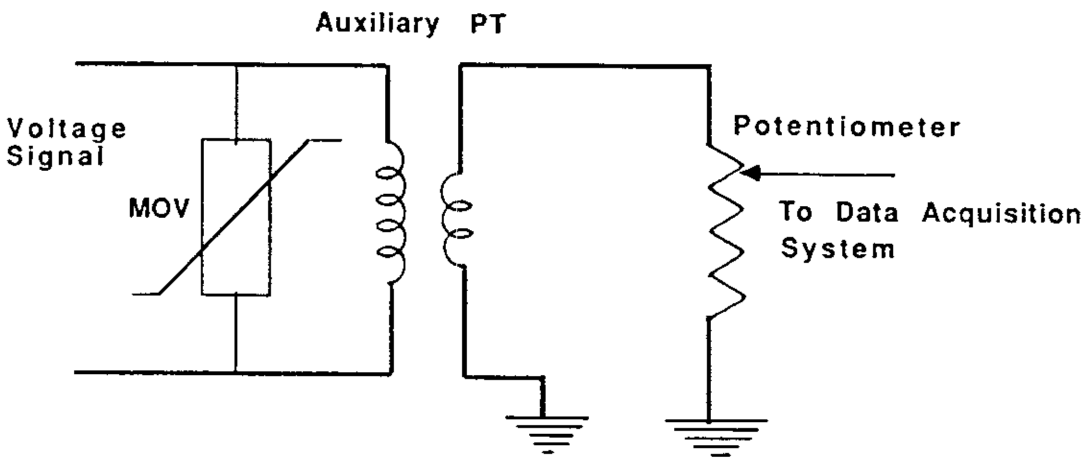

Figure 3: Isolation and Scaling of a Voltage Signal

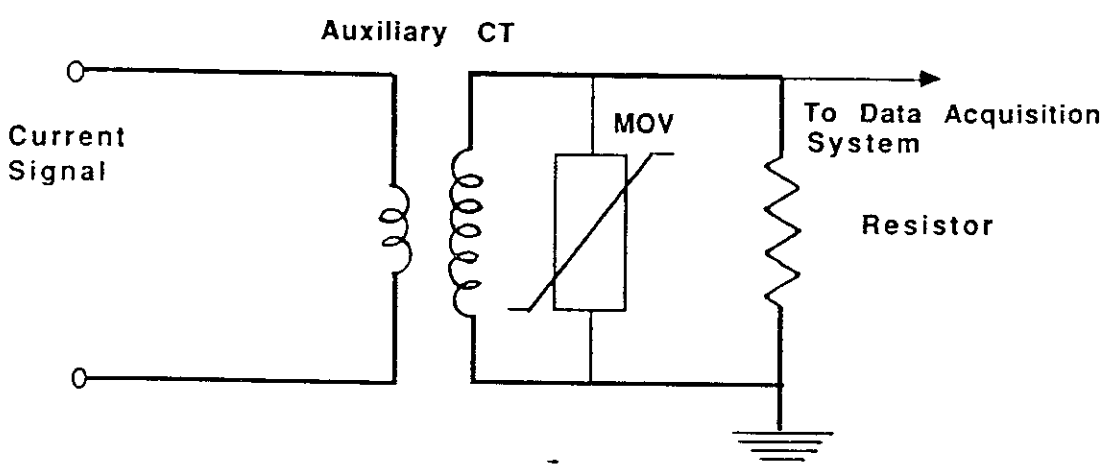

Figure 4: Isolation and Scaling of a Current Signal

connected across the resistor prevents high voltage transients in the signal from entering the data acquisition system.

Data Acquisition System

The data acquisition system has been designed in a modular form and consists of identical modules. Each module has four input channels for accepting the analog signals as shown in the block diagram in Figure 5. The number of input channels available to the relay can be increased in multiples of four by adding modules. However, the design restricts the maximum number of modules as four, that is, up to sixteen input channels. The module as well as channels in the module are software controlled. Therefore, the addition of modules (maximum of four) requires no hardware modifications.

Most relays use information pertaining to relative phase angles between various input quantities; therefore, the voltage and current signals should be digitized simultaneously. To achieve this, each channel in a data acquisition module consists of a high speed buffer for impedance matching, an analog filter and a sample and hold (S/H) amplifier (See Figure 5). At each sampling instant, all input signals are sampled and held in response to a control signal (under program control) from the microcomputer. Subsequently, a multiplexer in each module selects one signal at a time and routes it to the analog to digital (A/D) converter for quantization. This procedure latches all inputs at the same instant and provides the correct relative phase angles between the inputs as the hold strobe to all S/H units is given at the same instant. Various components used in a module are discussed below.

The analog filtering has been implemented using switched capacitor filters (product no MF10) [4]. The advantages of using switched capacitor filter are that they require no external capacitors and inductors. The design of the filter can be modified using external resistors. Suitable mounts have been provided for inserting resistors on the board. Their cut-off frequency can be set to a typical accuracy of $\pm$ 0.3% by an external clock.

The specifications of the chosen S/H unit are given in Table 1. The unit has a maximum drift rate of 0.5 $\mu v/\mu s$ and a maximum acquisition time of 1.5 μs. The drift rate is important because the signals must be held for the duration of the conversion of four signals. The acquisition time of the S/H should be as low as possible as this delay is implemented in software.

The analog multiplexer is a 4x1 differential input switch. This means that the switch can be controlled to provide an output from any one of its four differential inputs. It is one of the main reasons for designing four channels in a data acquisition module. Table 2 gives the important manufacturer specifications of the multiplexer. The A/D converter (HI 774A) [5] used in the design is a 12-bit successive approximation type. It has a conversion time of six micro-seconds. Also, it has the capability of latching the converted output until a signal is given to read it. This feature makes it possible to read the outputs of a number of A/D converts in a microcomputer one by one using an input port. The output

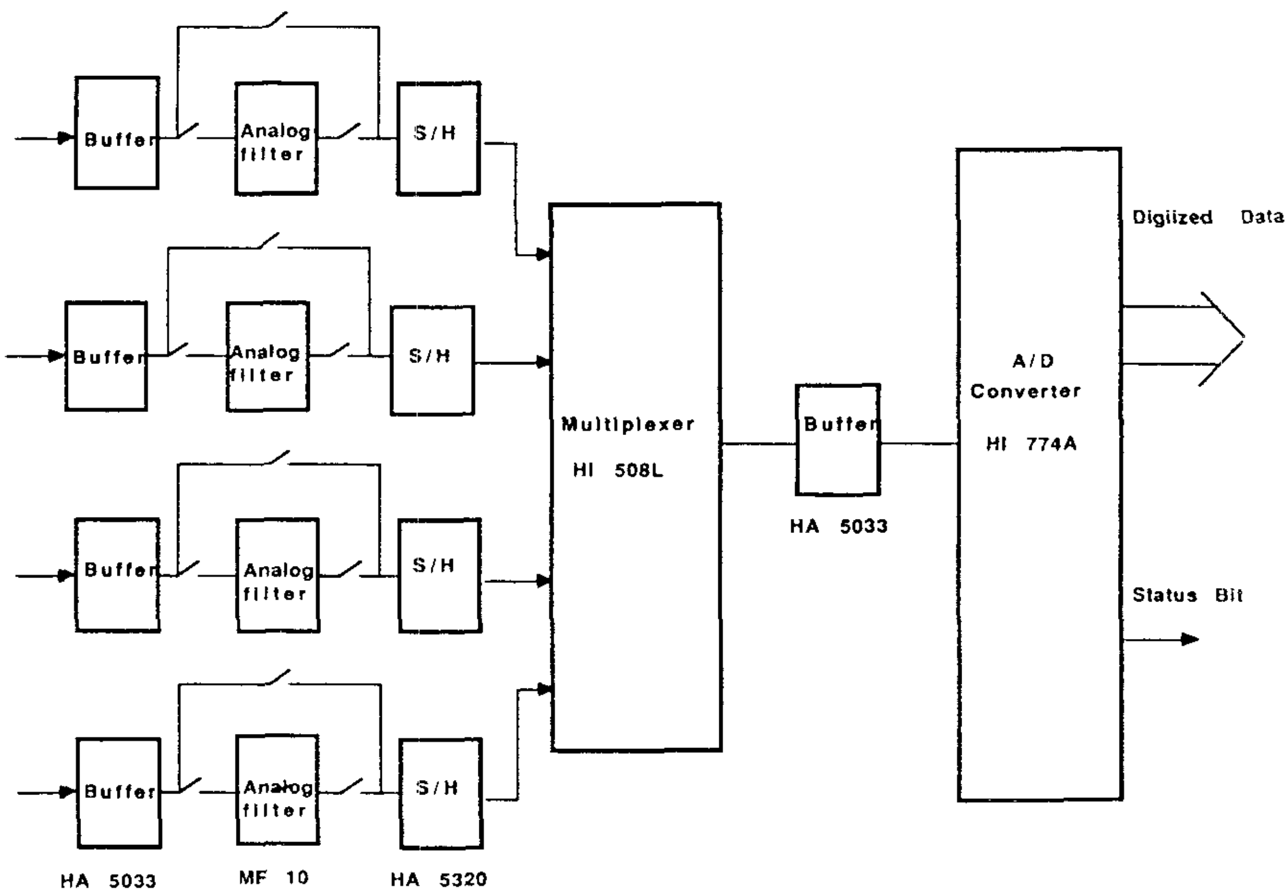

Figure 5: Schematic Diagram of a Data Acquisition Module

Table 1: Specifications of Sample & Hold Unit [5]

Sample & Hold HARRIS HA 5320		
Parameter	Value (Max)	Units
Acquisition time 10 volts step	1.5	μs
Droop Rate	0.5	μv/μs
Input Resistance	5	MΩ
Output Resistance	1	Ω

impedance of the multiplexer is 1200 ohms, however, the signal to the A/D converter should have a low impedance of the order of 1-4 ohms. To meet this requirement, a low output impedance (5 ohms) and high input impedance unity gain buffer (HA5033) [5] has been used between the output of a multiplexer and the input of the A/D converter.

Table 2: Specifications of Multiplexer Unit [5]

Multiplexer HARRIS HI 508L		
Parameter	Value (Max)	Units
On-Resistance	1200	M
Access Time	1.0	μs

The components used in the data acquisition system are such that it is possible to control their operation by sending signals from the microprocessor on an output port. Also, the status of the A/D converter and digitized output can be read using an input port. The control signal requirements for the data acquisition system in terms of the number of bits of the input/output port are as follows.

Output control signals		Input control signals	
S/H Amplifiers	1 bit	A/D converter output	12 bits
Multiplexer	2 bits	A/D converters status	1x4 bits
A/D converters	2x4 bits		
Total	11 bits	Total	16 bits

These requirements indicate that it is possible to control the data acquisition system using 16-bit input/output port.

Microcomputer

The operation of the data acquisition system is controlled by a single board microcomputer board. The implementation of digital relaying applications involves the simplification of mathematical equations using multiplications and additions. Therefore, any general purpose microcomputer board for signal processing applications with a 16-bit input/output port (for control of the data acquisition system) is suitable. However, in this work, a DSP-16 microcomputer board [6], based on a TMS-32025 digital signal processor, was selected. In addition to signal processing capabilities, the DSP-16 provides the following facilities.

- Program development system
- 16-Kwords of zero wait state program/data memory
- 16-bit programmable timer

The programmable timer is used to control the sampling rates for the data acquisition system. 16-bit input and output ports provided in the DSP-16 (through a Piggy Back board) are used for controlling the data acquisition system and bring the A/D converter outputs into the memory of the DSP-16 board.

Applications of the General Purpose Hardware

The designed hardware is versatile and flexible enough to be used for implementing microprocessor based relays, such as distance relays, transformer protection relays, overcurrent relays etc. This hardware is in use for developing and testing microprocessor based relays at the University of Saskatchewan. Two relays have already been developed and are briefly described in the following paragraphs. The implementation of several relays using this hardware is in progress. The relays in progress are for three-phase transformer differential and restricted earth-fault protection, volt-per-Hertz protection and high-speed distance protection for transmission lines.

The first relay designed involved the development and testing of a microprocessor based protection of a three-phase transformer. The details of the algorithm and the software used in the relay are given in Reference 7. This application requires that six voltage signals and six current signals be sampled at 1200 Hz. Therefore, three modules of the data acquisition system were needed to implement the relay. The software was developed to control the data acquisition system for implementing the algorithm. The performance of the relay was tested in the laboratory using a 15 KVA and 240/480 volts delta-star connected three-phase transformer for magnetising inrush, external fault and internal fault conditions. A typical magnetising inrush waveform of the transformer is shown in Figure 6. The transformer was switched at time t=0.0167 seconds. The relay issued no trip command for inrush. However, a single phase to ground was created at the secondary terminal of transformer, the waveforms of fault currents at primary side of transformer are shown in Figure 7. The time of fault inception was also at t=0.0167 seconds and the relay issued the trip command five samples after the inception of fault, that is, at t=0.02083 seconds. The software and performance results are described in details in the companion paper [7].

The second application involved the implementation of a three-phase inverse-time overcurrent relay. As only four currents (three-phase currents and one neutral current) were required to be monitored, only one module of the data acquisition system was used. The current signals were acquired at a sampling rate of 1200 Hz and were processed using the technique described in Reference 8. The performance of the relay was tested in the laboratory by performing primary injection tests using Doble Protection Apparatus Test System (Model F1) [9] of Doble Engineering Company. A typical operating characteristic of a Westinghouse CO-7 type overcurrent relay at a time dial setting of 5.0 is given in Table 3. The characteristic of the CO-7 type relay at time dial setting of 5.0 emulated by the designed relay is also shown in Table 3 for comparison.

Conclusion

This paper has described the design of a general purpose hardware for a protective relay. The hardware designed was tested in the laboratory for use in three-phase transformer protection and three-phase inverse-time overcurrent relays. The performance of both relays was found to be good. The designed hardware is also being used for implementing other protection applications.

Table 3: Comparison of manufacture characteristic and emulated characteristic of Westinghouse CO-7 relay

Current	CO-7	Emulated
2.5	2.720	2.765
3.0	2.300	2.327
4.0	1.875	1.875
5.0	1.630	1.630
6.0	1.475	1.475
7.0	1.370	1.370
8.0	1.300	1.300
9.0	1.225	1.220
10.0	1.180	1.176
11.0	1.130	1.147
12.0	1.095	1.100
13.0	1.060	1.060
14.0	1.040	1.042
15.0	1.000	1.026

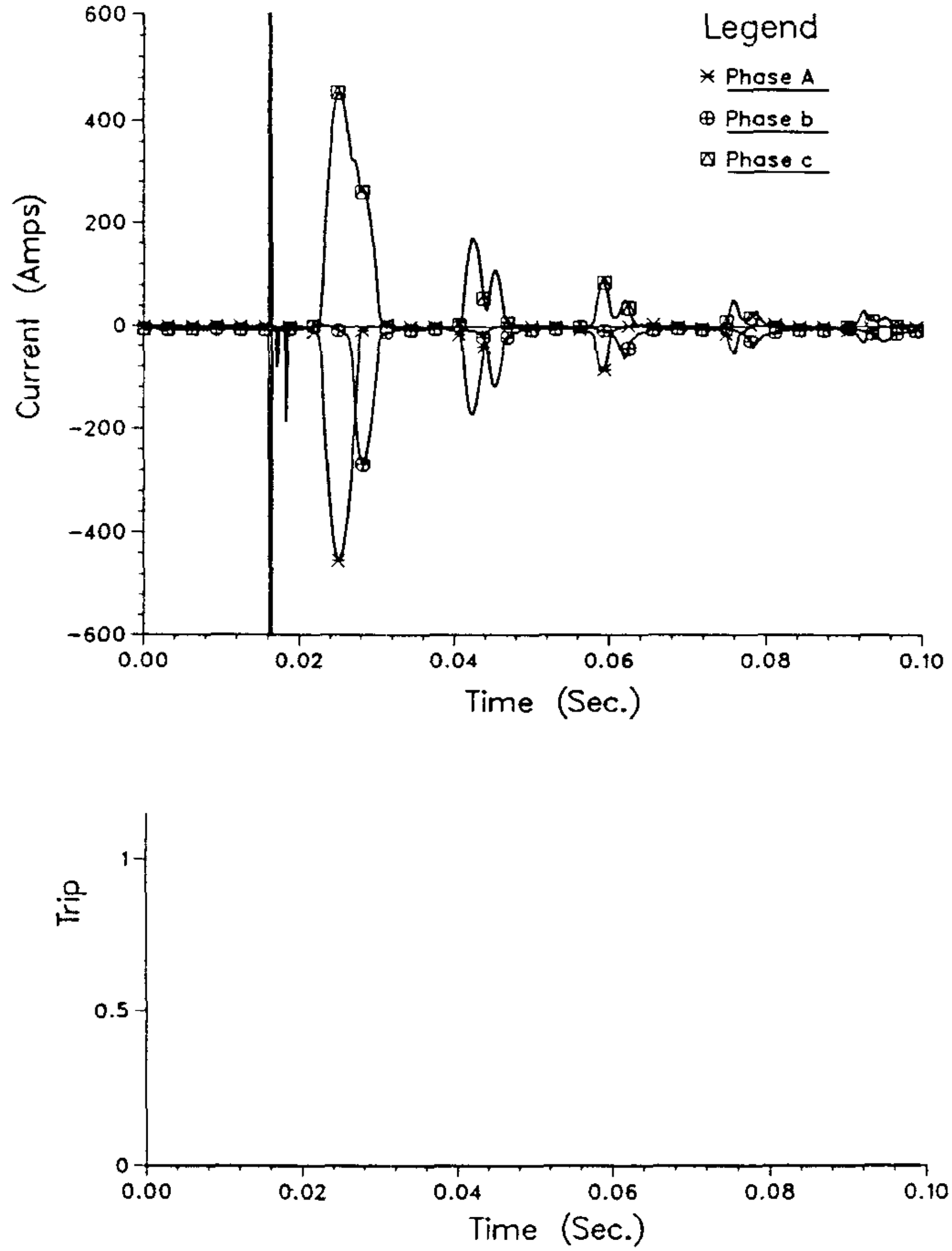

Figure 6: Magnetising Inrush - Transformer switched at time t=0.0167 sec.

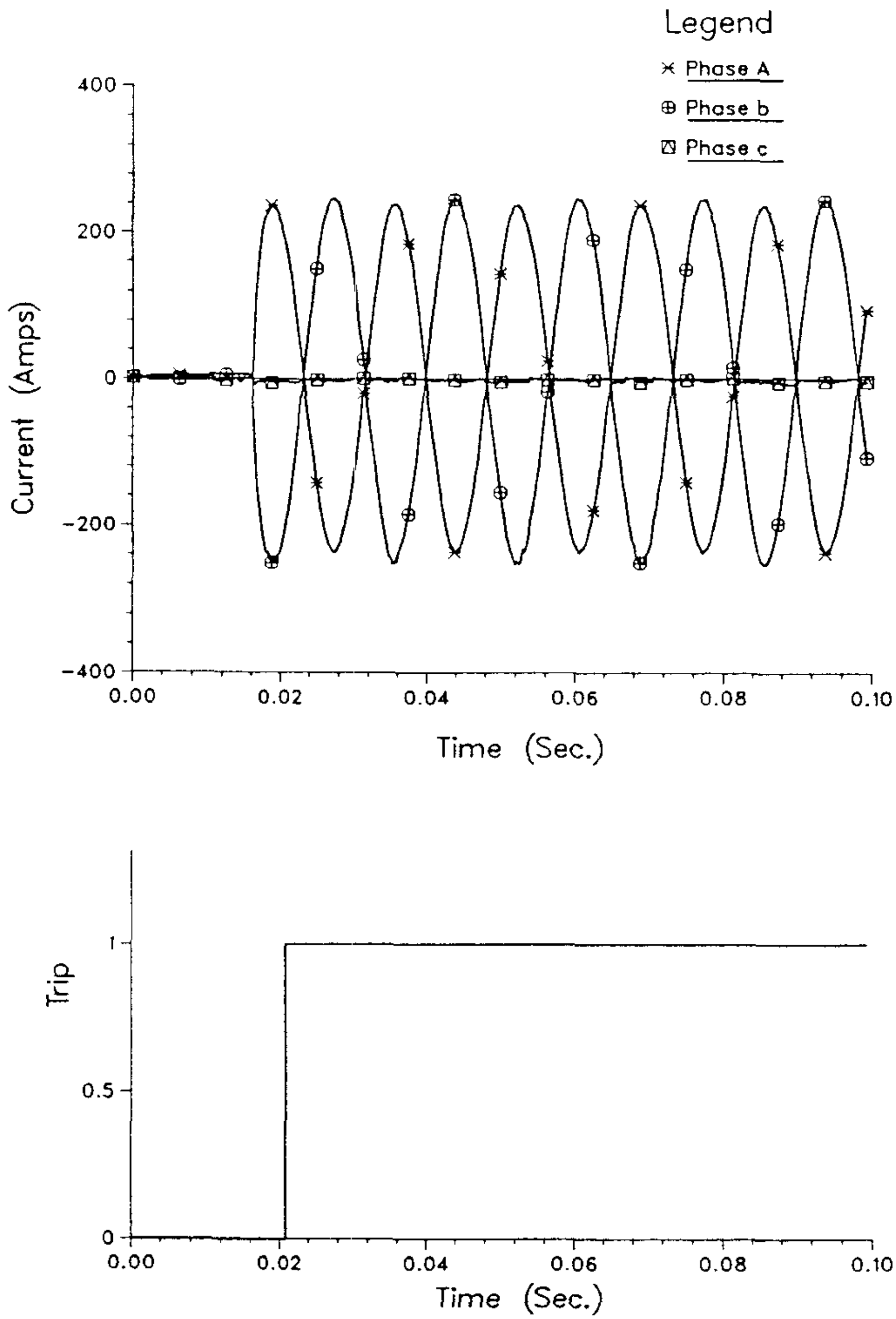

Figure 7: Primary Currents - Single Phase to Ground Fault on Secondary Side of Transformer Occurred at time t=0.0167 sec.

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