

**AN IMPEDANCE RELAY DESIGN
AND THE IMPACT OF ANTI-ALIASING
FILTERS ON ITS PERFORMANCE**

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By

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ABSTRACT

Faults occur in power systems because of the failure of insulation and structures. The faults almost always result in the flow of large quantities of currents. Protective relays are used, therefore, for detecting the faults and isolating the faulted section of the system before the damage spreads. Traditionally, electromechanical and static technologies have been used for designing and manufacturing relays. More recently, advancements in the VLSI technology have resulted in the development of microprocessor-based numerical relays. Several algorithms have been proposed in the past, which are suitable for using in numerical relays for detecting the occurrence of faults. The hardware of a numerical relay has several subsystems, such as, analog input subsystem, signal conditioning, digital input and output, digital processor and power supply subsystems.

Operating speed and accuracy of numerical relays are of major concern. Numerical relays use digital processors to implement protection algorithm. The limited power of the processors can limit the speed of operation of the relay. The speed of operation of the numerical relay also depends on the components of the analog input subsystem, such as, the characteristics of the anti-aliasing filters and the analog-to-digital converters (ADCs).

This thesis is concerned with the selection of the specialized digital processors for implementing the Discrete Fourier Transform (DFT) algorithm at different sampling frequencies, and the selection of suitable components for the analog input subsystem. The processors were selected based on the computational requirements of the DFT at different sampling frequencies. The filters were designed and simulation tests conducted to evaluate the group delay associated with them at different sampling frequencies. The ADC selection was based on the highest sampling rate it could support. Based on the selection of the digital processors and the ADC, suitable numerical relay hardware was purchased and a numerical distance relay was developed.

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Dedicated To My Beloved Parents

Dr. P. S. Bimbhra

Mrs. Surinder Kaur

TABLE OF CONTENTS

PERMISSION TO USE	i
ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
DEDICATION	iv
TABLE OF CONTENTS	v
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF ACRONYMNS	xvii
1. INTRODUCTION	1
1.1. Background	1
1.2. Power System Faults	3
1.2.1. Causes of Power System Faults	3
1.2.2. Types of Power System Faults	3
1.2.3. Effects of Power System Faults	4
1.3. Protective Relays	5
1.3.1 Reliability	5
1.3.2 Speed	5
1.3.3 Selectivity	5
1.3.4 Cost	5
1.4. Relays in Power Systems	5
1.4.1. Evolution of Power System Relays	7
1.5. Objective of the Thesis	8
1.6. Outline of the Thesis	9
1.7. Summary	10

2. NUMERICAL RELAYS FOR POWER SYSTEM PROTECTION	11
2.1. Introduction	11
2.2. Features of a Numerical Relay	11
2.2.1. Flexibility	11
2.2.2. Reliability and Self-Checking	12
2.2.3. Data Interface Access	12
2.2.4. Adaptive Capability	12
2.2.5. Mathematical Capability	12
2.2.6. Fault Locating Capability	13
2.3. Functional Description of a Numerical Relay	13
2.3.1. Analog Input Subsystem	13
2.3.2. Digital Input Subsystem	15
2.3.3. Digital Output Subsystem	15
2.3.4. Central Processing Unit	15
2.3.5. Memory	15
2.3.6. Power Supply	16
2.3.7. Other Components	16
2.4. Errors in Numerical Relays	16
2.4.1. Errors caused by Filters	17
2.4.2. Errors caused by Sample-and-Hold circuits	17
2.4.3. Errors caused by Analog-to-Digital Converters	17
2.4.3.1. Quantization Errors	18
2.4.3.2. Saturation Errors	19
2.4.4. Digital Signal Processor Errors	20
2.5. Summary	20
3. ALGORITHMS FOR NUMERICAL RELAYING	21
3.1. Introduction	21
3.2. Classification of Relaying Algorithms	21
3.2.1. Non-recursive Algorithms	22

3.3. Trigonometric Algorithms	23
3.3.1. Mikki and Mikano Algorithm	24
3.3.2. Mann and Morrison Algorithm	25
3.3.3. Rockefeller and Urden Algorithm	27
3.3.4. Comments about Trigonometric Algorithms	29
3.3.5. Analysis with Mann and Morrison Algorithm	29
3.4. Correlation Algorithms	32
3.4.1. Sine and Cosine Waveforms	32
3.4.2. Rectangular Waveform Algorithms	36
3.5. Least Error Squares Algorithm	41
3.6. Summary	45
4. NUMERICAL RELAY DESIGN CONSIDERATIONS	46
4.1. Introduction	46
4.2. Procedure followed for Selecting an Algorithm	46
4.2.1. Computational Burden	47
4.3. Hardware Considerations	50
4.3.1. Analog Input Subsystem	51
4.3.1.1. Need for Filtering Input Signals	51
4.3.1.2. Low-pass Filter Requirements	53
4.3.1.3. Analog-to-Digital Converters	55
4.3.1.3.1. Successive-Approximation Converters	55
4.3.1.3.2. Flash Converters	58
4.3.1.3.3. Pipeline Converters	62
4.3.2. Digital Processors	64
4.4. Selected Hardware	71
4.5. Summary	73

5. NUMERICAL RELAY DEVELOPMENT	74
5.1. Introduction	74
5.2. Diamond Real-Time Operating Software	74
5.2.1. Network Loading and Configuration	75
5.2.2. Analysis Procedure	77
5.2.3. Generation of Executable Application File	80
5.2.4. Running the Application	82
5.3. Design of a Numerical Relay	82
5.3.1. Impedance Computation	83
5.3.2. Design of a Three Phase Numerical Relay	85
5.4. Summary	88
6. SIMULATION AND SYSTEM STUDIES	90
6.1. Introduction	90
6.2. Implementation of the DFT algorithm	91
6.2.1. Implementation using C language	92
6.2.2. Implementation using Assembly language	92
6.2.3. Comparison of assembly and C programs	94
6.2.4. Application downloading to processor network	94
6.3. The Power System Model	102
6.4. Low-pass filter evaluation	104
6.4.1. Group delay associated with filters	107
6.5. Effect of eliminating low-pass filters	109
6.5.1. Sampling frequency of 720 Hz	109
6.5.1.1. Voltage Waveform Analysis	110
6.5.1.2. Current Waveform Analysis	113
6.5.2. Sampling frequency of 2,160 Hz	116
6.5.2.1. Voltage Waveform Analysis	117
6.5.2.2. Current Waveform Analysis	120
6.5.3. Effect of removing low-pass filters	123

6.6 Distance Relay Implementation	124
6.6.1 Impedance calculation at a Sampling rate of 720 Hz	124
6.6.2 Impedance calculation at a Sampling rate of 2,160 Hz	127
6.7 Summary	128
7. SUMMARY AND CONCLUSIONS	130
8. REFERENCES	133
Appendix A. Parameters of the System	135
A.1 Transmission Lines	136
A.2 Machines	136
A.3 Transformers	137
A.4 Loads	137
Appendix B. Additional Results	138
B.1 Sampling Frequency of 1,440 Hz	138
B.1.1 Voltage Waveform Analysis	138
B.1.2 Current Waveform Analysis	141
B.2 Sampling Frequency of 1,800 Hz	144
B.2.1 Voltage Waveform Analysis	144
B.2.1 Current Waveform Analysis	148
Appendix C. List of ADC boards	151
Appendix D. ADC Output	153
Appendix E. Digital Signal Processors	157

LIST OF TABLES

Table No.	Contents	Page No.
Table 2.1:	Error summaries for analog input subsystem components	19
Table 3.1:	Reference Sine and Cosine coefficients for DFT	35
Table 4.1:	DFT calculations for real and imaginary parts of the phasor	49
Table 4.2:	Computational burden at different sampling frequencies	50
Table 4.3:	Comparison of 8-bit and 14-bit ADC	61
Table 4.4:	Comparisons of ADC techniques	64
Table 4.5:	Digital Signal Processor Specifications	69
Table 6.1:	Execution times for different sampling frequencies for Assembly and C programs	93
Table 6.2:	Group delay at 60 Hz for different Sampling Rates	108
Table C.1:	Boards with 14-bit ADC	151
Table C.2:	Boards with 12-bit ADC	152
Table C.3:	Boards with successive approximation converters	152
Table D.1:	Specifications of SMT356 ADC board	154

LIST OF FIGURES

Figure No.	Contents	Page No.
Figure 1.1:	Basic elements of an electric power system	2
Figure 1.2:	Power system with protective zones	6
Figure 1.3:	Typical arrangement of a relay	7
Figure 2.1:	Block diagram of a typical numerical relay	14
Figure 2.2:	Representation of a signal from saturated ADC	20
Figure 3.1:	Data window of three samples	26
Figure 3.2:	Frequency response of Mann & Morrison real part filter	30
Figure 3.3:	Frequency response of Mann & Morrison imaginary part filter	31
Figure 3.4:	Schematic representation of Fourier Algorithm	37
Figure 3.5:	Frequency response of DFT sine filter	38
Figure 3.6:	Frequency response of DFT cosine filter	38
Figure 3.7:	Even and odd rectangular waves	39
Figure 4.1:	Selection procedures for relay algorithms	47
Figure 4.2:	Response of low-pass filter	54
Figure 4.3:	Successive approximation converter architecture	56
Figure 4.4:	Flash converter architecture	59
Figure 4.5:	Steps in current reduction from power system to ADC	61
Figure 4.6:	Architecture of Pipeline ADC	63
Figure 4.7:	Definition of real-time	65
Figure 4.8:	Illustration of logical position of cache memory	66
Figure 4.9:	Development tools	68
Figure 4.9:	Detailed description of hardware	72

Figure No.	Contents	Page No.
Figure 5.1:	Diamond development platform	74
Figure 5.2:	A TASK with input and output ports	75
Figure 5.3:	Steps in the creation of a TASK image file	76
Figure 5.4:	Single phase application	78
Figure 5.5:	TASKS connected together	80
Figure 5.6:	Application placed on ROOT processor	81
Figure 5.7:	Various tasks for calculation of Impedance	83
Figure 5.8:	Application for three phases of a power system	86
Figure 5.9:	Assignment of different TASKS	89
Figure 6.1:	Sampling rate versus time for C programs	92
Figure 6.2:	Sampling rate versus time for Assembly programs	92
Figure 6.3:	Application loading to processor network	95
Figure 6.4:	DFT peak value estimates for sampling rate of 720 Hz without and with filter	96
Figure 6.5:	DFT peak value estimates for sampling rate of 1,200 Hz without and with filter	97
Figure 6.6:	DFT peak value estimates for sampling rate of 1,440 Hz without and with filter	98
Figure 6.7:	DFT peak value estimates for sampling rate of 2,440 Hz without and with Filter	99
Figure 6.8:	DFT peak value estimates for sampling rate of 2,880 Hz without and with Filter	100
Figure 6.9:	DFT peak value estimates for sampling rate of 3,600 Hz without and with Filter	101

Figure No.	Contents	Page No.
Figure 6.10:	Single Line diagram of the Power System	102
Figure 6.11:	Generated voltage waveforms before filtering	103
Figure 6.12:	Generated current waveforms before filtering	103
Figure 6.13:	Generated voltage waveforms after filtering	104
Figure 6.14:	Generated current waveforms after filtering	104
Figure 6.15 (a):	Voltage waveform before filtering	105
Figure 6.15 (b):	Voltage waveform after passing through filter with 1,200 Hz cutoff frequency	105
Figure 6.15 (c):	Voltage waveform after passing through filter with 960 Hz cutoff frequency	106
Figure 6.15 (d):	Voltage waveform after passing through filter with 480 Hz cutoff frequency	106
Figure 6.15 (e):	Voltage waveform after passing through filter with 240 Hz cutoff frequency	107
Figure 6.16:	Sampling Rate versus Group Delay	109
Figure 6.17:	Three phase-to-ground fault voltages at a Sampling Frequency of 720 Hz	110
Figure 6.18:	DFT performed on Phase-A voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 720 Hz	111
Figure 6.19:	DFT performed on Phase-B voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 720 Hz	112
Figure 6.20:	DFT performed on Phase-C voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 720 Hz	112-113

Figure No.	Contents	Page No.
Figure 6.21:	Three phase-to-ground fault currents at a Sampling Frequency of 720 Hz	113-114
Figure 6.22:	DFT performed on Phase-A current data (a) without and (b) with low-pass filters at a Sampling Frequency of 720 Hz	114-115
Figure 6.23:	DFT performed on Phase-B current data (a) without and (b) with low-pass filters at a Sampling Frequency of 720 Hz	115
Figure 6.24:	DFT performed on Phase-C current data (a) without and (b) with low-pass filters at a Sampling Frequency of 720 Hz	116
Figure 6.25:	Three phase-to-ground fault voltages at a Sampling Frequency of 2,160 Hz	118
Figure 6.26:	DFT performed on Phase-A voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 2,160 Hz	118
Figure 6.27:	DFT performed on Phase-B voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 2,160 Hz	118-119
Figure 6.28:	DFT performed on Phase-C voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 2,160 Hz	119
Figure 6.29:	Three phase-to-ground fault currents at a Sampling Frequency of 2,160 Hz	120
Figure 6.30:	DFT performed on Phase-A current data (a) without and (b) with low-pass filters at a Sampling Frequency of 2,160 Hz	121
Figure 6.31:	DFT performed on Phase-A current data (a) without and (b) with low-pass filters at a Sampling Frequency of 2,160 Hz	122

Figure No.	Contents	Page No.
Figure 6.32:	DFT performed on Phase-A current data (a) without and (b) with low-pass filters at a Sampling Frequency of 2,160 Hz	122-123
Figure 6.33:	Flow chart for impedance calculation	125
Figure 6.34:	Impedance calculations for a Sampling Rate of 720 Hz	126
Figure 6.35:	Impedance calculations for a Sampling Rate of 720 Hz	127
Figure 6.36:	Impedance calculations for a Sampling Rate of 2,160 Hz	128
Figure B.1:	Three phase-to-ground fault voltages at a Sampling Frequency of 1,440 Hz	139
Figure B.2:	DFT performed on Phase-A voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,440 Hz	139
Figure B.3:	DFT performed on Phase-B voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,440 Hz	140
Figure B.4:	DFT performed on Phase-C voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,440 Hz	140-141
Figure B.5:	Three phase-to-ground fault currents at a Sampling Frequency of 1,440 Hz	141-142
Figure B.6:	DFT performed on Phase-A current data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,440 Hz	142
Figure B.7:	DFT performed on Phase-B current data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,440 Hz	143

Figure No.	Contents	Page No.
Figure B.8:	DFT performed on Phase-C current data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,440 Hz	143-144
Figure B.9:	Three phase-to-ground fault voltages at a Sampling Frequency of 1,800 Hz	145
Figure B.10:	DFT performed on Phase-A voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,800 Hz	146
Figure B.11:	DFT performed on Phase-B voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,800 Hz	146-147
Figure B.12:	DFT performed on Phase-C voltage data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,800 Hz	147
Figure B.13:	Three phase-to-ground fault currents at a Sampling Frequency of 1,800 Hz	148
Figure B.14:	DFT performed on Phase-A current data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,800 Hz	149
Figure B.15:	DFT performed on Phase-B current data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,440 Hz	149-150
Figure B.16:	DFT performed on Phase-C current data (a) without and (b) with low-pass filters at a Sampling Frequency of 1,440 Hz	150
Figure E.1:	TMS320C6x Block Diagram	157

LIST OF ACRONYMNS

EMTDC	Electro Magnetic Transient Direct Current Analysis
PSCAD	Power Systems Computer Aided Design
CT	Current Transformer
VT	Voltage Transformer
RAM	Random Access Memory
ROM	Read-Only Memory
PROM	Programmable Read Only Memory
EEPROM	Electronically Erasable Programmable Read-Only Memory
S&H	Sample and Hold
SAL	Successive Approximation Decision Logic
DAC	Digital to Analog Converter
MSB	Most Significant Bit
LSB	Least Significant Bit
ADC	Analog to Digital Converter
FSR	Full Scale Resolution
DSP	Digital Signal Processors
DFT	Discrete Fourier Transform
EHV	Extra High Voltage
HV	High Voltage

MV	Medium Voltage
LV	Low Voltage
SDB	Sundance Digital Bus
FIFO	First In First Out
SDRAM	Synchronous Dynamic Random Access Memory
SBRAM	Synchronous Burst Random Access Memory
RTOS	Real Time Operating Software
UI	User Interface
CPU	Central Processing Unit
DMA	Direct Memory Access
EMIF	External Memory Interface
T.I.	Texas Instruments

CHAPTER 1

INTRODUCTION

1.1 Background

Electrical energy plays a significant role in modern society. The increasing dependence on electrical energy is so marked that even a short interruption in electrical supply can lead to major disruption of everyday life in major urban centers. Computer networks, medical life support equipment, process industry, banking machines, communications and airports need an uninterrupted electrical power supply.

Electrical energy is usually supplied by power systems at reasonable cost and with minimum interruptions. An electric power system can be divided into four subsystems: generation, transmission, sub-transmission and distribution systems [1]. Electric power is produced at generating stations where generators convert mechanical energy into electrical energy. The generator output voltages, which are in the range of 11 kV to 35 kV, are applied to transformers that step-up the generated voltage to higher levels for transmission. The voltage levels of a transmission system are typically in excess of 230 kV. A transmission system, which is a vital link in an integrated power system, transmits electrical energy from a substation at one location to another substation at another location. In transmission substations, the power transformers step-down the voltage to sub-transmission levels that range from 69 kV to 138 kV. The sub-transmission systems are connected to distribution systems that can be classified into primary and secondary distribution systems. The primary distribution systems provide energy to small industrial customers at voltages that typically range from 4 kV to 34.5 kV. The secondary distribution system feeds the residential and commercial users at 120/240 V.

Advancements in technology have made it possible to design and construct power systems, which span wide geographic areas. The systems are comprised of many different items of equipment that are very expensive and so, therefore, power systems represent major capital investments. To maximize the return on this outlay, the power system should be operated efficiently and protected from damage due to abnormal operating conditions and faults, which occur occasionally.

Discriminative power system protection plays an important part. Progress in this field is vital and prerequisite for the operation and continuing development of power systems. Figure 1.1 [1], shows the basic elements of a power system.

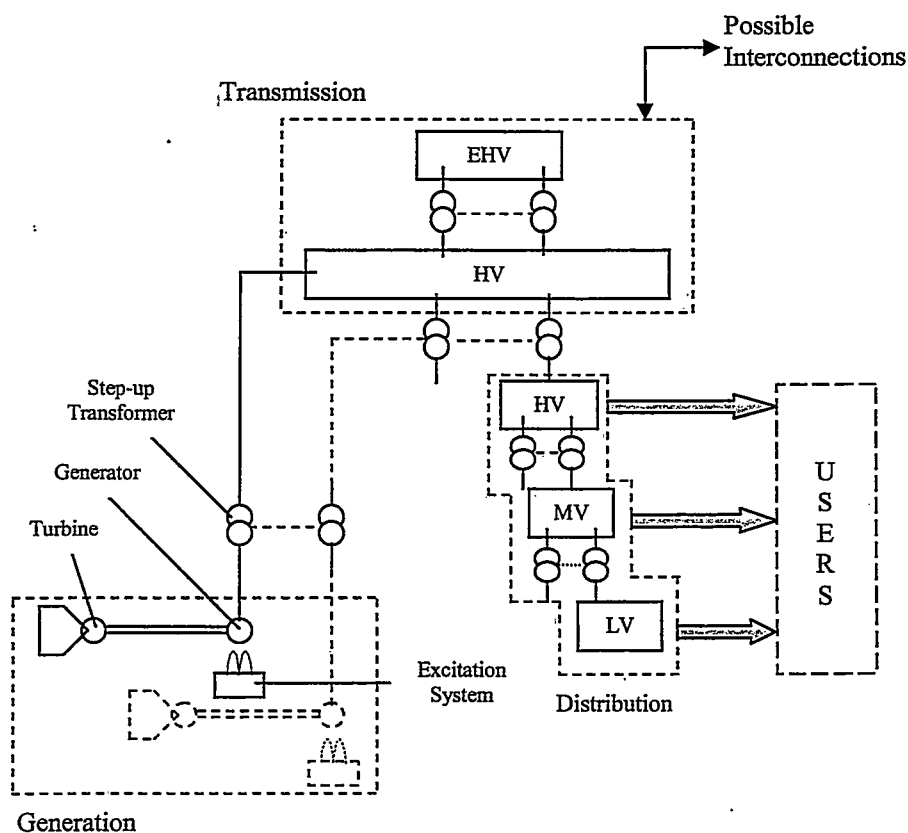


Figure 1.1 Basic elements of an electric power system

(EHV, HV, MV, LV denote extra-high, high, medium, and low voltage, respectively)

1.2 Power System Faults

A power system fault is an unhealthy or abnormal electrical condition in one of the components of the system; such a condition can potentially cause serious damage to the equipment and great loss of revenue. Faults should, therefore, be detected promptly and action should be taken to isolate the faulted element.

1.2.1 Causes of Power System Faults

Faults on a power system can occur due to:

- Lightning
- Punctured or broken insulators
- Birds and animals
- Aircraft or cars hitting power lines and structures
- Trees growing in to power lines
- Pollution (cement dust, moisture, soot, road salt)
- Ice and snow loading
- Wind
- Natural disasters (hurricanes, tornados, earthquakes)
- Failure of insulation due to moisture or aging
- Mechanical damage
- Flashover caused by over voltages due to transients
- Human errors.

1.2.2 Types of Power System Faults

The different types of faults [2] experienced on an electric power system are classified as follows:

1. Single phase to ground faults are experienced as a short circuit between any one of the phases and the ground. From 65% to 75% of all power system faults are single-phase to ground faults.

2. Two phase or phase-to-phase faults are encountered when any two phases are short-circuited. From 20% to 25% of all power system faults are phase-to-phase to faults.
3. Two phase to ground faults occur when any two phases of the power system are short circuited to the ground. From 10% to 15% of all power system faults are two-phase to ground faults.
4. Three phase and three phase-to-ground faults are relatively rare in power systems. From 3% to 5% of all power system faults are three phase-to-ground faults; and these are triggered when all the three phases of a power system are short circuited together.

1.2.3 Effects of Power System Faults

When a fault occurs in a power system, the following abnormal operating conditions are experienced:

- Increase of currents to several times their normal levels
- Decrease of voltage to substantially low levels
- Increase or decrease of the system frequency from its rated value
- Changes in the phase angles of voltages and currents

A power system could sustain serious and extended damage if abnormal conditions or faults were allowed to persist. To avoid the damage, some form of mechanism is needed to detect the occurrence of faults and to disconnect, as soon as possible, the faulted element of the power system. This function is provided by protective relays.

1.3 Protective Relays

Protective relays are devices that detect the presence of a fault and initiate the isolation of the faulted equipment from the remaining power system as quickly as possible. Quality of relaying depends upon the following basic principles [3].

1.3.1 Reliability

Reliability is the trustworthiness of a relay to operate correctly. This manifests in two forms known as dependability and security. Dependability is the certainty that the relay will operate on the occurrence of a fault and security is the ability to avoid incorrect operation during faults.

1.3.2 Speed

Speed is the minimum operating time required to initiate the opening of a circuit when a fault is experienced.

1.3.3 Selectivity

Selectivity is the ability of the protective relays to distinguish between conditions for which immediate action is required and the conditions for which no action is required.

1.3.4 Cost

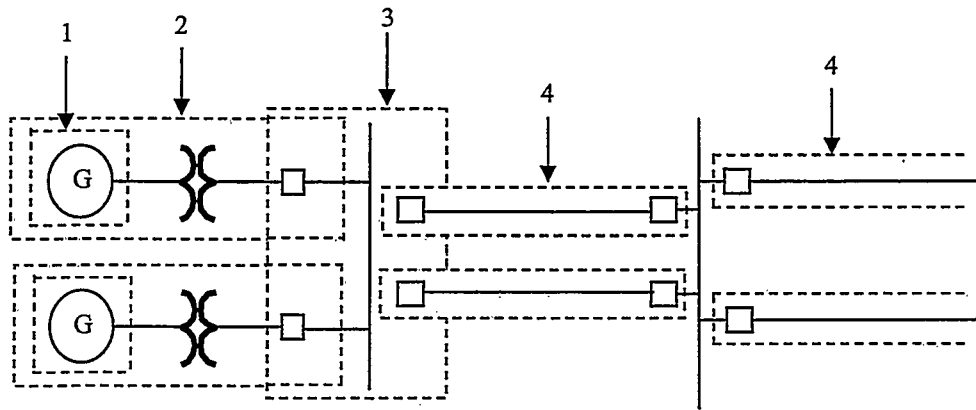
Protective relays should be able to provide maximum protection at the lowest cost.

1.4 Relays in Power Systems

Relays work in combination with circuit breakers by continuously monitoring the power system to ensure availability of maximum electrical supply with minimum damage to equipment, property and life. The basic principle of applying relays is to divide the power system into separate protection zones. Each protection zone has its own set of individual relays and circuit breakers. A typical power system is divided into protective zones for:

- generators
- transformers
- buses
- transmission and distribution systems
- motors

Figure 1.2 shows a basic power system and related protection zones. As seen from the figure, all the elements have their own protection zones. When a fault occurs in any component of the power system, the relays associated with that component detect it and send a signal to the circuit breakers to isolate the component. Adjoining zones overlap to ensure that no part of the power system is left unprotected. When a fault occurs in an overlapped region, relays of both zones operate and isolate both zones from the system.



- 1- Generator protection zone
- 2- Generator transformer protection zone
- 3- Bus bar protection zone
- 4- Transmission line protection zone

Figure 1.2 Power system with protective zones

Figure 1.3 shows a single line diagram of a typical relay [4]. The magnitudes of power system currents and voltages are very high and cannot be applied to relays directly. The current and voltage levels are reduced to typically 5 A and 110 V nominal values using current transformers (CTs) and voltage transformers (VTs).

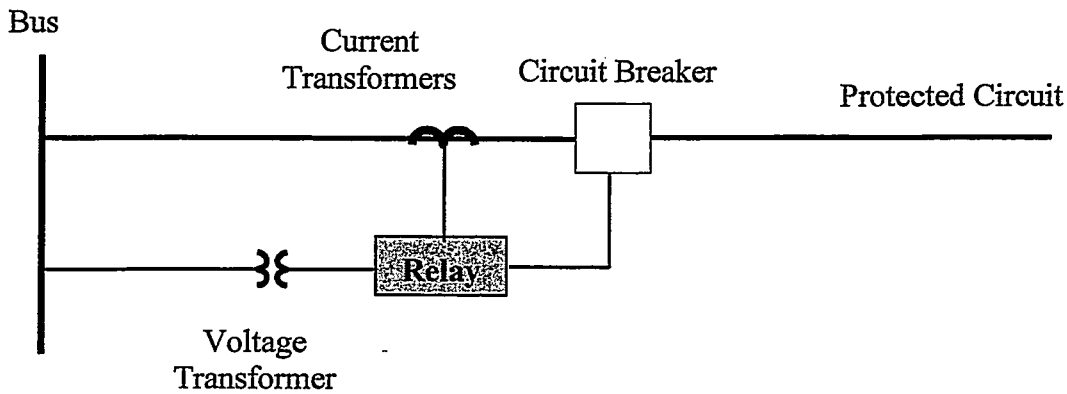


Figure 1.3 Typical arrangement of a relay

1.4.1 Evolution of Power System Relays

The earliest power system protection device used to isolate a faulted element was a fuse. Its major disadvantage is that it cannot distinguish a faulted zone from an unfaulted zone, and has to be replaced after each operation. Later, relays were developed using electromechanical and electromagnetic principles. The relays provided a considerable improvement in the protection of power systems. The electromechanical relays convert energy in the electrical inputs to mechanical force, which is translated to physical movement that closes one or more trip contacts [5]. These relays detect the occurrence of faults and energize the trip circuit of the circuit breakers provided to control the system element. With the increase in the complexity of power systems, advancements in protective devices continued to meet the system requirements.

Introduction of solid-state electronic relays began in the early 1960's. Their design was based on the use of analogue electronic devices to create the relay

characteristics. Early versions of electronic relays used discrete devices such as transistors and diodes in conjunction with resistors, capacitors, inductors; and had huge failure rates. Advances in electronics introduced Large Scale Integrated (LSI) technology, after which more reliable and accepted designs of electronic relays evolved [6]. As there are no moving parts in solid-state relays, they are also known as “static” relays. They provided faster operating speeds, versatile characteristics, low burden and incorporated several protective functions in one compact unit.

With the advent of digital technology, microprocessor-based relays were developed [6, 7, and 8]. Microprocessors and microcontrollers replaced analogue circuits used in static relays to implement relay functions. The first investigations in the use of digital technology for power system protection started in the 1960’s. Last and Stalewsky [9] proposed the use of real time computations for system protection in 1966. In 1968, Rockefeller [10] studied the feasibility of using a single computer for the protecting all major components in a substation. This work inspired the development and installation of the first microprocessor based relay at the Tesla substation as a joint venture between the Westinghouse Electric Corporation and the Pacific Gas and Electric Company [11]. A more detailed review of microprocessor-based relays, also called numerical relays, is provided in Chapter 2.

1.5 Objective of the Thesis

The objective of the research presented in this thesis is to investigate the different components in the analog input subsystem, and to evaluate the speed of execution of a numerical relay algorithm at different sampling frequencies, using specialized digital signal processors. A numerical relay uses processors to implement the protection algorithm. The limited power of the processors can restrict the number of samples of inputs that can be processed. The speed of execution of the numerical relay algorithm and thus the speed of operation of the numerical relay is determined by the processors’ computational ability. The speed of operation of the numerical relay, also depends on the

hardware components in the analog input subsystem, such as the anti-aliasing filters and the analog-to-digital converters.

1.6 Outline of the Thesis

This thesis is organized into eight chapters and four appendices. Chapter 1 introduces the background of power system protection, the focus of the research and outlines the organization of this work.

Chapter 2 describes the basic functional blocks of a typical numerical relay. An overview of the important features and the description of major functional components of a numerical relay are presented. This chapter also discusses the errors associated with the various hardware components that constitute a numerical relay.

The algorithms for numerical relays are presented in Chapter 3. The mathematical equations and the assumptions used in developing the algorithms are given. The advantages and disadvantages associated with the algorithms are also outlined.

Chapter 4 discusses the factors and the tradeoffs affecting the selection of the algorithms and the hardware for numerical relays. The procedures followed in the selection of the algorithm and the hardware used for this project are described. The importance, basic requirements and the design of anti-aliasing low-pass filters at the front end of numerical relays are presented. A description of the selected hardware for this project is also included.

Chapter 5 describes the implementation of the numerical relay algorithm on the selected processors using the real time operating software.

Chapter 6 describes the simulation studies executed to evaluate the performance of the algorithm and the impact low-pass anti-aliasing filters on the estimation of operating parameters. Results obtained from the studies are presented and discussed.

Finally, Chapter 7 includes a summary and conclusions drawn from the work reported in the thesis. A list of references is provided in Chapter 8.

There are five appendices included in this thesis. In Appendix A, an introduction to the EMTDC is given, and the parameters of the transmission line and other components of the power system used for generating the simulation data are presented. In Appendix B, some additional results are presented for different sampling frequencies. The list of various data acquisition boards considered, are tabulated in Appendix C. In Appendix D, the digital output of the analog-to-digital converter considered for this project is described. Appendix E gives a brief introduction to the digital processors.

1.7 Summary

In this chapter, a brief introduction to power system protection, various causes of faults, types of faults, and the impact of faults on the power system are discussed. Protective devices used to detect these faults and isolate the faulted elements from the power system are also described. The evolution of protective devices such as fuses, electromechanical, solid-state and numerical relays is reviewed. Finally, the objective of this research project and the outline of this thesis are presented.