DIGITAL PROTECTION OF POWER TRANSFORMER USING MICROCONTROLLER-BASED RELAY

ADEL HAMAD RAFA

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By

ADEL HAMAD RAFA

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ADEL HAMAD RAFA

september 2002

Chairman: **Senan Mahmod Bashi, Ph.D.**

Faculty: **Engineering**

In this thesis the fault types in the power transformer as well as their protection scheme have been studied, and the factors which lead to mal operation of differential protection such as : magnetizing inrush, over excitation, ratio mismatch and current transformer saturation have been investigated. The existing methods of discriminating internal faults from inrush magnetizing condition have been reviewed.

A method to discriminate internal fault from inrush current depended on the rate of change of primary current with respect to time at the first quarter cycle has been used in this work.

The percentage differential protection, over current protection, over voltage protection and under voltage protection are implemented in a microcontroller–based system. The design implementation and testing of the system are also presented. The performance of

the system was checked in the laboratory. The experimental results gave a good agreement with the theoretical ones.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai
memenuhi keperluan untuk ijazah Master Sains

DIGITAL PERLINDUNGAN UNTUK TRANSFORMER KUASA DENGAN MENGGUNAKAN GEGANTI BERASAKAN PENGAWALMIKRO

Oleh

ADEL HAMAD RAFA

September 2002

Pengerusi: **Senan Mahmod, Ph.D.**

Fakulti: **Kejuruteraan**

Dalam tesis ini, jenis-jenis kerosakan dan skim-skim perlindungan telah dikaji. Faktor-faktor yang menjurus kepada kepincangan tugas oleh perlindungan pembeza termasuklah: rempuh masuk pemagnetan, pengujaan melampau, nisbah tak padan dan pengubah arus ketepuan telah juga dikaji. Keadaan-keadaan rempuh-masuk pemagnetan telah juga diberi perhatian.

Kaedah untuk membezalayan kerosakan dalaman daripada arus rempuh-masuk bergantung kepada kadar tukaran primer permasa pada suku kitaran pertama telah diterangkan.

Peratusan pelindungan pembeza, perlindungan arus lampau, perlindungan voltan lampau dan perlindungan voltan kurang telah diimplementasikan pada sistem berasaskan pengawalmikro.

Rekabentuk sistem dan ujian keatas sistem tersebut juga dipersembahkan. Prestasi sistem yang telah direkabentuk telah diperiksa di makmal. Keputusan-keputusan ujikaji telah memberikan persamaan yang memuaskan dengan teori yang telah diterangkan.

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SENAN MAHMOD ABDULLAH, Ph.D.
Department Of Electrical And Electronic Engineering
Faculty Of Engineering
Universiti Putra Malaysia.
(Chairman)

NORMAN MARIUN, Ph.D.
Associate professor
Department Of Electrical And Electronic Engineering
Faculty Of Engineering
Universiti Putra Malaysia
(Member)

WAN ZUHA BIN WAN HASAN, MSc.
Department Of Electrical And Electronic Engineering
Faculty Of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, Ph.D.
Professor/ Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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LIST OF ABBREVIATIONS

Symbols

A/D	Analogue To Digital Converter.
ADCTL	A/D Control Status Register.
a_n	The Real Part of nth Harmonic.
b_n	The Imaginary Part of nth Harmonic.
CPU	Central Processor Unit.
CT	Current Transformer.
D	Decimal Value of the Digital Output Word.
DAS	Data Acquisition System.
DC	Direct Current.
D/I	Data Input.
D/A	Digital to Analogue Converter.
D/O	Data Output.
di/dt	Change Of Current With Respect to Time.
F	The State Transition Matrix.
H	The Matrix Giving The Noiseless Connection Between the Measurement and State Vector.
I&AS	The Isolation and Analog Scaling Block.
i_1	The Current in the Primary Windings.
i_2	The Currents in the Secondary Windings.
i_{1n}	The nth Samples of the Primary Current.
i_{2n}	The nth Sample of the Secondary Current.

I_{a1}, I_{b1} and I_{c1}	Are Primary Currents for Three Phase, A, B, C.
I_{a2}, I_{b2} and I_{c2}	Are Secondary Currents for Three Phase, A, B, C.
I_d	Differential Current.
I_R	Restraining Current.
I_{PU}	Pickup Current.
I_{CH}	Combined Harmonic Component in the Differential Current.
I_{CD}	Combined Differential Current.
I_0	The Initial Value of the DC Offset At Time T=0.
I_n	The Peak Value of the nth Harmonic Component.
I_{f2}	The Second-Harmonic Which Present in the Differential Current.
I_{f1}	Fundamental Components, Which Present in the Differential Current.
$I_{Rx1(fault)})$	The Currents at R_x Before the Occurrence of A Fault.
$I_{Rx1(pre\text{-}fault)}$	The Currents at R_x After the Occurrence of A Fault.
I_{y1}	The Pre-Fault Positive-Sequence Current at the Fault Location.
K	A Compensation Factor.
L_1	The Leakage Inductances of the Primary Windings.
L_2	Are the Leakage Inductances of the Secondary Windings.
LP	Low Pass.
n_1	Turns Ratios of Primary Current Transformer.
n_2	Turns Ratios of Secondary Current Transformer.
PT	Potential Transformer.
T	The Sampling Interval in Second.
TF	Threshold Value of Minimum di/dt.

TP	Tripping Permission From the Inrush Detector.
SPR	Sudden-Pressure Relay.
SHR	Second-Harmonic and Fundamental Components Harmonic Ratio.
SLP	The Slope Percentage Differential Protection Characteristic.
VA	Volt-Amperes.
V_1	The Voltage of the Primary Windings.
V_2	The Voltages of the Secondary Windings.
V_{1n}	The nth Samples of the Primary Voltage.
V_x	The Real Part of the Phasor that Represents Fundamental Component of the Faulted Voltage.
V_{yt}	The Imaginary Part of the Phasor that Represents The Fundamental component of the faulted voltage.
v_J	The Samples of Voltage Waveform.
$V_{Rx1(fault))}$	The Voltages at R_x Before the Occurrence of A Fault.
$V_{Rx1(pre\text{-}fault))}$	The Voltages at R_x After the Occurrence Of A Fault.
V/Hz	The Voltage/Frequency Ratio.
Vk	The Measurement Error.
V_y1	The Pre-Fault Positive-Sequence Voltage at the Fault Location.
x_k	The Process State Vector at Time t_k
Wk	Noise Vector-Assumed.
W (t)	The Average Power Flowing into Transformer During One Period.
Z_k	The Vector Measurement at t_k
ω	The Fundamental Supply Frequency in Radian Per Second.
Z_f	The Fault Impedance.

ΔV_{y1}	The Positive-Sequence Incremental Voltage.
ΔI_{y1}	The Positive-Sequence Incremental Current.
Z_{gx1}	The Positive-Sequence Impedance of Generator G_x.
Z_{t1}	The Positive-Sequence Impedance of Transformer.
Z_{gx2}	The Negative-Sequence Impedances of Generator G_x.
Z_{t2}	The Negative-Sequence Impedances of the Transformer.
Z_{gx2}	The Negative-Sequence Impedances of Generator G_x.
Z_{t2}	The Negative-Sequence Impedances of the Transformer.
y	Dependent Output Variable (Digital Code).
m	Slope Or Conversion Gain.
x	Independent Input Variable (Analog Input).
b	Y-Axis Intercept or Offset.
p	The Highest Harmonic Measured.
τ	The Time Constant of Any Decaying DC Component.
ω_0	The Fundamental Frequency of System In Radians/Second.
$i\ (t)$	The Instantaneous Value of the Current at Any Time T.
θ_n	Phase Angle of nth Harmonic Component.
$\theta_n^{(r)}$	Voltage Waveform Phase Angle.
λ	The Mutual Flux Linkages.
ΔT	The Sampling Interval Time.

CHAPTER 1

INTRODUCTION

Electric power system elements such as: generators, transformers and transmission lines are usually protected by relays. The purpose of protection relays is to minimize the effects of faults on electrical power system components.

The early relays designed for power systems used electromechanical technology. The various types of electromechanical relays such as magnetic attraction, magnetic induction, D'Arsonval, and thermal relays are provided for significant improvement in the protection of power systems [1].

In the late 1950's solid state relays were introduced. The solid state relays use various low power components: diodes, transistors, thyristors, associated resistors and capacitors. For several reasons, utilities did not accept those relays for almost fifteen years. However, their use has increased gradually during last several years [2].

Electromechanically and solid-state relays were and still used for protecting power system for the past several years, researchers have been studying the feasibility of designing relays using microprocessors. As a consequence of substantial research in the area of digital relaying, advancements in digital technology, and decrease in digital hardware prices, microprocessor relays are now available and being used for protecting power system [3].

Microprocessor-based distribution relays contribute to improved reliability and reduced costs on electric power systems. Microprocessor-based relays, also called digital relays, have a proven track record of reliability. A digital relay uses software to process quantized signals for implementing the relay logic.

Digital relays provide technical improvements and cost savings in several ways as below

- The relays use programmable logic to reduce and simplify wiring.
- The relays provide protection for bus faults, breaker failure, and high-side transformer blown fuse detection at no or minimal additional cost.
- The relays have metering functions to reduce or eliminate the need for panel meters and transducers.
- The relays reduce maintenance costs by providing self-test functions and high reliability.
- The relays provide remote targets and fault location information to assist operators in restoration of electrical service [4].

1.1. Basic Components of Digital Relay

Any digital relay can be thought of as comprising three fundamental subsystems as shown in Figure 1.1.

i. A signal conditioning subsystem

ii. A conversion subsystem

iii. A digital processing relay subsystem.

The first two subsystems are generally common to all digital protective schemes, while the third varies according to the application of particular scheme. Each of the three subsystems is built up of a number of components and circuits [5].

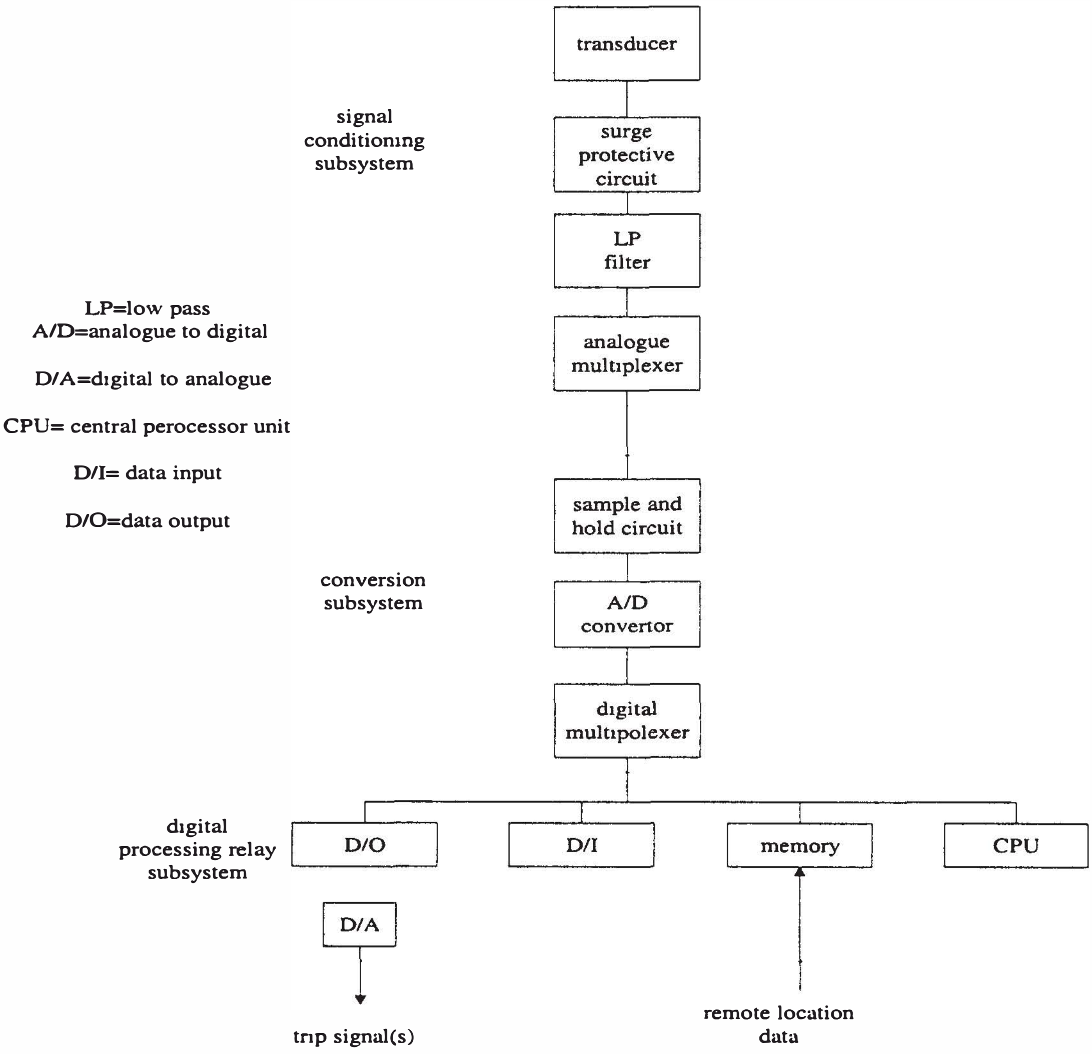

Figure 1.1: Basic components of a digital relay [5]