

**LOW IMPEDANCE
RESTRICTED EARTH FAULT ALGORITHMS
IN NUMERICAL RELAYS**

BABAK NIM TAJ

**FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR**

JULY 2010

ABSTRACT

Low impedance restricted earth fault protection is one of the protection function to protect the transformer winding with earthed neutral point. The purpose of this study is to investigate low impedance restricted earth fault algorithm in numerical relays. Five restricted earth fault numerical algorithms from **ABB**, **AREVA T&D**, **SIEMENS**, **SCHNEIDER ELECTRIC** and **GENERAL ELECTRIC** are employed for restricted earth fault algorithms assessment.

This dissertation is to find out advantages and disadvantages of selected algorithms. Moreover, this dissertation is to compare each algorithm with the other algorithms. Also, magnetizing inrush current, over excitation and CT saturation impression on restricted earth fault operation is presented. After the algorithms assessment, two of them (Siemens and General Electric) are selected for simulation (MATLAB SIMULINK). These algorithms are compared and advantages and disadvantages of them are presented.

ACKNOWLEDGMENT

I would like to show my gratitude to **my parents** who always support and encourage me. They provided the growth ways in my life and taught me to watch life optimistically.

Also, I am grateful to my dear supervisor **Dr.Ab.Halim Abu Bakar** whose guidance and support from the initial to final level of completing this dissertation was very useful. He enabled me to develop this dissertation by sharing his immense practical experiences and great knowledge.

Finally, I would like to thank **Dr.Hazlie Bin Mokhlis** and my dear friend **Amin Mahmoudi** because of their help during the completion of my dissertation.

CONTENTS TABLE

Abstract	I
Acknowledgment	II
Table of contents	III
List of figures	VIII
List of tables	VX
Chapter 1 Introduction	1
1.1 Introduction	1
1.2 Restricted earth fault (REF) protection	2
1.3 Problem statement	3
1.4 Approach to the problem	3
1.5 Thesis organization	4
Chapter 2 Literature review	5
2.1 Introduction	5
2.2 Types of fault in transformer	5
2.2.1 Winding fault	6
2.2.1.1 Type of winding and terminals fault	7
2.2.1.2 Fault study	8
2.2.1.3 Different fault types	9
2.3 Background knowledge of short circuit calculation	10
2.3.1 Symmetrical components	10
2.3.1.1 Positive component	10
2.3.1.2 Negative component	11
2.3.1.3 Zero component	12
2.3.1.4 General equation	12
2.3.2 Unbalance fault calculation	13

2.3.3	Single line to ground fault	14
2.4	Kinds of transformer windings protection	17
2.4.1	Differential protection using time over current relays	18
2.4.2	Differential protection using percentage differential protection	18
2.5	Why using restricted earth fault protection	21
2.5.1	Classification of system grounding	21
2.5.1.1	Solidly grounding	23
2.5.1.2	Low resistance grounding	23
2.5.1.3	High impedance grounding	24
2.5.1.4	Ungrounded system	24
2.5.2	Transformer winding earth fault	25
2.5.2.1	Solidly earthed	25
2.5.2.2	Resistance or reactance earthed	26
2.5.2.3	Earth fault in delta winding	27
2.5.3	Using restricted earth fault protection function	28
2.6	Review of restricted earth fault algorithm	29
2.6.1	Siemens	29
2.6.1.1	Function description	30
2.6.1.2	Operation algorithm	31
2.6.2	GE Multilin (Bogdan Kasztenny)	32

2.6.2.1	Operation algorithm for single breaker	33
2.6.2.1.1	Differential current	33
2.6.2.1.2	Restraining current	34
2.6.2.1.3	Zero sequence restraint	34
2.6.2.1.4	Positive sequence restraint	35
2.6.2.1.5	Negative sequence restraint	35
2.6.2.2	Operation algorithm for a breaker and half	36
2.6.3	New restricted earth fault (Areva T&D)	37
2.6.3.1	REF with dual slope percentage restraint	37
2.6.3.2	Suggested algorithm	38
2.6.4	Schneider low impedance REF	39
2.6.5	ABB	41
2.6.5.1	Differential and bias currents	42
2.6.5.2	Algorithm of the restricted earth fault	45
	protection (REF)	
Chapter 3	Methodology	47
3.1	Introduction	47
3.2	Magnetizing inrush current	47
3.3	Reason of inrush current	49
3.4	Discrimination between fault current and inrush current	61

3.4.1	Improved Fourier series (half cycle Fourier series)	61
3.4.2	Using wavelet transform	62
3.4.3	Waveform analysis	63
3.4.3.1	Low current detection method	63
3.4.3.2	DC blocking method	64
3.5	Over excitation	65
3.5.1	Over excitation harmonic analysis	66
3.6	Harmonic restraint and blocking	69
3.6.1	Harmonic restraint	69
3.6.2	Harmonic blocking	72
3.7	General Electric Multilin	77
3.8	Siemens algorithm	83
3.9	ABB	89
3.10	New restricted earth fault (Areva T&D)	91
3.11	Schneider low impedance REF	92
Chapter 4	Result and Discussion	93
4.1	Introduction	93
4.2	Simulation	93
4.3	Siemens algorithm	97

4.3.1	Normal condition	97
4.3.2	Out zone fault	102
4.3.3	In zone fault	107
4.4	General Electric Multilin	111
4.4.1	Normal condition	111
4.4.2	Out zone fault	117
4.4.3	In zone fault	121
Chapter 5	Conclusion	126
5.1	Introduction	126
5.2	Conclusion	126
References		128

LIST OF FIGURES

Figure 1.1	Restricted earth fault protection	2
Figure 2.1	Transformer fault statistic	6
Figure 2.2	Transformer fault	8
Figure 2.3	Single line to ground fault	9
Figure 2.4	Line to line and double line to ground fault	9
Figure 2.5	Three phase to ground fault	9
Figure 2.6	Symmetrical components, illustrate positive, negative, Zero sequence	10
Figure 2.7	Sequence network for transformer	13
Figure 2.8	Equivalent circuit of the single line to ground fault (Steady state)	16
Figure 2.9	Zero sequence current and voltage of ground fault protection	16
Figure 2.10	Differential relay diagram	17
Figure 2.11	Current direction for external fault	19
Figure 2.12	Currents direction for internal fault	19
Figure 2.13	Percentage differential operating	20
Figure 2.14	Connection for three windings transformer	21
Figure 2.15	Grounded and ungrounded systems	22
Figure 2.16	Solidly grounded network	23
Figure 2.17	Low impedance grounded network	24

Figure 2.18	Ungrounded system	24
Figure 2.19	Star connection – solidly earthing	25
Figure 2.20	Resistance or reactance earthed neutral	26
Figure 2.21	Earth fault in delta connection	27
Figure 2.22	Percentage of winding protected between REF and differential relay	28
Figure 2.23	A-earth fault inside protection zone (left), b-earth fault outside protection zone (right)	30
Figure 2.24	Connection principle of restricted earth fault protection	31
Figure 2.25	Operating and restraining areas	32
Figure 2.26	Transformer REF connection –(a) single breaker, (b) one and half breaker	33
Figure 2.27	Logic controlling negative restraint	35
Figure 2.28	Setting of the REF characteristic	36
Figure 2.29	Dual slopes relay characteristic	37
Figure 2.30	REF suggested characteristic curve	39
Figure 2.31	SEPAM REF tripping characteristic	40
Figure 2.32	Currents at an external earth fault	41
Figure 2.33	Currents at an internal earth fault	42

Figure 2.34	REF function block	43
Figure 3.1	Typical magnetizing inrush current wave form	48
Figure 3.2	Transformer single phase equivalent circuit	49
Figure 3.3	Core excitation of transformer	51
Figure 3.4	Hysteresis loop	51
Figure 3.5	Relation of the magnetizing inrush current and core material	53
Figure 3.6	Voltage angle during magnetizing	55
Figure 3.7	Phase displacement 90° between voltage and flux	55
Figure 3.8	Positive and negative remanent flux at 90° angle	56
Figure 3.9	B/H curve	58
Figure 3.10	Effect of switching angles in the percentage of second harmonic	58
Figure 3.11	Flux wave	59
Figure 3.12	Low current detection inrush current	64
Figure 3.13	Logic diagram for DC blocking	65
Figure 3.14	Approximation of the normalized magnetizing core	67
Figure 3.15	Approximated hysteresis loop to the line	67
Figure 3.16	Differential relay with restraint and operation circuit	70
Figure 3.17	Second and fifth harmonic restraint logic circuit	71
Figure 3.18	Differential unit	72

Figure 3.19	Harmonic block unit	73
Figure 3.20	Transformer relay second harmonic contact	74
Figure 3.21	Harmonic blocking and restraint logic diagram	74
Figure 3.22	Independent harmonic blocking and restraint	75
Figure 3.23	Operating during clearing fault	77
Figure 3.24	Phases and ground currents of external double line to ground fault	78
Figure 3.25	Symmetrical components of external double line to ground	79
Figure 3.26	External double line to ground fault restraint component and total	80
Figure 3.27	External double line to ground fault restraint and differential current	80
Figure 3.28	Relay characteristic of external double line to ground and clearing	81
Figure 3.29	Tripping area depends an earth currents ratio	84
Figure 3.30	Phasor diagram during external fault	86
Figure 3.31	Tripping characteristic by phase limit	86
Figure 3.32	Polar characteristic show	87
Figure 3.33	Simple logic diagram of the REF	88
Figure 3.34	Siemens REF characteristic curve	89
Figure 3.35	Relay characteristic curve	90

Figure 4.1	Case study	94
Figure 4.2	Source parameters	95
Figure 4.3	Circuit breaker parameters	95
Figure 4.4	Transformer parameters	96
Figure 4.5	Load parameters	96
Figure 4.6	Siemens relay connected to the network	98
Figure 4.7	Siemens REF algorithm simulation	99
Figure 4.8	Three phase current at normal condition in Siemens algorithm	100
Figure 4.9	Star point current at normal condition in Siemens algorithm	100
Figure 4.10	Restraint (above) and tripping (below) current At normal condition in Siemens algorithm	101
Figure 4.11	Relay operation command at normal condition in Siemens algorithm	102
Figure 4.12	Out of zone fault in Siemens relay	103
Figure 4.13	Three phase current at out of zone fault in Siemens algorithm	104
Figure 4.14	Star point current at out of zone fault in Siemens algorithm	104
Figure 4.15	Fault current at out of zone fault in Siemens algorithm	105
Figure 4.16	Relay operation command at out of zone fault in Siemens algorithm	105

Figure 4.17	Restraint (above) and tripping (below)	106
	current at out of zone fault in Siemens algorithm	
Figure 4.18	Three phase current at in zone fault in Siemens algorithm	107
Figure 4.19	In zone fault in Siemens relay	108
Figure 4.20	Star point current at in zone fault in Siemens algorithm	109
Figure 4.21	Fault current at in zone fault in Siemens algorithm	109
Figure 4.22	Restraint (above) and tripping (below)	110
	current at in zone fault in Siemens algorithm	
Figure 4.23	Relay operation command at in zone fault in Siemens algorithm	111
Figure 4.24	GE relay connected to the network	112
Figure 4.25	GE REF algorithm simulation	113
Figure 4.26	Three phase current at normal condition in GE algorithm	114
Figure 4.27	Star point current at normal condition in GE algorithm	114
Figure 4.28	Differential current waveform (above) and	115
	Magnitude (below) at normal condition in GE algorithm	
Figure 4.29	Relay operation command at normal condition in GE algorithm	116
Figure 4.30	Restraint current at normal condition in GE algorithm	116
Figure 4.31	Three phase current at out of zone fault in GE algorithm	117
Figure 4.32	out of zone fault in GE REF algorithm simulation	118

Figure 4.33	Star point current at out of zone fault in GE algorithm	119
Figure 4.34	Restraint current at out of zone fault in GE algorithm	119
Figure 4.35	Differential current waveform (above) and Magnitude (below) at out of zone fault in GE algorithm	120
Figure 4.36	Relay operation command at out of zone fault in GE algorithm	121
Figure 4.37	In zone fault in GE REF algorithm simulation	122
Figure 4.38	Three phase current at in zone fault in GE algorithm	123
Figure 4.39	Star point current at in zone fault in GE algorithm	123
Figure 4.40	Differential current waveform (above) and Magnitude (below) at in zone fault in GE algorithm	124
Figure 4.41	Relay operation command at in zone fault in GE algorithm	125
Figure 4.42	Restraint current at in zone fault in GE algorithm	125

LIST OF TABLES

Table 2.1	Transformer sequence component connection	14
Table 2.2	Input signal for REF	43
Table 2.3	Output signal for REF	44
Table 2.4	Bias characterize of the REF	45
Table 3.1	Comparing between harmonic restraint and blocking	76
Table 3.2	K factor and limit angle	87
Table 3.3	Data of bias characteristic of REF in ABB relay	90