PERFORMANCE OF GENERATOR NEGATIVE-SEQUENCE PROTECTION DURING SINGLE-PHASE FAULT

JUNAIDAH BINTI ALI MOHD JOBRAN

UNIVERSITI TEKNOLOGI MALAYSIA

PERFORMANCE OF GENERATOR NEGATIVE-SEQUENCE PROTECTION DURING SINGLE-PHASE FAULT

JUNAIDAH BINTI ALI MOHD JOBRAN

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical – Power)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2012

Specially dedicated:

To my beloved mother and father,
To my beloved sisters and brothers,
All my friends, colleagues and relatives,

For their encouragement, support and motivation

ACKNOWLEDGEMENT

Alhamdulillah, thanks to Allah S.W.T the most merciful and the most compassionate for the guidance and knowledge bestowed upon me, for without it I would not have been able to come this far. Peace is upon him, Muhammad the messenger of God.

I would like to express my sincere gratitude and appreciation to my supervisor, Prof. Ir. Dr. Abdullah Asuhaimi Bin Mohd Zin and my co-supervisor Dr. Sazali P. Abdul Karim for their guidance, advices, patience and encouragement during my study on this master project. Their support and assistance in preparation of this thesis is much appreciated.

A special thank to my family, friends and colleagues for their advise, patience and motivation. I also would like to express my thanks to my employer, Universiti Malaysia Perlis, who has given me the opportunity to continue my studies. Lastly my heartfelt appreciation goes to all who have directly or indirectly helped me to make this project success.

ABSTRACT

Negative-sequence current is a component that resulted from unbalance conditions that occur in the system. Theoretically, problems caused by the negative-sequence current are rare and can be ignored, but in reality the presence of negative-sequence current which exceeds the permitted level will affect the performance of the generator. Therefore, some utility companies tend to adopt more passive method by tripping and separating the generator from the system if negative-sequence current is higher than the predefined level. However, tripping of major generation facilities may create social, security and economic problem. In order to protect the generator from negative-sequence current, there are many methods can be used as the negative-sequence protection. One of the methods is using negative-sequence impedance directional element. In this project, several types of unbalanced conditions are tested on the parallel system, which have four main parts to be completed namely three-phase parallel line system, breaker control, fault control and negative-sequence protection system. The design circuit is constructed and simulated using PSCAD/EMTDC software, to check the comparison between the generator with negative-sequence protection and generator without negative-sequence protection. The data are analyzed based on the rms value of the generator, to evaluate the generator's performance during unbalanced conditions. From the result, it shown that the performance of the generator with negative-sequence protection is stable with very small value of negative-sequence current compared to the generator without negative-sequence protection. In the end, new techniques are suggested as the alternatives to improve the performance of the generator.

ABSTRAK

Arus jujukan negatif merupakan satu komponen yang terhasil daripada keadaan yang tidak seimbang yang berlaku pada sistem. Secara teori, masalah-masalah yang disebabkan oleh arus jujukan negatif jarang berlaku dan boleh diabaikan, tetapi secara realiti kehadiran arus jujukan negatif yang melebihi tahap yang telah ditetapkan akan menjejaskan prestasi penjana. Oleh itu, beberapa syarikat utiliti cenderung untuk menggunakan kaedah yang lebih pasif dengan menyandung dan memisahkan penjana daripada sistem jika arus jujukan negatif lebih tinggi daripada aras yang telah ditentukan. Walaubagaimanapun, dengan menyandung kebanyakkan kemudahan penjanaan utama boleh mewujudkan masalah sosial, keselamatan dan ekonomi. Dalam usaha untuk melindungi penjana semasa daripada arus jujukan negatif, terdapat banyak kaedah yang boleh digunakan sebagai perlindungan jujukan negatif. Salah satu kaedah adalah dengan menggunakan *negative-sequence impedance directional element*. Dalam projek ini, beberapa keadaan tidak seimbang telah diuji ke atas sistem selari, yang mempunyai empat bahagian utama yang perlu dilengkapkan iaitu sistem talian selari tiga fasa, kawalan pemutus, kawalan kerosakan dan sistem perlindungan jujukan negatif. Rekabentuk litar dibina dan disimulasi menggunakan perisian PSCAD/EMTDC. Prestasi penjana dengan perlindungan jujukan negatif dibandingkan dengan prestasi pejana tanpa perlindungan jujukan negatif. Data yang dianalisis adalah berdasarkan nilai rms pada penjana untuk mengetahui prestasi penjana semasa keadaan tidak seimbang. Daripada keputusan, ia menunjukkan prestasi penjana dengan perlindungan jujukan negatif adalah stabil dengan nilai arus jujukan negatif yang sangat kecil berbanding dengan penjana tanpa perlindungan jujukan negatif. Akhirnya, teknik-teknik baru dicadangkan sebagai cara alternatif untuk memperbaiki prestasi penjana.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xii
	LIST OF ABBREVIATIONS	xv
	LIST OF SYMBOLS	xvii
	LIST OF APPENDICES	xviii
1	**INTRODUCTION**	1
	1.1 Introduction	1
	1.2 Problem Statement	3
	1.3 Project Objectives	4
	1.4 Scope of Project	5
	1.5 Methodology	5
	1.6 Thesis Outline	7
2	**LITERATURE REVIEW**	9
	2.1 Introduction	9
	2.2 Unsymmetrical Components from Symmetrical Components	10

2.3 Unbalanced Conditions 12
  2.3.1 Unbalanced Load 13
  2.3.2 Phase Faults and Ground Faults 15
2.4 Power System Protection 16
2.5 Negative-Sequence Protection 18
  2.5.1 Negative-Sequence Relay 18
  2.5.2 Static Negative-Sequence Relay 23
  2.5.3 Static VAR Compensator 25
  2.5.4 Single-Phase Active Power Filter 26
  2.5.5 Negative-Sequence Impedance Directional Element 26
2.6 Summary 28

3 MODELLING OF PARALLEL SYSTEM 30
3.1 Introduction 30
3.2 Characteristic of PSCAD 31
3.3 Characteristic of EMTDC 34
3.4 Network Design 34
  3.4.1 Test System 35
    3.4.1.1 Source 36
    3.4.1.2 Overhead Transmission Line 36
    3.4.1.3 Three-Phase Load 38
  3.4.2 Breaker Control 39
  3.4.3 Three-Phase Fault 40
  3.4.4 Negative-Sequence Protection System 41
3.5 Summary 44

4 SIMULATIONS RESULT 45
4.1 Introduction 45
4.2 Unbalance Load 46
4.3 Faulted Phase A at Transmission 1 49
4.4 All Phases at Transmission 1 Have Fault 53
4.5 Phase A at Both Transmissions Have Fault 56
4.6 Phase A at Transmission 1 and Phase C at

Transmission 2 Have Fault 60

4.7 Transmission 1 is on Outage 63

4.8 Both Lines are Trip Simultaneously 67

4.9 Summary 70

5 CONCLUSION AND RECOMMENDATION 72

5.1 Conclusion 72

5.2 Recommendation for Future Study 74

REFERENCES 75

Appendices A-G 78 – 98

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Fault statistics with reference to the type of fault	15
2.2	Fault statistics with reference to power system elements	16
4.1	Test result for the unbalance load system before and after using negative-sequence protection.	49
4.2	The result for the system without protection during fault at Phase A	51
4.3	The result for the system with negative-sequence protection during fault at Phase A	52
4.4	The result for the system without negative-sequence protection when all phases at Transmission 1 have fault	54
4.5	The result for the system with negative-sequence protection when all phases have fault	56
4.6	The result of the system without negative-sequence protection When Phase A at both lines have fault	58
4.7	The result for the system with negative-sequence protection when Phase A at both lines have fault	60
4.8	The result for the system without negative-sequence protection when different phases from both lines have fault	62
4.9	The result for the system with negative-sequence protection when different phases from both lines have fault	63
4.10	The result for the system without negative-sequence protection when one line is on outage	65

4.11 The result for the system with negative-sequence protection when one line is on outage 67
4.12 The result for the system without negative-sequence protection when both networks trip simultaneously 68
4.13 The result for the system with negative-sequence protection when both networks trip simultaneously 70

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Example of parallel line system	6
1.2	Flow chart of research methodology	7
2.1	Three set of balance phasor which are symmetrical components of three unbalanced phasors	11
2.2	Sequence networks: (a) positive-sequence (b) negative-sequence (c) zero-sequence	11
2.3	Unbalance loading of stator causes the rotor to overheat	14
2.4	Simple scheme of negative-sequence relay	19
2.5	Phasor diagram of two branches of I_R	20
2.6	Phasor diagram in balanced system	21
2.7	Phasor diagram during unbalanced system	22
2.8	Phasor diagram of zero-sequence current	22
2.9	CTs connection to avoid zero-sequence current in the network	23
2.10	The arrangement of SGC Relay	23
2.11	A power system with SVC	24
2.12	Connection of the single-phase APF to the system	26
2.13	The characteristic of traditional negative-sequence element	27
3.1	Double line circuit	35
3.2	Single-line diagram of the parallel system	35
3.3	Three-phase source (a) single line diagram (b) three phase diagram	36
3.4	Overhead transmission line (a) remote connection (b) direct connection	37

3.5 Cable configuration of PSCAD 37
3.6 Pre-constructed transmission line tower 38
3.7 The breakout and three-phase loads 38
3.8 Breaker control 39
3.9 Three-phase faults with on-line dial control 40
3.10 FFT and the sequence filter 41
3.11 Negative-sequence impedance directional elements 42
3.12 Breaker control for breaker at generation 43
4.1(a) Phase voltage at generator 46
4.1(b) Phase current at generator 46
4.1(c) RMS voltage at generator 47
4.2 System with negative-sequence protection during unbalanced load (a) phase voltage (b) phase current (c) RMS voltage 48
4.3 System without negative-sequence protection during fault at Phase A (a) phase voltage (b) phase current (c) RMS voltage 50
4.4 System with negative-sequence protection during fault at Phase A (a) phase voltage (b) current voltage (c) RMS voltage 52
4.5 System without negative-sequence protection when all phases at Transmission 1 have fault (a) phase voltage (b) phase current (c) RMS voltage 54
4.6 System with negative-sequence protection when all phases at Transmission 1 have fault (a) phase voltage (b) phase current) (c) RMS voltage 56
4.7 System without negative-sequence protection when Phase A at both lines have fault (a) phase voltage (b) phase current (c) RMS voltage 57
4.8 System with negative-sequence protection when Phase A at both lines have fault (a) phase voltage (b) phase current (c) RMS voltage 59
4.9 System without negative-sequence protection when different phases from both lines have fault (a) phase voltage (b) phase current (c) RMS voltage 61

4.10 System with negative-sequence protection when different phases from both lines have fault (a) phase voltage (b) phase current (c) RMS voltage 63

4.11 System without negative-sequence protection when one line is on outage (a) phase voltage (b) phase current (c) RMS voltage 64

4.12 System with negative-sequence protection when one line is on outage (a) phase voltage (b) phase current (c) RMS voltage 66

4.13 System without negative-sequence protection when both lines trip simultaneously (a) phase voltage (b) phase current (c) RMS voltage 68

4.14 System with negative-sequence protection when both lines trip simultaneously (a) phase voltage (b) phase current (c) RMS voltage 69

LIST OF ABBREVIATIONS

AC	-	Alternating current
APF	-	Active Power Filter
CT	-	Current transformer
DC	-	Direct current
DFIG	-	Double Fed Induction Generator
EMTDC	-	Electromagnetic Transient Program with DC Analysis
FACTS	-	Flexible AC Transmission System
FC-TCR	-	Fixed Capacitor Thyristor-Controlled Reactor
FFT	-	Fast Fourier Transform
HVDC	-	High Voltage Direct Current
IEEE	-	Institute of Electrical and Electronics Engineers
km	-	kilometer
kV	-	kilovolt
LL	-	line-to-line fault
LLG	-	line-to-line-to ground fault
LLL	-	line-to-line-to-line fault
MATLAB	-	Matrix Laboratory
MFC	-	Microsoft Foundation Class
MMF	-	magnetomotive force
MTA	-	characteristic angle of the transmission line
MVA	-	megavolt ampere
N_s	-	number of turn in the secondary coil
PCC	-	point of common coupling
PIR	-	Proportional Integral and Resonant Controller
PSCAD	-	Power System Computer Aided Design

PT	-	Potentional transformer
rpm	-	rotation per minute
rms	-	root mean square
SLG	-	single line-to-ground fault
SVC	-	Static Var Compensator

LIST OF SYMBOLS

E_a	-	Internal voltage
I_a^0	-	zero-sequence current for phase A
I_a^1	-	positive-sequence current for phase A
I_a^2	-	negative-sequence current for phase A
I_B	-	current for phase blue
I_R	-	current for phase red
I_Y	-	current for phase yellow
V_a^0	-	zero-sequence voltage for phase A
V_b^0	-	zero-sequence voltage for phase B
V_c^0	-	zero-sequence voltage for phase C
V_a^1	-	positive-sequence voltage for phase A
V_b^1	-	positive-sequence voltage for phase B
V_c^1	-	positive-sequence voltage for phase C
V_a^2	-	negative-sequence voltage for phase A
V_b^2	-	negative-sequence voltage for phase B
V_c^2	-	negative-sequence voltage for phase C
Z^0	-	zero-sequence impedance
Z^1	-	positive-sequence impedance
Z^2	-	negative-sequence impedance
Z_n	-	Grounding impedance
%	-	percentage

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Voltage and current at transmission lines during unbalance load	78
B	Voltage and current at transmission lines when Phase A at Transmission 1 has fault	81
C	Voltage and current at transmission lines when all phases at Transmission 1 have fault	84
D	Voltage and current at transmission lines when Phase A at both transmissions have fault	87
E	Voltage and current at transmission lines when Phase A at Transmission 1 and Phase C at Transmission 2 have fault	90
F	Voltage and current at transmission lines when Transmission 1 is on outage	93
G	Voltage and current at transmission lines when both network are trip	96

CHAPTER 1

INTRODUCTION

1.1 Introduction

The modern society has become to depend heavily upon continuous and reliable availability of electricity. With the constantly increase demand on electricity supply in both developing and developed country, the need to achieve an acceptable level of reliability, quality and safety at an economic price becomes more important to users. Safety on the electricity supply has become a vital part in any supply system. A well designed system followed with the proper maintenance can control the number of faults.

A fault will occur when a path of the load current is cut short due to breakdown of insulation. This situation is called 'short circuit'. The insulation may fail because of the following factors [1,2];

1. Ageing
2. Temperature
3. Rain, hail or snow
4. Chemical pollution

5. Foreign objects
6. Other causes.

Other than the factors stated above, overvoltage also become the reason of the insulation failure. Overvoltage can be divided into two; internal overvoltage which is due to the switching while external overvoltage is due to lightning. These situations contributing to an unbalance condition in the system and hence create unbalance current.

The unbalance current occurred from the unbalance condition of a system which resulted negative-phase sequence component called negative-sequence current [3,4]. The negative-sequence current which appears on generator terminal may downgrade their performance and even damage the generator [5,6,7]. The generator negative-sequence current can result from any unbalance conditions on the system including untransposed lines, unbalance type line faults, single-phase loads and open conductor. The negative-sequence current which are produced by untransposed lines and load unbalances for machines tied into the transmission network usually does not exceed 2 or 3 percent within the continuous capabilities of the generator [8].

The presence of negative-sequence current induces a current which double the system frequency in the rotor iron. This current will induce reverse direction flux in the air gap of a generator and hence produce negative torque which in turn causes vibration, increase the temperature and reduces the efficiency of a generator [6]. Even though every generator is capable of withstanding a certain level of negative-sequence current, but an excess amount and persistence of this current may cause rotor overheating and cause serious damage [9]. The overheating, which is caused by over currents also causes deterioration of the insulation, thus weakening it further [2].

The problems of negative-sequence current are rarely severe enough to endanger the operation of power system and the generator; however there are no effective methods to overcome this problem. Therefore, some of the utility companies tend to adopt more passive method, tripping and separating the generator from the system if negative-sequence current is higher from the predefined level [6]. However, tripping of major generation facilities may create social, security and economic problem.

1.2 Problem Statement

The appearance of negative-sequence current will induce reverse direction flux in the air gap of a generator and produced negative torque which in turn causes vibration, increases the operation temperature and reduces the efficiency of a generator. Negative-sequence component induced double frequency current in the field system and rotor body which produced large eddy current. Hence, severe and excessive heating will quickly heat the brass rotor slot wedges to the softening point. The extremely high internal short-circuit may result in severe heat and mechanical damage, whilst asynchronous magnetic field components may exceed the allowable design value and damage the rotor [10].

There are a lot of comprehensive study has been done about the negative-sequence component, but mostly are focused on the unbalance condition at the generator itself, but less study focused on unbalance occurring on the transmission line. The interaction of inductive and capacitive element in the network can produce resonance effects. This can lead to overvoltage and failure in the electrical equipments and hence the instability condition might appear. If the line is unbalance, it will have a negative-sequence component which will produce voltage in the generator with the higher harmonic [4]. The negative-sequence fault at the generator that occurs due to the unbalance condition at the transmission overhead line will cause the great financial loss to the country [11].

Traditionally, passive compensators have been used to compensate the negative-sequence current. However, their compensation is influenced by the load characteristics, and the passive element could introduce possible serial or parallel resonance with the source impedance. Besides, other types of protection such as over current protection also can eliminate the fault which is caused by several unbalance conditions.

Therefore, this project intends to investigate the performance of generator-negative sequence protection during different types of unbalance that occur at the parallel line network by using negative sequence relay as the protection device system.

1.3 Project Objectives

The objectives of this project are:

i. To simulate negative-sequence protection system using PSCAD/EMTDC software.
ii. To simulate and analyze the performance of generator negative-sequence protection using PSCAD/EMTDC software.
iii. To observe and analyze the performance of generator between the system with negative-sequence protection and the system without negative-sequence protection when unbalance conditions occur.
iv. To suggest the alternative techniques that can improve the performance of the generator.

1.4 Scopes of Project

The scopes of the project are:

i. To study the negative-sequence directional element for negative sequence protection.
ii. To apply different types of unbalanced conditions in the parallel network.
iii. To design medium transmission line system for the parallel network.
iv. To study the performance of the generator negative-sequence protection if unbalance conditions occur.

1.5 Methodology

In order to achieve the project objectives, the methodology is constructed and categorized into several stages as follows.

1. Literature reviews

In literature review, the current issues of negative-sequence component are reviewed. Besides, some discussion of the protection scheme and the unbalance conditions are investigated in order to get more information to complete this project. Most of the information comes from various types of sources such as journals, paper works, books and also from the internet. All the information gathered from the literature review is used to understand the problems that occur during the negative-sequence current. Therefore, literature review is the important stage in order to get some idea to meet the project's objectives.

2. Network construction using PSCAD

The design of network system is based on the requirement of the objectives and the scope of the project that require a parallel transmission line network as shown in Figure 1.1. In this design, the main part is to focus on the design of the negative-sequence protection system using negative-sequence directional element device. Most of the idea to design the system is gained from the PSCAD's examples itself and also from the previous papers and journals, but with some modification to suit with the project requirement.

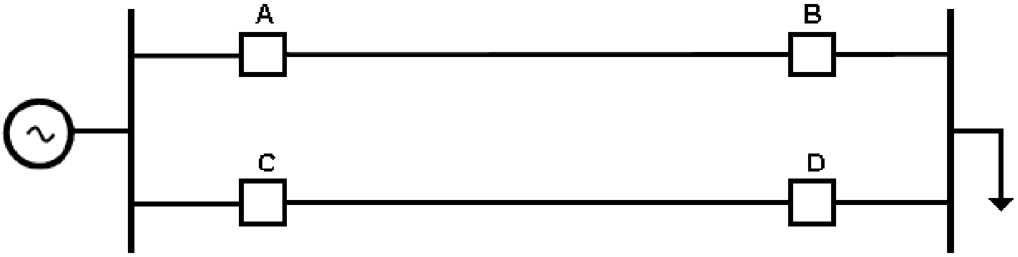

Figure 1.1 Example of parallel line system

3. Circuit simulation.

The generation negative-sequence protection designed is simulated using PSCAD/EMTDC software in order to investigate the performance of generator during unbalance conditions.

4. Design verification

The system that been designed is verified based on case study of the unbalance conditions. In the case study, fault location is setup based on single-phase fault. Then, the obtained results are recorded.

5. Report writing

Report writing is conducted in order to document the project's procedures and the results. All procedures involved is documented and explained in detail for understanding purposed.

Figure 1.2 shows the flow chart of research methodology in order to complete the research.

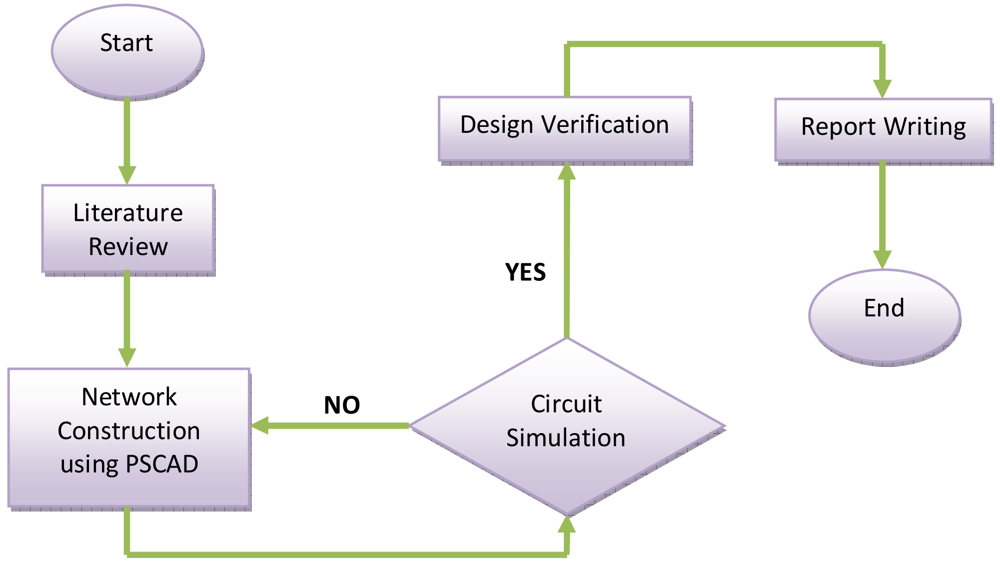

Figure 1.2 Flow chart of research methodology

1.6 Thesis Outline

This thesis consists of five chapters. In Chapter 1, project introduction is elaborated including the objectives and scopes of the project. In Chapter 2, the theory of unsymmetrical components, unbalance loads and phase fault and ground fault are discussed briefly. The theory about negative-sequence protection also been discussed in this chapter. Followed by Chapter 3 is the part where all designed systems using PSCAD/EMTDC software are discussed in detail. Subsequently, Chapter 4 is the result documentation of the generator's performance obtained from the case study. Finally, the project conclusion and future work recommendation is documented in Chapter 5.

REFERENCES

1. Prof. Ir. Dr. Abdullah Asuhaimi Mohd Zin. *Power System Protection*. Universiti Teknologi Malaysia, 2011
2. Paithankar, Y.G. and Bhide, S.R. *Fundamental of Power System Protection*. New Delhi: Prentice Hall of India.2007
3. Jeong, B.C. and Song, S.H. Torque Ripple Compensation Using Negative Sequence Current Control during Unbalanced Grid Conditions in a DFIG System. *Telecommunications Energy Conference 2009, INTELEC 2009, 31st International*. October 18-22, 2009. 1-5.
4. Ramirez, A., Semlyen, A., Iravani, R. Harmonic Domain Characteristic of the Resonant Interaction between Generator and Transmission Line. *IEEE Transactions on Power Delivery*. 2005. 20(2):1753-1762.
5. Pollard, E.I. Effect of Negative-Sequence Currents on Turbine-Generator Rotors. *Presentation at the AIEE Winter General Meeting*. January 19-23, 1953. New York: AIEE Committee. 1953. 53-96
6. Ding. H.F., Duan, X.Z. and Shi, D.Y. Use of a Single-Phase Active Power Filter for Generator Negative Sequence Current Reduction. *Power Engineering Society General Meeting,* 2003. 1(0): 4.
7. Lee, W.J., Ho, T.Y., Liu, J.P and Liu, Y.H. Negative Sequence Current Reduction for Generator/Turbine Protection. *Industry Application Society Annual Meeting 1993, Conference record of the 1993 IEEE*. 1993. 2(0): 1428-1433.
8. Graham, D.J. , Brown, P.G. and Winchester, R.L. Generation Protection with a New Static Negative Sequence Relay. *Power Apparatus and System, IEEE Transaction on*. 1975. 94(4): 1208-1213.

9. Chen, J.H., Lee, W.J and Chen, M.S. Use of a Static Var Compensator for Generator Negative-Sequence Current Reduction. *Electric Power System Research*. 1996. 38(3): 183-190.

10. Liangliang, H., Yuguang, S. and Arui, Q. Analysis on the Negative Sequence Impedance Directional Protection for Stator Internal Fault of Turbo Generator. *Electrical Machines and Systems (ICEMS), 2010 International Conference on*. October 10-13, 2010. 1421-1424.

11. Zin, A. A. M and Karim, S.P.A. The Application of Fault Signature in Tenaga National Berhad Malaysia. Power Delivery, *IEEE Transaction on*. 2007. 22(4): 2047-2056.

12. Grainger, J.J. and Stevenson,Jr., W. D. *Power System Analysis*. Singapore: McGraw-Hill. 1994

13. Wang, J. and Hamilton, R. A review of Negative Sequence Current. *Protective Relay Engineers, 2010 63rd Annual Conference for*. March 29-April 1, 2010. 1-18.

14. Muljadi, E., Yildirim, D., Batan, T. and Butterfield, C.P. Understanding the Unbalanced-Voltage Problem in Wind Turbine Generation. Industry. *Industry Applications Conference, 1999. Thirty-Fourth IAS Annual Meeting. Conference Record of the 1999 IEEE*. 1999. 2(0): 1359-1365.

15. Gers, J.M. and Holmes, E.J. *Protection of Electricity Distribution Networks*. 2nd edition. London: The Institution of Electrical Engineers. 2004

16. Negative Phase Sequence Relay. March 2009. Available at http://www.circuitmaniac.com/. (26 January 2012)

17. Fleming, B. (1998). *Negative Sequence Impedance Directional Element*. Unpublished note. Schweitzer Engineering Laboratories, Inc.

18. PSCAD Electromagnetic Transient User's Guide, The Professional's Tool for Power System Simulation. Version 4.2.

19. Cedrat Groupe (2008). *PSCAD Power System Simulator*. [Brochure]. France: Cedrat.

20. Apostolov, A., Tholomier, D., Sambasivan, S. and Richards, S. Protection of Double Circuit Transmission Lines. *Protective Relay Engineer, 2007 60th Annual Conference for*. March 27-29, 2007. 85-101.

21. Jha, B. and Rao, K.R.M. Compensation Techniques for Improving FRT Capability of DFIG. *International Journal of Engineering Science and Technology (IJEST)*. 2011. 3(1): 514-524.

22. Zhang, H., He, J., Li, B. and Bo, Z. An Improved Transformation Protection Scheme Based on Integrated Protection System. *Universities Power Engineering Conference (UPEC), 2009 Proceedings of the 44th International*. September 1-4, 2009. 1-4