UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

STUDIES BETWEEN CLARKE TRANSFORMATION AND SYMMETRICAL COMPONENTS FOR FAULT ANALYSIS OF POWER DISTRIBUTION SYSTEM USING PSCAD

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Master of Electrical Engineering
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STUDIES BETWEEN CLARKE TRANSFORMATION AND SYMMETRICAL COMPONENTS FOR FAULT ANALYSIS OF POWER DISTRIBUTION SYSTEM USING PSCAD

ALI ABDULHASAN ABDULZAHRA

A dissertation submitted
in partial fulfillment of the requirements for the degree of Master of Electrical Engineering (Industrial Power)

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2016

DECLERATION

I declare that this research entitle "Comparative Studies between Clarke Transformation and Symmetrical Components for Fault Analysis of Power Distribution System using PSCAD " is the result of my own research except as cited in the references. The research has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……. ....

Name : Ali Abdulhasan Abdulzahra

Date : ……. ....

APPROVAL

I hereby declare that I have read this research and in my opinion this report is sufficient in terms of scope and quality as a partial fulfillment of Master of Electrical Engineering (Industrial Power).

Signature	:	....
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Date	:	....

DEDICATION

To my beloved parents, and my dear wife

ABSTRACT

Fault analysis studies are essential analytic tool for designing and planning of power systems. They are considered the most important and complicated matter in power engineering. Customarily, analyzing of power systems under fault conditions is restricted to using of Symmetrical Components method although there is another useful method such as Clarke Transformation. This research presents performing theoretical and simulation fault analysis studies for low voltage distribution system using both Symmetrical Components and modified Clarke Transformation methods, comparing between both techniques, and highlighting the interrelation between them. This research gives a general derivations of equivalent circuits for various operating conditions in power system based on modified Clarke Transformation. A comprehensive theoretical fault analysis for 3-PH, 3-PH-G, S-L-G, L-T-L, and D-L-G fault conditions in power distribution system have been implemented based on Symmetrical Components and modified Clarke Transformation. Moreover, simulation fault analysis studies using PSCAD/EMTDC Software are presented in this research for performing the fault conditions using both methods. The findings of this research show some advantages for using Clarke Transformation method in fault analysis compared to using Symmetrical Components. Analysis results show that Clarke Transformation provides easier solution and equivalent circuits for most of fault conditions. Furthermore, simulation results show that fault conditioning provided by Clarke Transformation is clearer and simpler than thus provided by Symmetrical Components.

ABSTRAK

Kajian analisis kerosakan merupakan analisis penting untuk mereka bentuk dan perancangan bagi sistem kuasa. Ianya dianggap perkara yang paling penting dan rumit dalam bidang kejuruteraan kuasa. Lazimnya, menganalisis sistem kuasa di bawah keadaan kerosakan adalah terhad dengan menggunakan kaedah Komponen Simentri walaupun terdapat kaedah lain yang berguna seperti Transformasi Clarke. Kajian ini membentangkan pelaksanaan secara teori dan analisis simulasi kerosakan untuk sistem pengagihan voltan rendah dengan menggunakan kedua-dua kaedah iaitu Komponen Simetri dan Transformasi Clarke yang telah diubahsuai, perbandingan antara kedua-dua teknik, dan hubungkait di antara keduanya ditekankan. Kajian ini memberikan terbitan umum litar setara bagi pelbagai keadaan operasi dalam sistem kuasa berdasarkan Transformasi Clarke yang telah diubah suai. Sebuah analisis komphrehensif mengenai teroi kerosakan untuk 3-PH, 3-PH-G, S-L-G, L-T-L, dan keadaan kerosakan D-L-G dalam sistem pengagihan kuasa telah dilaksanakan berdasarkan kaedah Komponen Simetri dan Transformasi Clarke yang telah diubah suai. Selain itu, kajian simulasi analisis kerosakan menggunakan perisian PSCAD / EMTDC Software juga dibentangkan dalam kajian ini untuk melaksanakan keadaan kerosakan menggunakan kedua-dua kaedah tersebut. Dapatan kajian ini menunjukkan beberapa kelebihan menggunakan kaedah Transformasi Clarke dalam analisis kerosakan berbanding menggunakan Komponen Simetri. Keputusan analisis menunjukkan bahawa Transformasi Clarke memberikan penyelesaian yang mudah dan litar setara bagi kebanyakan keadaan kerosakan. Tambahan pula, keputusan simulasi menunjukkan bahawa keadaan kerosakan diberikan oleh Transformasi Clarke adalah lebih jelas dan lebih mudah daripada kaedah Komponen Simetri.

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LIST OF ABBREVIATIONS

3-PH	-	Three-Phase
S-L-G	-	Single-Line-to-Ground
D-L	-	Line-to-Line
D-L-G	-	Double-Line-to-Ground
0-1-2	-	Symmetrical Sequence Components
0	-	Zero Sequence Component
1	-	Positive Sequence Component
2	-	Negative Sequence Component
0-α-β	-	Clarke Transformation Components
PSCAD	-	Power System Computer Aided Design
//	-	Parallel connection of impedances
Y / Δ	-	Star / Delta Connection

LIST OF SYMBOLS

V_a, V_b, V_c	-	Phase Voltages of Phases a, b and c in phasor form
v_a, v_b, v_c	-	Phase Voltages of Phases a, b and c in instantaneous form
V_{ab}, V_{bc}, V_{ca}	-	Line Voltages of Phases a, b and c in phasor form
V_{af}, V_{bf}, V_{cf}	-	Phase Voltages of Phases a, b and c during Fault Condition
V_0, V_1, V_2	-	Zero, Positive, and Negative sequence Voltages in phasor form
V_0, V_α, V_β	-	Zero, Alpha, and Beta Voltage Components in phasor form
v_0, v_α, v_β	-	Zero, Alpha, and Beta Voltage Components in instantaneous form
V_{0f}, $V_{\alpha f}$, $V_{\beta f}$	-	Zero, Alpha, and Beta Voltage Components during Fault Condition
I_a, I_b, I_c	-	Phase Currents of Phases a, b and c in phasor form
i_a, i_b, i_c	-	Phase Currents of Phases a, b and c in instantaneous form
I_{af}, I_{bf}, I_{cf}	-	Phase Currents of Phases a, b and c during Fault Condition
I_0, I_1, I_2	-	Zero, Positive, and Negative sequence Currents in phasor form

I_0, I_α, I_β - Zero, Alpha, and Beta Current Components in phasor form

i_0, i_α, i_β - Zero, Alpha, and Beta Current Components in nstantaneous form

I_{0f}, $I_{\alpha f}$, $I_{\beta f}$ - Zero, Alpha, and Beta Current Components during Fault Condition

[S] - Symmetrical Transformation Matrix

$[S]^{-1}$ - Invers Symmetrical Transformation Matrix

[C] - Clarke Transformation Matrix

$[C]^{-1}$ - Invers Clarke Transformation Matrix

[A] - Forward Linear Transformation Matrix

$[A]^{-1}$ - Invers Linear Transformation Matrix

S_{abc} - Complex Power in an original System

S_{ABC} - Complex Power in an Transformed System

S_{012} - Complex Power in Symmetrical Components Coordinate

$S_{0\alpha\beta}$ - Complex Power in Clarke Transformation Coordinate

pu - Per-Unit

V_b - Base Voltage in Three Phase System

V_F - Phase Voltage at the Fault Point

V_R - Rated Voltage at a certain Point

I_b - Base Current in Three Phase System

S_b - Base MVA in Three Phase System

S_{pu} - Per-Unit Power in Three Phase System

Z_{pu} - Per-Unit Impedance in Three Phase System

V_{pu}	-	Per-Unit Voltage in Three Phase System
I_{pu}	-	Per-Unit Current in Three Phase System
a	-	Operator = $1\angle 120^{\circ}$
$S_{3\Phi}$	-	Complex Power in Three Phase System
$P_{3\Phi}$	-	Real Power in Three Phase System
$Q_{3\Phi}$	-	Reactive Power in Three Phase System
*	-	conjucate
t	-	Transpose
$Q_{3\Phi}$	-	Reactive Power in Three Phase System
Z	-	Impedance
Z_L	-	Load Impedance
Z_s	-	Source Impedance
Z_T	-	Transformer Impedance
Z_C	-	Cable Impedance
X	-	Reactance
X_L	-	Load Reactance
X_s	-	Source Reactance
X_T	-	Transformer Reactance
X_C	-	Cable Reactance
R	-	Resistance
R_L	-	Load Resistance
R_s	-	Source Resistance
R_T	-	Transformer Resistance
R_C	-	Cable Resistance

Z_{eq}	-	Equivalent Impedance
Z_0, Z_1, Z_2	-	Zero, Positive, and Negative sequence Impedance
V	-	Volt
A	-	Amper
kV	-	Kilo Volt
kA	-	Kilo Amper
kVA	-	Kilo Volt Amper
MVA	-	Mega Volt Amper
Ω	-	Ohm

CHAPTER 1

INTRODUCTION

1.1 Background

Fault studies are considered the essential analytic tool for electric power systems. Planning and installing of power systems requires implementing these studies to determine the maximum and minimum fault currents and voltages at different parts of power system for various fault conditions (Kasibama, 1993). Based on fault study's results, the appropriate protective schemes, circuit breakers, and relays can be selected in order to protect the power system against abnormal operation conditions within minimum time (Paithankar, and Bhide, 2010; Abouelenin, 2002). Obviously, withstanding capabilities of electrical power system's equipment and settings of protective relays are determined according to fault analysis results (Mubarak et al., 2015).

Most faults are frequently occurred in distribution power systems in the form of short-circuiting either to the earth or among live conductors. Almost, these faults consequently cause excessive currents flowing through the short-circuited path which potentially result in overheating, conductor melting, circuit damage, explosion or fire (Oldham-Smith and Madden, 2008; Godse and Bakshi, 2010). Short-circuits are usually caused by equipment damage, flash-over, insulation failure, heavy winds, birds, trees falling on live lines, kites, and human errors (Hambley, 2005). Commonly, short-circuits can be classified into: three-phase, three-phase-to-ground, phase-to-phase, phase-to-phase-to-ground, and single-phase-to-ground (Sousa Martins et al., 2005).

Fault analysis is usually grouped into symmetrical and asymmetrical fault analysis based on the fault types mentioned above (Adepoju et al., 2013) . The first two types of faults are called symmetrical faults because they cause equal currents flowing through the system phases so that the power system can be analyzed by simple single-phase circuit representation. However, the other types of faults are called asymmetrical faults because of the unequal currents flowing through system phases caused by these types of faults.

The power system under unbalanced conditions cannot be analyzed by simple single phase circuit representation. For this reason, the three phase circuit representation is always very complicated to analyze, even for smaller system models, so the analysis of the three phase circuit is practically impossible and cannot be obtained. Therefore, alternative technique is required to analyze the power systems under these conditions that is symmetrical components technique, which was originally developed by Charles Legeyt Fortescue in 1918.

The symmetrical components technique is considered a type of variables transformation tool from a mathematical perspective. It can provide a good way to simplify and express three phase circuit by analytical equivalent circuits (Hase, 2013). It can express three electrical quantities in a-b-c three phase system by set of three variables named positive (1), negative (2), and zero (0) sequence quantities in 0-1-2 coordinate. Therefore, the power system quantities a-b-c can be transformed into the 0-1-2 quantities for simplifying the analysis process. Then, the obtained solution and results in the 0-1-2 coordinate can be retransformed into the original a-b-c quantities. It can be said that this technique is considered the essential analytical technique for the power system fault analysis that commonly used by designers and engineers. However, the symmetrical sequence components is not always the best method for solving unbalanced power system problems (Rao et al., 1966).

There is also another transformation can be useful in power system fault analysis that is Clarke Transformation. This transformation can be used to transform a-b-c quantities into 0-α-β coordinate. According to (Hase, 2013), Clarke Transformation can be considered a complementary analytic tool of Symmetrical Components. Moreover, in some special applications such as transient phenomena, 0-α-β components provide easier solutions for the problems for which Symmetrical Sequence Components cannot give good solutions (Hase, 2013). Nowadays, Clarke Transformation tool is widely used in power system protection, fault detection and recognition, and control.

This research aims to examine using of both symmetrical components and Clarke transformation in distribution power system fault analysis and point out the specifications, differences, and advantages of each technique analytically and by simulation through PSCAD/EMTDC software. In addition, this study aims to find out the interrelation between the symmetrical components in 0-1-2 coordinate and Clarke components in 0-α-β coordinate.

1.2 Motivation for Research

Fault analysis studies are crucial. It provides important information, which is necessary for relay setting, circuit breaker selection, and the power system stability (Gungor, 1988; Kakilli, 2013). It usually involves unbalanced conditions of power system operation. Unsymmetrical analysis is usually carried out using symmetrical components (0-1-2). However, Clarke Transformation (0-α-β) may provide easier solutions for