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

Ali Abdulhasan Abdulzahra

Master of Electrical Engineering
(Industrial Power)

2016
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)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016
DECLARATION

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 : ….. ..................................
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 : ..........................................................
Supervisor Name : Prof. Dr. Marizan Bin Sulaiman
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

ACKNOWLEDGEMENT

First and foremost, all praises and thanks to ALLAH, the almighty. Alhamdulillah, and peace and blessings of ALLAH be upon the last Prophet Mohamed S.A.W. I am ever grateful to HIS endless blessings throughout my research work which is the main reason behind the success for the completion of this research.

I would like to express my deepest gratitude and appreciation to Engr. Professor Dr. Marizan bin Sulaiman, my supervisor, from Faculty of Electrical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his encouragement, patience, and guidance during my study.

I am extremely grateful to my beloved parents for their love and prayers. I am also very much thankful to my wife for her love, understanding, prayers and continuing support to complete this research work. My sincere thanks to my family, my relatives, and friends who all gave me courage and support.

I would like to thank Ministry of Electricity/Republic of Iraq (MOE) and general directorate of electrical distribution for the south for the financial support during my study in Malaysia.

Finally, I am extending my thanks to all the people who have supported me to complete the research work directly or indirectly.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>DECLARATION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td></td>
</tr>
<tr>
<td>APPROVAL</td>
<td></td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td>xiii</td>
</tr>
</tbody>
</table>

## CHAPTER

1. INTRODUCTION  1
   1.1 Background  1
   1.2 Motivation of Research  3
   1.3 Problem Statement  4
   1.4 Objectives of Research  4
   1.5 Scope of Research  5
   1.6 Contribution of Research  6
   1.7 Organization of Research  7

2. LITERATURE REVIEW  9
   2.1 Introduction  9
   2.2 Fault Analysis  9
   2.3 Symmetrical Sequence Components  11
      2.3.1 Fundamental Concept of Symmetrical Components  11
      2.3.2 Definition and Theory of Symmetrical Components  13
      2.3.2 Operator a  15
      2.3.2 Power Calculation in Symmetrical Components  16
   2.4 Fault Analysis Using Symmetrical Components  17
      2.4.1 Three-Phase Fault  19
      2.4.2 Single-Line-to-Ground Fault  21
      2.4.3 Line-to-Line Fault  22
      2.4.4 Double-Line-to-Ground Fault  24
   2.5 Clarke Transformation  25
      2.5.1 Concept of Clarke Transformation  25
      2.5.2 Clarke Transformation In Fault Analysis  30
      2.5.3 Applications of Clarke Transformation in Power System  34
      2.5.4 Modified Clarke Transformation  35
   2.6 Linear Transformation and Power Invariant Requirement  36
      2.6.1 Linear Transformation Concept  36
      2.6.2 Power Invariant Requirement  38
   2.7 Per-Unit Calculations in Fault Analysis  39
2.7.1 Per-Unit System
2.7.2 Three-Phase System Analysis
2.7.3 Change of Base
2.8 Using of Power System Computer Aided Design in Fault Analysis
2.8.1 Definition of Power System Computer Aided Design
2.8.2 The PSCAD Environment
2.8.3 The Implementations of PSCAD/EMTDC in Fault Analysis
2.9 Summary

3. RESEARCH METHODOLOGY
3.1 Introduction
3.2 Research Procedure
3.3 Power Invariant Requirement
3.3.1 Symmetrical Sequence Components under Power Invariant requirement
3.3.2 Clarke Transformation under Power Invariant Requirement
3.4 Interrelation between Clarke Transformation and Symmetrical Components
3.5 Interrelation between Clarke Voltage and Current Components
3.6 Interrelation between Clarke and Sequence Impedance Matrices
3.7 Equivalent Circuits of 0-α-β Components
3.7.1 Normal Balanced Condition
3.7.2 Balanced Fault Condition
3.7.3 Single-Line-to-Ground Fault Condition
3.7.4 Line-to-Line Fault Condition
3.7.5 Double-Line-to-Ground Fault Condition
3.8 Fault Circuit Analysis Event
3.8.1 Analyzing using Real Values
3.8.1.1 Fault Analysis Using Symmetrical Sequence Components
3.8.1.1.1 Three Phase-to-Ground Fault
3.8.1.1.2 Single-Line-to-Ground fault
3.8.1.1.3 Line-to-Line Fault
3.8.1.1.4 Double-Line-to-Ground fault
3.8.1.2 Fault Analysis Using Clarke Transformation
3.8.1.2.1 Three Phase Fault Condition
3.8.1.2.2 Single-Line-to-Ground fault
3.8.1.2.3 Line-to-Line Fault
3.8.1.2.4 Double-Line-to-Ground fault
3.8.2 Analyzing Using Per Unit Values
3.8.2.1 Fault Analysis Using Symmetrical Sequence Components
3.8.2.1.1 Three Phase Fault Condition
3.8.2.1.2 Single-Line-to-Ground Fault
3.8.2.1.3 Line-to-Line Fault
3.8.2.1.4 Double-Line-to-Ground fault
3.8.2.2 Fault Analysis Using Interrelation Formulas

3.8.2.2.1 Three Phase Fault Condition

3.8.2.2.2 Single-Line-to-Ground Fault

3.8.2.2.3 Line-to-Line Fault

3.8.2.2.4 Double-Line-to-Ground fault

3.9 Assessment and Comparison between both Techniques

3.10 Summary

4. RESULTS AND DISCUSSION

4.1 Introduction

4.2 Case for Simulation Study

4.2.1 Creating New Components

4.3 Normal Steady State Operation Condition

4.4 Continuous Fault Conditions

4.4.1 Three-Phase Fault

4.4.2 Three-Phase-to-Ground Fault

4.4.3 Single-Line-to-Ground Fault

4.4.4 Line-to-Line Fault

4.4.5 Double-Line-to-Ground Fault

4.5 Fault Conditions with Clearing Time

4.5.1 Three-Phase Fault

4.5.2 Three-Phase-to-Ground Fault

4.5.3 Single-Line-to-Ground Fault

4.5.4 Line-to-Line Fault

4.5.5 Double-Line-to-Ground Fault

4.6 Discussion of Simulation Results

4.7 Chapter Summary

5. CONCLUSION

5.1 Conclusion

5.2 Attainment of Research Objectives

5.3 Significance of Research Outcomes

5.4 Suggestions for Future Research

REFERENCES

LIST OF APPENDICES
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Relation between $0$, $\alpha$, and $\beta$ Components of Voltages and Currents during Faults In Three Phase Power System</td>
<td>30</td>
</tr>
<tr>
<td>3.1</td>
<td>The Scalar Relation between Fault Currents and Clarke Current Components</td>
<td>109</td>
</tr>
<tr>
<td>3.2</td>
<td>Clarke and Symmetrical Components’ Specifications at Different Fault Conditions</td>
<td>105</td>
</tr>
<tr>
<td>4.1</td>
<td>Fault Recognition based on Clarke Components Specifications</td>
<td>157</td>
</tr>
<tr>
<td>4.2</td>
<td>Fault Recognition based on Symmetrical Components Specifications</td>
<td>158</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Types of Faults</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>Decomposing of Phases a-b-c Quantities Into Their Sequence Components</td>
<td>12</td>
</tr>
<tr>
<td>2.3</td>
<td>Phasor Diagram of Various Powers and Functions of Operator A</td>
<td>16</td>
</tr>
<tr>
<td>2.4</td>
<td>Equivalent Circuits Of Balanced Power System in a-b-c Coordinate</td>
<td>19</td>
</tr>
<tr>
<td>2.5</td>
<td>0-1-2 Network Connection During Three-Phase Fault Condition</td>
<td>20</td>
</tr>
<tr>
<td>2.5</td>
<td>0-1-2 Network Connection During Single-Phase-To-Ground Fault Condition</td>
<td>22</td>
</tr>
<tr>
<td>2.7</td>
<td>0-1-2 Network Connection During Line-To-Line Fault Condition</td>
<td>23</td>
</tr>
<tr>
<td>2.8</td>
<td>0-1-2 Network Connection During Double-Line-To-Ground Fault Condition</td>
<td>25</td>
</tr>
<tr>
<td>2.9</td>
<td>The 0αβ-Component Currents Through Power System During Single-Line-To-Ground Fault Condition</td>
<td>26</td>
</tr>
<tr>
<td>2.10</td>
<td>Graphical Representation of Clarke Transformation</td>
<td>29</td>
</tr>
<tr>
<td>2.11</td>
<td>Equivalent Circuit of 0-α-β Components and It’s Network Connections During Various Fault Conditions</td>
<td>32</td>
</tr>
<tr>
<td>3.1</td>
<td>Flowchart of the Research Procedure</td>
<td>47</td>
</tr>
<tr>
<td>3.2</td>
<td>Flowchart of Implementation of Fault Analysis</td>
<td>94</td>
</tr>
<tr>
<td>3.3</td>
<td>Equivalent Circuits of Power System in 0-1-2 and 0-α-β Coordinates</td>
<td>63</td>
</tr>
<tr>
<td>3.4</td>
<td>0-α-β Networks Connection During Three-Phase Fault Condition</td>
<td>65</td>
</tr>
<tr>
<td>3.5</td>
<td>0-α-β Networks Connection During Single-Line-To-Ground Fault Condition</td>
<td>66</td>
</tr>
<tr>
<td>3.6</td>
<td>0-α-β Networks Connection During Line-To-Line Fault Condition</td>
<td>68</td>
</tr>
<tr>
<td>3.7</td>
<td>0-α-β Networks Connection During Double-Line-To-Ground Fault Condition</td>
<td>70</td>
</tr>
<tr>
<td>3.8</td>
<td>Fault Analysis on Power Distribution System Configuration</td>
<td>71</td>
</tr>
<tr>
<td>3.9</td>
<td>The Positive Sequence Network for Per-Unit Analysis</td>
<td>79</td>
</tr>
<tr>
<td>3.10</td>
<td>Sequence Networks Connection for S-L-G Fault</td>
<td>75</td>
</tr>
</tbody>
</table>
3.11 Sequence Networks Connection for D-L-G Fault
3.12 Sequence Networks Connection for D-L-G Fault
3.13 Power System Representation With Base Voltage Indication
3.14 The Positive Sequence Network during Three-Phase Fault Condition
4.1 The System Configuration in PSCAD
4.2 Clarke Transformation Component With Its Script in PSCAD
4.3 Inverse Clarke Transformation Component With Its Script in PSCAD
4.4 Clarke Transformation Component With Phasor Sequence Components
4.5 Component for Instantaneous Symmetrical Components in PSCAD
4.6 Current Waveforms for a-b-c System, Sequence Components, and 0-α-β Coordinates at Normal Load Condition
4.7 Voltage Waveforms for a-b-c System, Sequence Components, and 0-α-β Coordinates at Normal Load Condition
4.8 Current Waveforms for a-b-c System, Sequence Components, and 0-α-β Coordinates at 3-Ph Fault Condition
4.9 Voltage Waveforms for a-b-c System, Sequence Components, and 0-α-β Coordinates at 3-Ph Fault Condition
4.10 Current Waveforms for a-b-c System, Sequence Components, and 0-α-β Coordinates at 3-Ph-G Fault Condition
4.11 Voltage Waveforms for a-b-c System, Sequence Components, and 0-α-β Coordinates at 3-Ph-G Fault Condition
4.12 Current Waveforms In a-b-c System, Sequence Components, and 0αβ Coordinates at S-L-G Fault Condition
4.13 Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at S-L-G Fault Condition
4.14 Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at D-L Fault Condition
4.15 Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at D-L Fault Condition
4.16 Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinate at D-L-G Fault Condition
4.17 Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β- Coordinates at D-L-G Fault Condition
4.18 Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at 3-Ph Fault Condition With Fault Clearing Time 0.2 Second

4.19 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After 3-Ph Fault Ocurring

4.20 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After 3-Ph Fault Clearing

4.21 Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at 3-Ph Fault Condition With Fault Clearing Time 0.2 Second

4.22 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After 3-Ph Fault Ocurring

4.23 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After 3-Ph Fault Clearing

4.24 Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at 3-Ph-G Fault Condition With Fault Clearing Time 0.2 Second

4.25 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After 3-Ph-G Fault Ocurring

4.26 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After 3-Ph-G Fault Clearing

4.27 Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at 3-Ph-G Fault Condition And Fault Clearing Time 0.2 Second

4.28 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After 3-Ph-G Fault Incident

4.29 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After 3-Ph-G Fault Clearing

4.30 Current Components In a-b-c System, Sequence Components, and 0-α-β Coordinates at S-L-G Fault Condition With Fault Clearing Time 0.2 Second

4.31 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After S-L-G Fault Ocurring

4.32 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After S-L-G Fault Clearing

4.33 Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at S-L-G Fault Condition With Fault Clearing Time 0.2 Second

4.34 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After S-L-G Fault Ocurring
4.35 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After S-L-G Fault Clearing
4.36 Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at D-L Fault Condition With Fault Clearing Time 0.2 Second
4.37 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After D-L Fault Ocurring
4.38 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After D-L Fault Clearing
4.39 Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at D-L Fault Condition With Fault Clearing Time 0.2 Second
4.40 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After D-L Fault Ocurring
4.41 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After D-L Fault Clearing
4.42 Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinate at D-L-G Fault Condition With Fault Clearing Time 0.2 Second
4.43 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After D-L-G Fault Ocurring
4.44 Transient Current Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After D-L-G Fault Clearing
4.45 Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates at D-L-G Fault Condition With Fault Clearing Time 0.2 Second
4.46 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After D-L-G Fault Ocurring
4.47 Transient Voltage Waveforms In a-b-c System, Sequence Components, and 0-α-β Coordinates After D-L-G Fault Clearing
### LIST OF ABBREVIATIONS

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

$V_0, V_\alpha, V_\beta$ - Zero, Alpha, and Beta Voltage Components in phasor form

$v_0, v_\alpha, v_\beta$ - Zero, Alpha, and Beta Voltage Components in instantaneous form

$V_{0f}, V_{af}, V_{bf}$ - 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 instantaneous form
I_{0f}, I_{αf}, I_{βf} - 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_{0αβ} - 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°

\( S_{3\phi} \) - Complex Power in Three Phase System

\( P_{3\phi} \) - Real Power in Three Phase System

\( Q_{3\phi} \) - Reactive Power in Three Phase System

* - Conjugate

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
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z_{eq}$</td>
<td></td>
<td>Equivalent Impedance</td>
</tr>
<tr>
<td>$Z_0, Z_1, Z_2$</td>
<td></td>
<td>Zero, Positive, and Negative sequence Impedance</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td>Volt</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td>Amper</td>
</tr>
<tr>
<td>kV</td>
<td></td>
<td>Kilo Volt</td>
</tr>
<tr>
<td>kA</td>
<td></td>
<td>Kilo Amper</td>
</tr>
<tr>
<td>kVA</td>
<td></td>
<td>Kilo Volt Amper</td>
</tr>
<tr>
<td>MVA</td>
<td></td>
<td>Mega Volt Amper</td>
</tr>
<tr>
<td>Ω</td>
<td></td>
<td>Ohm</td>
</tr>
</tbody>
</table>
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