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**ANALYSIS AND DEVELOPMENT OF GRID CONNECTED FRONT-END  
AC TO DC CONVERTER USING VOLTAGE ORIENTED CONTROL (VOC)**

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**A report submitted in partial fulfilment of the requirements for the degree of  
Electrical Engineering (Power Electronic and Drives)**

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## STUDENT DECLARATION

I declare that this report entitled “Analysis and Development of Grid Connected Front-End Ac to Dc Converter Using Voltage Oriented Control (VOC)” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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## **DEDICATION**

To my beloved mother and father  
I will not complete without both of you

## ACKNOWLEDGEMENT

In this moment, I would like to give big thanks and express my sincere appreciation to my supervisor, Dr. Azziddin bin Mohamad Razali, for his encouragement and guidance throughout this project. I was so grateful as he keeps on motivate and give advice that contribute to the completion of this report.

Besides, I would like to thank my beloved family as they support my project and until the end. Other than that, I am grateful to have my colleagues that help me with many ideas and tips on doing this project. Unfortunately, it is possible for me to list all of them in this limited space.

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## ABSTRACT

This project is about the analysis and development of grid connected front end AC to DC converter using Voltage Oriented Control (VOC). Nowadays, the use of power electronic converters in industry are kept expanding. In industry, there is a problem in transmission and distribution lines as the harmonic and reactive currents are being injected into the system. Therefore, in electric power system, voltage control is important for proper operation for electrical power equipment. This is important to prevent any damage that might occur. Besides, the input current with non-sinusoidal shape drawn by conventional AC to DC converter generates significant harmonic components. The current harmonic components increase the current consumption and increase the power loss of utility equipment. As a result, overheating might happen in the generator and motor windings and the transmission line. One of the control methods for AC to DC converter is VOC. VOC controls the active and reactive power between grid and load by controlling approximately the three phase line currents and magnitude of the converter DC output voltage. Sinusoidal Pulse Width Modulation (SPWM) is used to determine the switching state of the converter. In addition, matrix transformations like Clarke Transformation, Park Transformation, Inverse Clarke Transformation and Inverse Park Transformation are used to simplify the development of the control method. The steady state performance and Total Harmonic Distortion (THD) of the line currents are analysed before and after the implementation of VOC method. The operation is kept at unity power factor with lower current THD. In a nutshell, by using VOC method, the three-phase input currents and voltages are almost in sinusoidal shape. Finally, a regulated DC power supply utilizing three-phase AC to DC converter can be constructed.

## ABSTRAK

*Projek ini adalah mengenai analisis dan perubahan terhadap grid yang bersambung dari hujung AC sampai ke hujung DC dengan menggunakan Kawalan Berorientasikan Voltan (VOC). Pada masa kini, penggunaan kuasa penukar eletronik dalam industri terus berkembang. Dalam industri ini, terdapat masalah dalam talian penghantaran dan pengedaran sebagai arus yang harmoni dan reaktif yang bersambung dalam sistem. Oleh itu, dalam sistem kuasa elektrik, kawalan voltan adalah penting untuk operasi yang betul untuk peralatan kuasa elektrik. Hal ini sangat penting bagi mengelakkan sebarang kerosakan yang mungkin berlaku. Selain itu, arus masuk dalam bentuk sinusoidal yang dibentuk oleh konvensional AC kepada penukar DC menghasilkan komponen harmoni yang ketara. Ini menyebabkan terdapat peningkatan terhadap voltan peralatan utiliti. Komponen harmoni semasa meningkatkan penggunaan semasa dan meningkatkan kehilangan kuasa peralatan utiliti. Akibatnya, pemanasan melampau mungkin berlaku di penjana dan litar motor dan talian penghantaran. Salah satu kaedah kawalan AC untuk penukar DC ialah VOC. VOC mengawal kuasa aktif dan reaktif antara grid dan beban dengan mengawal kira-kira arus tiga arus fasa dan magnitud voltan keluar penukar DC. Modulasi Lebar Pulse Sinusoidal (SPWM) digunakan dengan menggunakan fungsi MATLAB. Di samping itu, matrik transformasi seperti Transformasi Clarke, Transformasi Park, Transformasi Songsang Clarke dan Transformasi Songsang Park digunakan untuk mempermudah pembangunan kaedah kawalan. Kedudukan prestasi yang mantap dan Jumlah Masalah Harmoni (THD) arus elektrik dianalisis sebelum dan selepas pelaksanaan kaedah VOC. Operasi dikekalkan pada faktor kuasa satu dengan THD elektrik yang lebih rendah. Akhir sekali, dengan menggunakan kaedah VOC, arus dan tegangan masuk elektrik dan voltan tiga fasa hampir mencapai bentuk sinusoidal. Akhir sekali, bekalan kuasa DC yang dikawal menggunakan tiga fasa penukar AC ke DC boleh dibina.*

## TABLE OF CONTENT

	<b>Page</b>
<b>ACKNOWLEDGEMENT</b>	<b>ii</b>
<b>ABSTRACT</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>v</b>
<b>LIST OF TABLES</b>	<b>viii</b>
<b>LIST OF FIGURES</b>	<b>ix</b>
<b>LIST OF SYMBOLS</b>	<b>xii</b>
<b>LIST OF APPENDICES</b>	<b>xiii</b>
<b>CHAPTER 1 INTRODUCTION</b>	<b>1</b>
1.1 Project Background	1
1.2 Problem Statement	2
1.3 Objective	2
1.4 Scope of Research	3
1.5 Research Methodology	3
1.6 Report Outline	5
<b>CHAPTER 2 LITERATURE REVIEW</b>	<b>6</b>
2.1 Three Phase Bidirectional AC to DC Converter	6
2.2 Mathematical Model	8
2.3 Vector Transformation	9
2.3.1 Clarke Transformation	9
2.3.2 Park Transformation	10
2.3.3 Inverse Clarke Transformation	12
2.3.4 Inverse Park Transformation	12
2.4 Instantaneous Power	13



2.5	Control Strategies	14
2.5.1	Introduction	14
2.5.2	Voltage and Virtual Flux Oriented Control (VOC and VFOC)	15
2.5.3	Comparison and Discussion	16
2.6	Pulse Width Modulation (PWM)	18
2.6.1	Hysteresis Current Control PWM	19
2.6.2	Sinusoidal Pulse Width Modulation (SPWM)	20
2.6.3	Space Vector PWM	21
2.7	Phase Locked Loop	23
2.8	Development of current controller and voltage controller	25
2.8.1	Synchronous PI control	26
2.8.2	Development of current controller	26
2.8.3	Development of voltage controller	27
<b>CHAPTER 3 ANALYSIS AND DEVELOPMENT OF VOLTAGE ORIENTED CONTROL (VOC)</b>		<b>28</b>
3.1	Software Implementation	28
3.2	Block diagram	29
3.2.1	Development of Simulation Block Scheme	30
3.3	Subsystem Configuration	33
3.3.1	Clarke Transformation	33
3.3.2	Park Transformation	34
3.3.3	Phase Locked Loop (PLL)	35
3.3.4	MATLAB Function	37
3.3.5	Voltage Controller	38
3.3.6	Current Controller	39
3.3.7	Inverse Park Transformation	41
3.3.8	Inverse Clarke Transformation	42
3.3.9	Sinusoidal Pulse Width Modulation (SPWM)	43
<b>CHAPTER 4 SIMULATION AND DISCUSSION OF RESULTS</b>		<b>44</b>
4.1	Simulation of open loop rectifier	44

4.2	Simulation of three-phase AC to DC converter using VOC	51
4.3	Power Factor Operation Modes	55
4.4	Dynamic Performance	57
4.4.1	Load Variation	57
<b>CHAPTER 5 CONCLUSION AND RECOMMENDATION</b>		<b>63</b>
5.1	Conclusion	63
5.2	Recommendation on Future Work	64
<b>REFERENCES</b>		<b>65</b>
<b>APPENDICES</b>		<b>63</b>

**LIST OF TABLES**

<b>Table</b>	<b>Title</b>	<b>Page</b>
Table 2.1:	Comparison and Discussion of Control Strategies for Pulse Width Modulation (PWM) rectifier.	17
Table 2.2:	Commutation states of three-upper switch	22
Table 3.1:	Electrical Parameters for Simulation	33

## LIST OF FIGURES

<b>Figure</b>	<b>Title</b>	<b>Page</b>
Figure 1.1:	Flowchart of Research Methodology	4
Figure 2.1:	Three-phase bidirectional AC-DC converter topology	7
Figure 2.2:	(a) Clarke Transformation from $abc$ -coordinates to $\alpha\beta$ -coordinates for voltages	10
Figure 2.2:	(b) Clarke Transformation from $abc$ -coordinates to $\alpha\beta$ -coordinates for currents	10
Figure 2.3:	Phasor Diagram of Park Transformation	11
Figure 2.4:	Phasor diagram of Inverse Clarke Transformation	12
Figure 2.5:	Phasor diagram of Inverse Park Transformation	13
Figure 2.6:	Control strategies	14
Figure 2.7:	(a) Block diagram of VOC	16
Figure 2.8:	Hysteresis current controller for phase “a”	19
Figure 2.9:	Hysteresis Band configuration	20
Figure 2.10:	diagram of SPWM	21
Figure 2.11:	SPWM basic waveforms	21
Figure 2.12:	Basic switching Voltage Vectors and Sector Division	22
Figure 2.13:	Switching for all vectors.	23
Figure 2.14:	Phase detector	24
Figure 2.15:	The PLL blocks	25
Figure 2.16:	Decoupled controller.	26
Figure 2.17:	Current control loop with PI controller.	27
Figure 2.18:	Voltage control loop with PI controller.	27
Figure 3.1	Block diagram for Voltage Oriented Control (VOC) [11].	29
Figure 3.2	Simulation Circuit Diagram of VOC.	31
Figure 3.3:	(a) Block diagram of Clark transformation for three-phase voltages. (b) Block diagram of Clarke transformation for three-phase currents.	34

Figure 3.4: Block diagram of Park Transformation.	35
Figure 3.5: PLL Scheme.	36
Figure 3.6: Block diagram of PLL	36
Figure 3.7: PI controller with Voltage Control Loop.	38
Figure 3.8: Open loop voltage controller bode diagram.	39
Figure 3.9: PI controller with current control loop.	39
Figure 3.10: Open loop current controller bode diagram.	41
Figure 3.11: The block diagram of Inverse Park Transformation.	41
Figure 3.12: Block diagram of Inverse Clarke Transformation.	42
Figure 3.13: Simulink block of Sinusoidal Pulse Width Modulation.	43
Figure 4.1: Circuit of open loop rectifier.	44
Figure 4.2: Waveform of input voltages in $abc$ -frame.	45
Figure 4.3: Waveform of input voltages in $\alpha\beta$ -frame.	45
Figure 4.4 Figure Waveform of input currents in $abc$ -frame.	46
Figure 4.5 Waveform of input currents in $\alpha\beta$ -frame.	46
Figure 4.6: Voltage angle produced by $\text{atan2}$	47
Figure 4.7: Block diagram of PLL.	47
Figure 4.8: Voltage angle produced by $\text{atan2}$ and PLL.	47
Figure 4.9: Supply voltage in synchronously rotating dq reference frame.	48
Figure 4.10: Supply current in synchronously rotating dq reference frame.	48
Figure 4.11: frequency spectrum of grid current.	49
Figure 4.12: Waveform of Active power and Reactive power.	49
Figure 4.13: Generated dc-link output voltage.	50
Figure 4.14: Waveform of input voltages and generated dc-link output voltage.	50
Figure 4.15: Complete structure of VOC in MATLAB.	51
Figure 4.16: Three phase input current.	52
Figure 4.17: Phase a voltage and current at unity power factor.	52
Figure 4.18: Frequency spectrum of line current.	53
Figure 4.19: Supply current in synchronously rotating dq-reference frame.	53
Figure 4.20: Active and reactive powers of system.	54
Figure 4.21: DC-link output voltage with reference voltage.	54
Figure 4.22: Line current in dq-frame with $Q_{ref} = 100\text{Var}$	55
Figure 4.23: Phase a voltage and phase a current.	56

Figure 4.24: Line current in dq-frame with $Q_{ref} = -100\text{Var}$ .	56
Figure 4.25: Phase a voltage with phase a current.	57
Figure 4.26: VOC with load variation	58
Figure 4.27: DC-link output voltage with $100\ \Omega$ of resistor in parallel.	59
Figure 4.28: Line current in rotating frame with $100\ \Omega$ in parallel.	59
Figure 4.29: Phase a current with $100\ \Omega$ in parallel.	60
Figure 4.30: Power flow of system with $100\ \Omega$ in parallel.	60
Figure 4.31: DC-link output voltage with $200\ \Omega$ of resistor in parallel.	61
Figure 4.32: Line current in rotating frame with $200\ \Omega$ in parallel.	61
Figure 4.33: Phase a current with $200\ \Omega$ in parallel.	62
Figure 4.34: Power flow of system with $200\ \Omega$ in parallel.	62

**LIST OF SYMBOLS**

VOC	-	Voltage Oriented Control
DPC	-	Direct Power Control
VFOC	-	Virtual Flux Oriented Control
VF-DPC	-	Virtual Flux Direct Power Control
PWM	-	Pulse Width Modulation
SPWM	-	Sinusoidal Pulse Width Modulation
PLL	-	Phase Locked Loop
THD	-	Total Harmonic Distortion
A/D	-	Analogue to Digital
SVM	-	Space Vector Modulation
IGBT	-	Insulated Gate Bipolar Transistor

**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Gantt Chart	



# CHAPTER 1

## INTRODUCTION

### 1.1 Project Background

In industry, the harmonic pollution of power system is increased rapidly and reach a critical level that is beyond the tolerable limits. This pollution is mainly caused by nonlinear loads such as diode and thyristor rectifiers. There are several techniques can be used to reduce the harmonic pollution. There are from the application of active and passive filters and the use of Pulse Width Modulation (PWM) rectifiers. Throughout the studies, most of the researchers found out that PWM rectifiers have an additional advantage of the bi-directional power flow and hence PWM rectifiers becomes the best application amongst all.

Furthermore, the use of PWM rectifiers have presented four types of control techniques. Overall of control techniques can be distinguished as Voltage Oriented Control (VOC), Voltage-based Direct Power Control (V-DPC), Virtual-Flux Oriented Control (VFOC) and Virtual-Flux-based Direct Power Control (VF-DPC). For purpose of this study, a VOC is a method that been chosen for the analysis and development of grid connected front-end AC to DC converter.

Sinusoidal Pulse Width Modulation (SPWM) is used in VOC by properly control the pulses in the converter, thus assure the power flows are enough with stable frequency. The details of the process will be explained in this thesis. Other than that, VOC have no sensitive to line inductance variation with fixed switching frequency. Considering of all the advantages of VOC, VOC is one of the technique that can

overcome the rapid growth of ac adjustable speed drives (ASDs). Hence, VOC is the best method to convert from AC to DC.

## 1.2 Problem Statement

Power electronic systems are used wisely and very common usage in our daily life nowadays. Thus, same goes to AC to DC converter that are very common for most of us to hear about. However, there are problem that arise that might not be knowing by some of us when the converters are being connected in transmission and distribution lines. This problem is due to the harmonic and reactive currents that are injected into the system. The non-sinusoidal input currents that supply to the rectifier converter causes the significant harmonic components being generated. Finally, the volt-ampere rating of the utility equipment such as the transformers, generators and the transmission lines will then increase. A three-phase AC to DC converter can be controlled by a system known as the VOC scheme which produce a sinusoidal input current with a unity power factor.

## 1.3 Objective

The objectives are:

- i. To design a complete scheme of Voltage Oriented Control (VOC) using MATLAB Simulink.
- ii. To develop and test the control algorithm of the converter.
- iii. To analyse and study on the steady-state performance of three-phase diode rectifier

## **1.4 Scope of Research**

The scopes of this project are:

- i. Design and simulate a complete VOC in MATLAB.
- ii. Obtain a lower Total Harmonic Distortion (THD) of grid current.
- iii. Able to obtain almost sinusoidal three-phase input current with almost unity power factor.
- iv. Achieving the DC output voltage that is close to the DC reference voltage.

## **1.5 Research Methodology**

Figure 1.1 shows the flow chart of the research of this project. A complete schedule is illustrated in a Gantt chart in Appendix A.

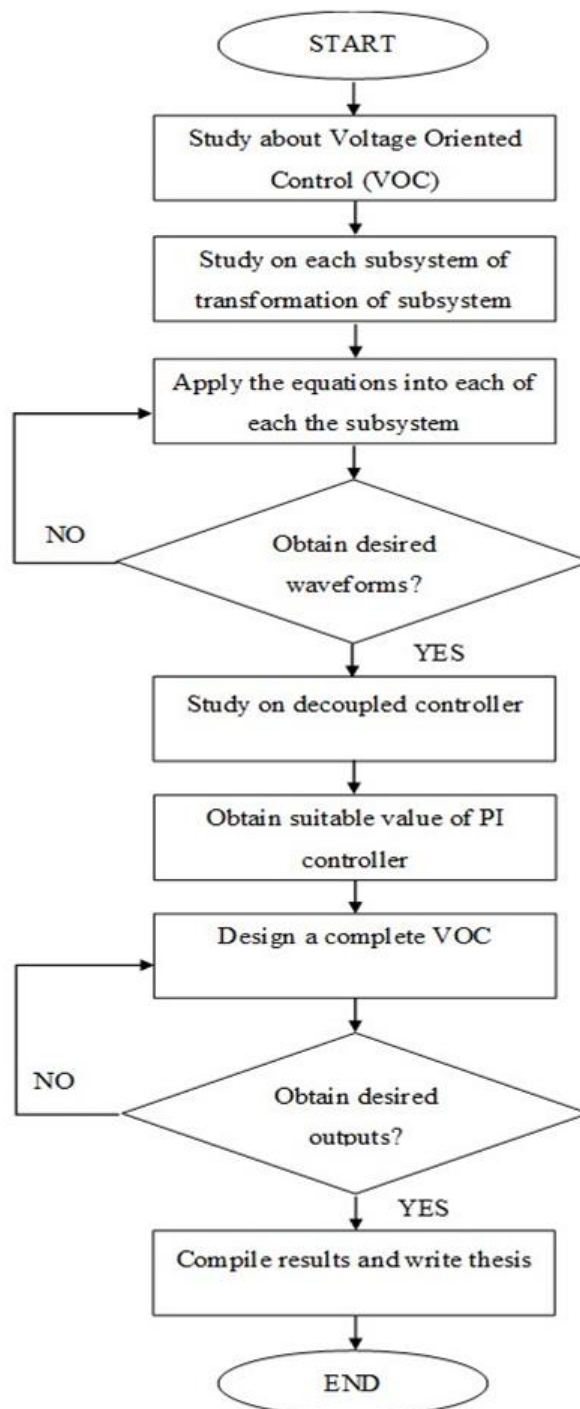


Figure 1.1: Flowchart of Research Methodology

## 1.6 Report Outline

In this report, there are six chapters as follows:

1. Chapter 1: Introduction
2. Chapter 2: Literature Review
3. Chapter 3: Analysis and Development of Voltage Oriented Control (VOC)
4. Chapter 4: Simulation Results and Discussions
5. Chapter 5: Conclusion and Recommendation.

In chapter 1, there are introduction that briefly describe about the design of the three-phase AC to DC converter. The objectives and the problem statements are described in this chapter. This will help to understand more and why is there needed to purpose and do this project. Besides, the flow of this project is shown as a guidance on doing and make the project more successful.

Chapter 2 is on the literature review that must be known and study before further on doing this project more deeply. Besides, through the fully understanding of the study, project becomes smoothly to work on. Other than that, the theory and calculations part are study to cover on the vector transformation, the control strategies and the mathematical modelling.

Chapter 3 covers the methodology being used to develop the regulated high voltage DC power supply utilizing the three-phase converter. All the models being use in order completing the design of VOC is shown this chapter. Thus, a complete simulation on VOC can be seen here.

All the simulation results of VOC are shown clearly in this chapter 4 with full explanations on each of the results which obtain from MATLAB Simulink. All the outputs and waveforms are organized to display the steady state and dynamic performance of the AC to DC converter either before nor after the introduction of VOC.

Lastly, this report is ended in chapter 5. In this chapter, it will summarise all the task been done in the project. Hence, there will be some recommendation in order having impressive performance of the project. Any future work for this project will be discuss in this chapter too.

## CHAPTER 2

### LITERATURE REVIEW

This chapter will review on research that been done by researches on Voltage Oriented Control (VOC). In the beginning, this thesis will start with an overview of three-phase controlled rectifiers. Next, will be move on to the mathematical modelling for each part of VOC, vector transformation, instantaneous power, control strategies and the Phase Locked Loop (PLL).

#### 2.1 Three Phase Bidirectional AC to DC Converter

Higher harmonic content with lower of power factor effect the power distribution system. In order limiting the problems. Thus, there are new topologies that had been introduced for rectification applications. In this project, we will study on the most famous and universal topology, known as the universal bridge topology [1]. Through the analysis, three-phase voltage is connected to the two level of VSC. Basically, VSC consists of six insulated gates bipolar transistor (IGBT) with anti-parallel fast recovery diode.

Figure 2.1 shows the universal bridge topology which have the regulation of DC output voltage, low harmonic distortion of line current, near sinusoidal current waveforms, power factor correction, bidirectional power flow and unity power factor. The three-phase voltage is injected to each of the line inductors. A sinusoidal line currents and become the line filters by decrease the current ripples are the main function of the inductors.

The function of IGBTs is to boost the performance of the converter, where the IGBTs are suitable power switch as the gate driver can operates in high switching

frequency. The power switch can perform a continuous sinusoidal current from ac power supply with a lower Total Harmonic Distortion (THD) as mentioned before and minimum the grid needed for side power factor at unity in order obtaining the power transfer with a minimum current stress. In this project, the magnitude of  $V_{dc}$  need to be higher, where the minimum of DC link output voltage is required as of the equation (2.1).

$$V_{dc} > \sqrt{2} \times \sqrt{3} \times E_g, \text{ pahse, (rms)} = 2.45 \times E_g, \text{ pahse, (rms)} \quad (2.1)$$

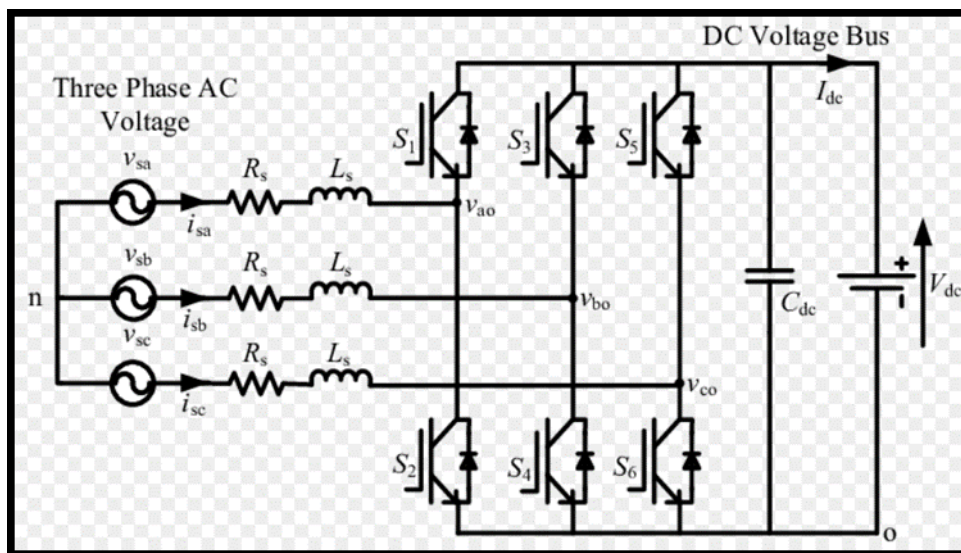


Figure 2.1: Three-phase bidirectional AC-DC converter topology

## 2.2 Mathematical Model

The three-phase line voltages and currents can be expressed in Equations (2.2) and (2.3) respectively as follow:

$$\begin{aligned} V_{sa} &= V_m \cos(\omega t) \\ V_{sb} &= V_m \cos\left(\omega t - \frac{2\pi}{3}\right) \\ V_{sc} &= V_m \cos\left(\omega t - \frac{4\pi}{3}\right) \end{aligned} \quad (2.2)$$

$$\begin{aligned} I_{sa} &= I_m \cos(\omega t + \varphi) \\ I_{sb} &= I_m \cos\left(\omega t + \varphi - \frac{2\pi}{3}\right) \\ I_{sc} &= I_m \cos\left(\omega t + \varphi - \frac{4\pi}{3}\right) \end{aligned} \quad (2.3)$$

With  $V_m$  as the input voltage and  $I_m$  as the input current. However, since that there is no neutral connection, the current can be obtained as Equation (2.4) below:

$$I_{m,sa} + I_{m,sb} + I_{m,sc} = 0 \quad (2.4)$$

Next, Equation (2.5) shows the voltages of each phase that can be determined and expressed as [2]

$$\begin{aligned} V_{\text{conv}, sa} &= (2S_a - S_b + S_c) \frac{V_{dc}}{3} \\ V_{\text{conv}, sb} &= (2S_b - S_a + S_c) \frac{V_{dc}}{3} \\ V_{\text{conv}, sc} &= (2S_c - S_a + S_b) \frac{V_{dc}}{3} \end{aligned} \quad (2.5)$$

The three-phase system are then described with only the two components which are  $\alpha$ , the real part and  $\beta$ , the imaginary part.