ANALYSIS AND DEVELOPMENT OF GRID CONNECTED FRONT-END AC TO DC CONVERTER USING DIRECT POWER CONTROL (DPC) SCHEME

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering

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"I hereby declare that I have read through this report entitled "Analysis and development of grid connected front-end AC to DC converter using Direct Power Control (DPC) scheme." and found that it complies the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering."

Signature : ………………………………………….

Supervisor's Name : DR.AZZIDDIN BIN MOHAMAD RAZALI

Date : …………………………………………

I declare that this report entitled “Analysis and development of grid connected front-end AC to DC converter using Direct Power Control (DPC) scheme” 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.

Signature : ………………………………………….

Name : OOI JIA SHENG

Date : …………………………………………

To my beloved mother and father.

I would not be here if were not for them.

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ABSTRACT

This project focuses on development of grid connected front-end AC to DC converter using Direct Power Control (DPC) scheme. Nowadays, three-phase AC to DC converters consisting of power electronic switched have been widely used in various industrial applications. However, power electronic switches such as diode and thyristor will generate non-sinusoidal shape of input currents from the main supply. These currents consists of high harmonic components which lead to the increasing of currents total harmonic distortion. The proposed DPC is able to reduce the current harmonics, hence lower the total harmonic distortion of the three-phase input current. DPC is able to control the active and reactive power without any internal current control loop. The optimum switching states for the converter are determined from a switching table. Therefore, the main objective of this project is develop a three-phase AC to DC converter controlled by Direct Power Control (DPC) scheme. Simulation will be done by using MATLAB Simulink. Besides, the three-phase input currents and voltages will be transformed into αβ frame by applying Clarke transformation. The current and voltage in αβ frame are used to estimate the active and reactive power. The power errors (S_p, S_q) and sector signal, θ_n will be used as input parameters to the switching table. Thus, the switching table is responsible to select the optimal rectifier voltage vector and output the corresponding switching state (S_a ,S_b , S_c). After implementing the DPC method, three-phase input currents are almost sinusoidal and current total harmonic distortion is lower. By supplying zero reference reactive power for all sectors, the AC to DC converter operation is maintained at unity power factor. Lastly, the magnitude of DC-link voltage is almost same as the reference DC voltage.

ABSTRAK

Projek ini memberi tumpuan kepada pembangunan grid yang menyambungkan penukar arus ulang alik (AU) kepada arus teurs (AT) dengan menggunakan skim Direct Power Control (DPC). Pada masa kini, penukar tiga fasa AU kepada AT yang mempunyai kuasa elektronik suis telah digunakan secara meluas dalam pelbagai aplikasi perindustrian. Walau bagaimanapun, suis elektronik kuasa seperti diode dan thyristor akan menjana arus masuk yang tidak sinusoidal. Arus yang mempunyai komponen harmonik yang tinggi akan membawa peningkatan arus jumlah herotan harmonik. DPC yang dicadangkan dapat mengurangkan harmonic komponen dan menurunkan jumlah herotan harmonik arus masuk. DPC boleh mengawal kuasa aktif dan kuasa reaktif tanpa gelung kawalan arus dalaman. Status pensuisan yang optimum ditentukan daripada satu jadual pensuisan. Oleh itu, objectif projek ini adalah untuk membangunkan pengawal penukar AU kepada AT dengan mengunakan konsep DPC. Simulasi juga akan dilakukan dengan menggunakan MATLAB Simulink. Selain itu, arus masuk dan voltan masuk tiga fasa akan berubah menjadi paksi αβ dengan menggunakan transformasi Clarke. Arus dan voltan yang dihasilkan dalam paksi αβ digunakan untuk menganggarkan kuasa aktif dan kuasa reaktif. Kesalahan kuasa (S_p, S_q) dan isyarat sector, $\theta_n$akan dimasukan ke dalam jadual pensuisan. Oleh itu, jadual pensuisan akan memilih vektor voltan penerus optimum dan status pensuisan penukar arus (Sa, Sb, Sc) akan diberikan. Selepas mengguankan DPC, arus tiga fasa adalah hampir sinusoidal dan jumlah herotan harmonic menjadi lebih rendah. Dengan membekalkan kuasa reaktif rujukan sifar kepada semua sektor, operasi penukar AU kepada AT dikekalkan pada factor daya uniti. Akhir sekali, nilai voltan DC-link hampir sama dengan voltan DC rujukan.

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AC	-	Alternating Current
ASDs	-	Adjustable-speeds Drive
ADC	-	Analog to Digital Converter
ADCH	-	Analog to Digital Channel
DC	-	Direct Current
DPC	-	Direct Power Control
DAC	-	Digital to Analog Converter
DACH	-	Digital to Analog Channel
HVDC	-	High-voltage Direct Current
HCC	-	Hysteresis Current Controller
IGBT	-	Insulated-Gate Bipolar Transistor
PWM	-	Pulse Width Modulation
PCB	-	Printed Circuit Board
RTI	-	Real-Time interface
UPSs	-	Uninterruptible Power Supplies
VFOC	-	Virtual-flux Oriented Control
VF-DPC	-	Virtual-flux-Based Direct Power Control
V-DPC	-	Voltage-based Direct Power Control

CHAPTER 1

INTRODUCTION

1.1 Motivation

Three-phase AC to DC converter have been frequently used in industrial applications such as high-voltage direct current (HVDC) system, adjustable-speeds drive (ASDs), uninterruptible power supplies (UPSs) and so on. Traditionally, a three-phase diode rectifier or phase-controlled thyristor rectifier are normally used as AC to DC power supply. However, they generate problem of poor power quality in terms of current harmonics being injected back to the main supply, low efficiency, voltage distortion and low power factor [1].

There are various control methods that can be implement on AC to DC converter. The control methods are known such as voltage-oriented control (VOC), Hysteresis current controller (HCC) and Direct Power Control (DPC) [2]. This project will focus on analysis and development of Grid connected Front-End AC to DC converter using Direct Power Control (DPC) scheme.

In energy conversion system, the converter need to be well controlled in order to achieve dynamic performance and satisfactory steady state [3]. DPC scheme is a control method to control the active and reactive power without any internal current control loop and pulse width modulator. By implementing DPC scheme, low harmonic content in line current can be generated which leads to the achievement of almost sinusoidal input current and have almost unity power factor. Meanwhile, the switching states are selected via a switching table. Switching table is used to determine optimum switching state for the converter. There are three signal inputs to the switching table, which are voltage sector position, instantaneous error of active power and reactive power.

1.2 Problem Statement

Nowadays, AC to DC converter has been widely used in industrial applications specifically in power transmission. However, there are a few problems when implementing AC to DC converter into the transmission system. Power diode and thyristor that are commonly used in the AC to DC converter will generate harmonics and reactive currents. The non-sinusoidal shape of input current supply is the main issue that generates significant harmonic components [2]. The currents are distorted and deviate from sinusoidal waveforms. Harmonic currents have significant impacts on the electrical distribution systems and facilities such as lower the system power factor, increase the energy losses, overheating and so on.

To overcome those problems, a three-phase AC to DC converter controlled by DPC scheme is proposed in this project. DPC scheme is able to produce input currents which are close to sinusoidal waveform and have almost unity power factor.

1.3 Objective

The objectives of this project are:

1) To design and run the simulation of three-phase AC to DC converter controlled by Direct Power Control (DPC) scheme by using MATLAB Simulink.
2) To obtain a sinusoidal three-phase input current which have almost unity power factor through simulations
3) To regulate the DC output voltage according to the reference DC value.
4) To develop the hardware of three-phase AC to DC converter controlled by Direct Power Control (DPC) scheme.

1.4 Scope of Research

The scope of this project are:

1) Understand the concept of Direct Power control (DPC) scheme.
2) To transform the three-phase current and voltage into alpha-beta frame by applying Clark transformation.
3) Acquire the instantaneous active and reactive power of three-phase AC to DC converter.
4) Determine the sector position (θ_n) and converter voltage vector (V_n).
5) Determine the switching states of the converter by utilizing the switching table.
6) Development of hardware for DPC and connect with dSpace.
7) Enable gate drivers for implementation of DPC to the three-phase AC to DC converter.

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CHAPTER 2

LITERATURE REVIEW

This chapter is mainly focusing on the research and analysis that have been done by various researchers. In this chapter, the basic concept and theories of Direct Power Control (DPC) on the three-phase AC to DC converter will be emphasised. Related information of previous studies are extracted as references and discussion will be done.

2.1 Topology of three-phase AC to DC converter

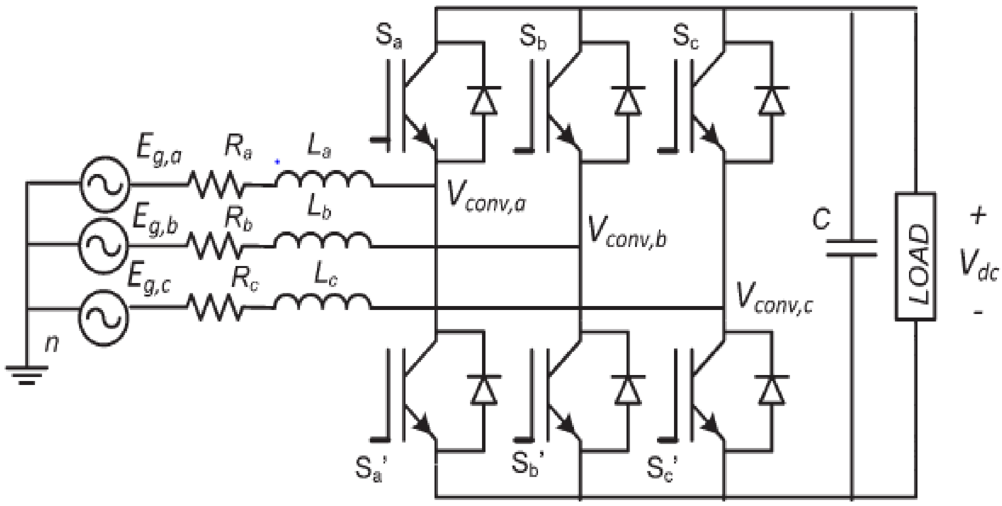

Figure 2.1 Topology of three-phase bidirectional AC-DC converter [4]

The circuit of a three-phase AC to DC converter is shown in Figure 2.1. $E_{a,b,c}$ stand for grid phase voltage and each phase is shifted 120^0 from another phase. The RL branch is connected in between the source and the converter. The present of inductance is to smoothing the current with minimum ripples. Besides, V_{dc} is the DC-link output voltage and $S_{a,b,c}$ is the switching state of the converter [4].

Figure 2.1 clearly shows that six insulated gate bipolar transistors (IGBT) are involved in rectifying the input voltage. IGBT have simple gate drives requirements, high power rating and able to operate in high switching frequency [2]. IGBT have better performance compare to conventional three-phase rectifier. Conventional three-phase rectifier have low power factor, and high harmonic component in input currents. Thus, IGBTs are proposed to be used in this projects.

2.2 Mathematical Model

The equations of the three-phase voltage supply are shown as below. Meanwhile, the E represent the maximum phase voltage and the ω represent the angular frequency of the power source.

$$E_a = E\cos(\omega t) \quad (2.1)$$

$$E_b = E\cos\left(\omega t - \frac{2\pi}{3}\right) \quad (2.2)$$

$$E_c = E\cos\left(\omega t + \frac{2\pi}{3}\right) \quad (2.3)$$

Based on Figure 2.1, $V_{conv,abc}$ is the is the three-phase converter pole voltage. The phase voltage at the poles of the converter can be determine by applying equations below [4, 23].

$$V_{conv,a} = \left(\frac{2S_a - S_b + S_c}{3}\right)V_{dc} \quad (2.4)$$

$$V_{conv,b} = \left(\frac{2S_b - S_a + S_c}{3}\right)V_{dc} \quad (2.5)$$

$$V_{conv,c} = \left(\frac{2S_c - S_a + S_b}{3}\right)V_{dc} \quad (2.6)$$

2.3 Vector Transformation

Vector transformation need to be involved when transform three-phase quantities into two phase quantities and vice versa. Among the various transformation method available, the most common transformation are Clarke transformation, Inverse Clarke transformation, Park transformation, and Inverse Park transformation.

2.3.1 Clarke Transformation

Clarke transformation able to converts balanced three-phase quantities into balanced two-phase quantities. The Clarke transformation for three-phase systems without zero sequence symmetrical components is given by [5]:

$$\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \quad (2.7)$$

Simplified the equations above and the final equations will be shown as below:

$$X_\alpha = \frac{2}{3}(X_a) - \frac{1}{3}(X_b+X_c) \quad (2.7)$$

$$X_\beta = \frac{1}{\sqrt{3}}(X_b-X_c) \quad (2.9)$$

Where X_a, X_b, X_c are three-phase quantities and X_α, X_β are stationary orthogonal reference frame quantities. Equation above is applicable for transformation of both currents and voltage as X represent I and V. Figure 2.2 and Figure 2.3 shows the Clarke transformation from abc-coordinates to αβ-coordinates.

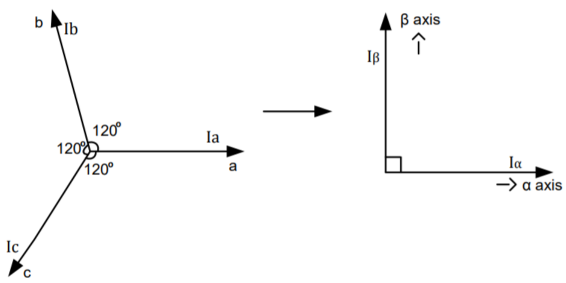

Figure 2.2 abc-coordinates to αβ-coordinates.

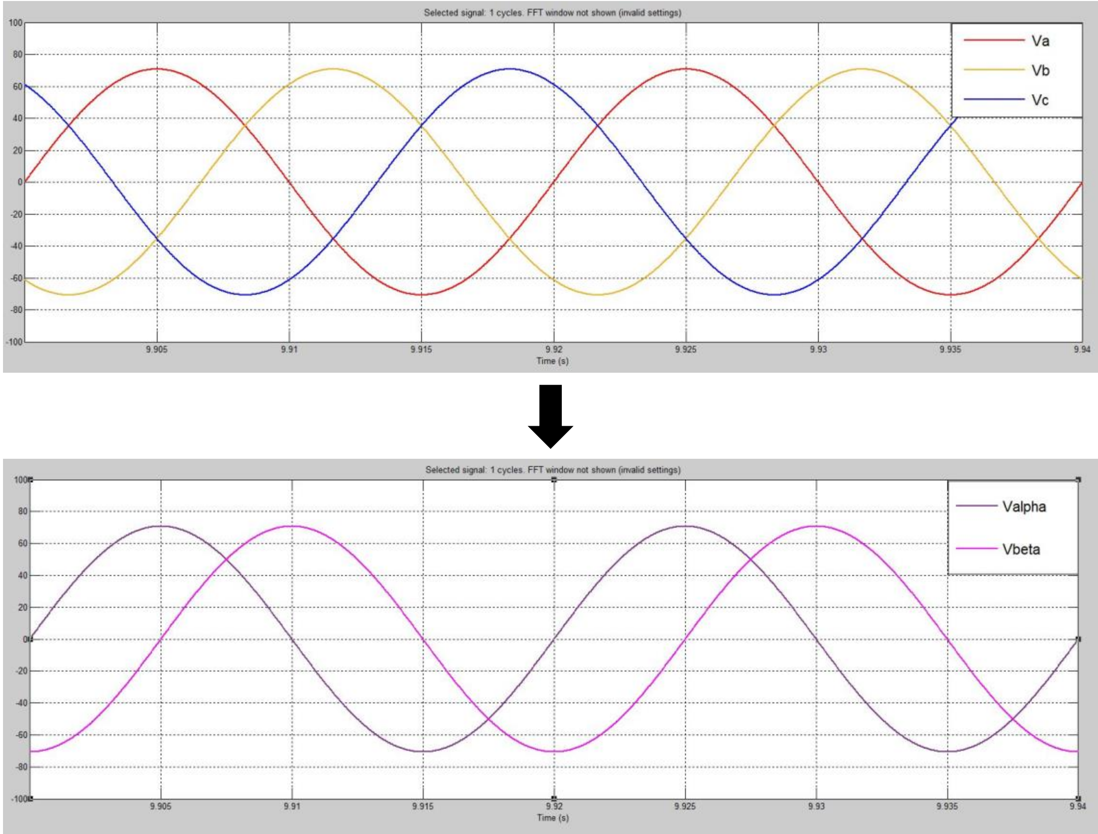

Figure 2.3 Clarke transformation (before and after)

2.3.2 Inverse Clark Transformation

Inverse Clarke transformation able to converts balanced two-phase quantities into balanced three-phase quantities. The Inverse Clark Transformation is expressed by the following equations:

$$\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} = \frac{3}{2}\begin{bmatrix} \frac{2}{3} & 0 \\ -\frac{1}{3} & \frac{1}{\sqrt{3}} \\ -\frac{1}{3} & -\frac{1}{\sqrt{3}} \end{bmatrix}\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} \tag{2.10}$$

Simplified the equations above and the final equations will be shown as below:

$$X_a = X_\alpha \tag{2.11}$$

$$X_b = \frac{1}{2}\left(-X_\alpha + \sqrt{3}\, X_\beta\right) \tag{2.12}$$

$$X_c = \frac{1}{2}\left(-X_\alpha - \sqrt{3}\, X_\beta\right) \tag{2.13}$$

Where X_α, X_β are stationary orthogonal reference frame quantities and X_a, X_b, X_c are three-phase quantities. Equation above is applicable for transformation of both currents and voltage as X represent I and V. Figure 2.4 shows the inverse Clarke transformation from αβ-coordinates to abc-coordinates.

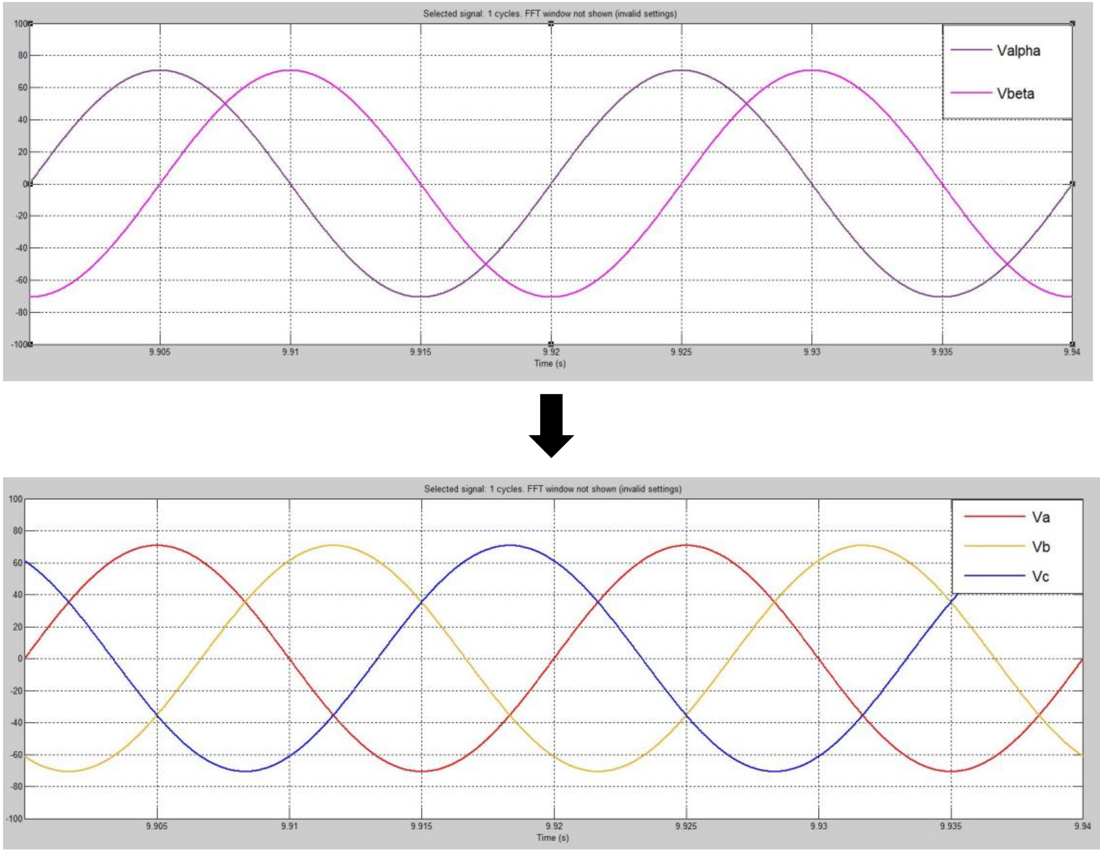

Figure 2.4 Inverse Clarke transformation (before and after)