DESIGN AND CONTROL THREE PHASE AC TO DC CONVERTER FOR GRID CONNECTED APPLICATIONS

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DECLARATION

I declare that this thesis entitled "Design And Control Three Phase AC to DC Converter For Grid Connected Applications" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Siti Hanum Binti Muhammad Shahril

Date : 10 April 2018

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality as a partial fulfilment of Master of Electrical Engineering (Power Electronics and Drives).

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Date	:...

DEDICATION

To my husband and soulmate, Mr. Mohd Zafri Bin Che Hamat, my dear sons, Muhammad Amsyar and Muhammad Akid, my beloved father and mother, Mr. Muhammad Shahril bin Abdullah and Mdm. Hamidah binti Taib, my little brother and sister, Mohd Hairi and Siti Hanim. This thesis is merely the reflection of your tireless support and sacrifice. I owe it all to you. May Allah bless you.

ABSTRACT

The problem in transmission and distribution lines due to the harmonic and reactive current injected to the grid system by line commutated power diode and thyristor rectifiers has triggered the vast development in power electronic devices since the last decade. The three phase ac-dc converters with the proper control strategies have gained more interest in medium and high voltage applications because of their various benefits such as nearly sinusoidal input current, reduce harmonic in the line current, and operate near to unity power factor. In this dissertation, the voltage oriented control is applied through the usage of the outer voltage control loop and inner current control loop which is can improved the performance of the converter among the other control technique. The proposed system is designed and analysed using MATLAB/Simulink software. Various performances results from the simulation of proposed ac-dc converter have been investigated. Based on the analysis from the simulation results, it has been found that the proposed VOC is able to produce three phase sinusoidal input current with low total harmonic distortion, near unity power factor and adjustable dc-link output voltage under balanced, unbalanced and distorted input voltage supply.

ABSTRAK

Masalah dalam talian penghantaran dan pengagihan disebabkan harmonik dan arus reaktif yang disuntik kepada sistem grid oleh garis diod kuasa berganti dan penerus thyristor menyebabkan pembangunan yang luas terhadap peranti elektronik kuasa sejak sedekad yang lalu. Dengan strategi kawalan yang sesuai, penukar tiga fasa arus ulang alik (AU) – arus terus (AT) menjadi tarikan bagi aplikasi voltan sederhana dan tinggi disebabkan oleh pelbagai faedah seperti masukan arus yang hampir kepada gelombang sin, mengurangkan harmonik di dalam talian arus , dan beroperasi hampir kepada faktor kuasa satu. Disertasi ini membentangkan Kawalan Berorientasikan Voltan (KBV) tiga fasa yang mana bertindak sebagai teknik kawalan bagi penukar tiga fasa AU-AT dengan kaedah Modulasi Lebar Denyut (MLD) yang disambungkan ke grid bekalan voltan tiga fasa. Sistem yang dicadangkan, direka dan dianalisis dengan menggunakan perisian MATLAB / Simulink. Pelbagai keputusan keluaran simulasi dari penukar tiga fasa AU – AT yang dicadangkan telah disiasat. Berdasarkan analisis daripada hasil simulasi, ianya telah mendapati bahawa KBV yang dicadangkan mampu menghasilkan masukan arus yang hampir kepada gelombang sin dengan jumlah herotan harmonik yang rendah, hampir dengan faktor kuasa satu dan keluaran voltan dc link yang boleh di laras di bawah voltan bekalan masukan yang seimbang, tidak seimbang dan voltan bekalan masukan yang diherotkan.

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LIST OF ABBREVIATIONS

DPC	-	Direct Power Control
FOC	-	Field Oriented Control
IGBT	-	Insulated gate bipolar transistor
PAM	-	Phase and Amplitude Control
pf	-	Power Factor
PFC	-	Power Factor Correction
PI	-	Proportional Integrals
PLL	-	Phase Locked Loop
PWM	-	Pulse Width Modulation
SPWM	-	Sinusoidal Pulse Width Modulation
SRF	-	Synchronous Reference Frame
SVM	-	Space Vector Modulation
THD	-	Total Harmonic Distortion
VOC	-	Voltage Oriented Control
VSC	-	Voltage Source Converter
VSR	-	Voltage Source Rectifier

LIST OF SYMBOLS

C	-	dc-link capacitor
d,q	-	direct and quadrature axis rotating synchronous reference frame
f	-	grid voltage frequency
f_s	-	sampling frequency
T_s	-	sample period
$E_{g,i}$	-	grid voltage of phase I (i=a,b,c)
E_{LL}	-	grid line to line voltage
E_{phase}	-	grid phase to neutral voltage
$E_{g,an}$	-	grid phase a voltage vector
E_m	-	amplitude of the phase voltage
$V_{conv,an}$	-	converter pole voltage vector at leg a
S_i	-	gate signal at converter upper switch of leg $i(i=a,b,c)$
R_i	-	internal resistance
L_i	-	line inductance of phase $i(i=a,b,$c)
$I_{g,i}$	-	grid line current of phase $i(i=a,b,c)$
I_m	-	amplitude of line current
V_o	-	output voltage

$I_{g.\alpha\beta}$	-	stationary components of the grid current
$I_{g.dq,\ Idq}$	-	direct and quadrature components of the grid current
$I_{g.dq,\ ref}$	-	direct and quadrature components of the grid current reference
$E_{g.\alpha\beta}$	-	stationary components of the grid voltage
$E_{g.dq}$	-	direct and quadrature components of the grid voltage
$V_{conv.\alpha\beta}$	-	stationary components of the converter pole voltage
$V_{conv.dq}$	-	direct and quadrature components of the converter pole voltage
ω	-	grid operating frequency in radian per second
θ	-	angle of the grid voltage vector
$\bar{E}_{g.\ \alpha\beta}$	-	grid voltage vector in stationary reference frame
$\bar{E}_{g.dq}$	-	grid voltage vector in rotating synchronous reference frame
P	-	estimated active power
P_{ref}	-	command/reference active power
Q	-	estimated reactive power
Q_{ref}	-	command/reference reactive power
ΔP	-	active power error signal
ΔQ	-	reactive power error signal
δ	-	angle different between the converter pole voltage vector and grid voltage vector

CHAPTER 1

INTRODUCTION

1.1 Background Study

The research in power electronics area is still being explored by many investigators even though the introductions of the transistor and thyristor devices have been made since the 1950s. Nowadays, power electronic converters are widely applied in adjustable-speed drives (ASDs), high voltage direct current (HVDC) systems, uninterruptible power supplies (UPSs) (Committee et al. 2014), battery charging for electric vehicles and process technology such as electroplating welding units (Singh et al. 2004). The power electronic converters are also employed in processing the renewable energy such as the energy produced by the solar photovoltaic, wind energy system and the battery storage system. A significant aspect of an HVDC technology for example, is the utilized converter topology. The continuous growth of the semi-conductor devices technology provides the industry with numerous converter design consideration. Consequently, tradeoff studies take place in order to choose what might be the suitable converter design.

There are a few topologies of ac-to-dc converter applied in electrical machine drives such as a diode bridge rectifier and a line commutated phase controlled thyristor bridge rectifier. These two topologies offer a simple physical structure with high reliability but at the same time deliver low power factor, uncontrolled dc-link output voltage and unidirectional power flow (Razali, 2013). Furthermore, the line commutated converters have major inherent drawback such as they generate harmonic active and reactive powers (Rodr, 2010). Those features will reduce the efficiency and decrease the power quality in the whole power conversion system. In order to improve and meet the power quality at accepted level which in line with the standard and regulation of IEEE Std 519, the active filters (Soares et al., 2000) and passive filters (Das, 2004) are also being used in grid voltage system. Nevertheless, these type of filters are usually employed with the thyristors and conventional diodes. These additional devices can reduce the efficiency of the power conversion system by having significant losses and also need extra cost.

Another method to overcome the power quality problems is by using the so-called power factor correction (PFC) method. Power factor corrected (PFC) converters are an important area of study and research in the power electronics field. This method can be applied in different topologies of AC to DC converters such as boost, buck, buck-boost and multilevel AC to DC converters (Bhat & Agarwal, 2008). Some of the PFC features are near unity power factor operation, simple control strategies, less sensitive to load change and nearly sinusoidal input current that result in less than 10% total harmonic distortion in line current (Razali, 2013). The proposed AC to DC converters offer high input power factor with stable DC voltage at the output. This features makes PFC converters are extremely attractive choice for AC to DC for power conversion applications and offline power supplies due to of increasing concerns about variety standards and power quality regulation. These converters consider to the special essential of a large number of applications. Since the problems related to the distorted line current and the standards, the manufacturers must equip their power supply product with power factor correction (PFC) circuits.

The three-phase voltage source AC to DC converters or are also known as the phase voltage source rectifiers (VSRs) provide more features than the PFC method. The basic operation of VSR is maintaining the DC-link output voltage according to the reference value by using feedback control loop. As a result of the massive undergoing developments in the semiconductor industry, pulse-width modulated (PWM) power converters are becoming more feasible. Such converters offer nearly sinusoidal input current, good power factor and compactness. The control of such converters stands a significant issue as it determines the stability and power quality of the system. There are several switching techniques can be applied with the voltage source rectifier controller to decrease the voltage and current harmonics. The most popular switching technique is sinusoidal pulse width modulation (SPWM) (Islam et al., 2013). In this technique, a sinusoidal signal is compared with carrier signal which is usually a triangular signal to produce the gating signals. The comparator generates a train of pulses when the magnitude of sine voltage is greater or lower than the triangular voltage. The gate pulses are used to trigger the respective converter switches. In the next section, the demand and standard like IEEE Std 519, is dealing with the power quality related issues such as the allowable amount of injected current harmonics to the grid system in term of the permissible current total harmonic distortion (THD) is studied.

1.2 Demands and Standard

When the issue of power grid stability and efficiency is concerned, significant investments are being dedicated recently to the development of power electronic converter to ensure the stability and power quality, lower overall cost, easier interfacing with renewable energy sources and better controllability. Besides that, the quality of the generated power must comply with the international standard in order to connect the converter to the grid system. The international standard like IEEE Std 519, is dealing with the power quality related issues such as the allowable amount of injected current harmonics to the grid system in term of the permissible current total harmonic distortion (THD). Subsequently, the standard provides research direction on dealing with voltage and current harmonics introduced by non-linear loads. Table 1.1 (Hoevenaars et al. 2003) shows the voltage distortion limits in IEEE Std 519. It is used as a guideline for designing the power system when nonlinear loads are presented. According to the Table 1.1, IEEE Std 519 established harmonics limits on voltage as 5% for total harmonic distortion factor with no more than 3% for largest single harmonic of the fundamental voltage. The special application as mention in Table 1.1 is refer to medical equipment and an airport which is limit the THD of voltage less than 3%. A dedicated system is defined as one that is exclusively dedicated to converter loads assuming the equipment manufacture will allow for operation below than 10% of THD voltage. For application in general system such as petrochemical industries, harmonics limit on voltage is below than 5%. According to the standard, the users are responsible for not drawing heavy nonlinear or distorted load currents back to the grid system, meanwhile the power providers are responsible to provide good quality sine wave voltage to the users.

Table 1.1: Harmonic voltage distortion limits

	Special Applications	**General System**	**Dedicated System**
Notch Depth	10%	20%	50%
THD (Voltage)	3%	5.0%	10%
Notch Area	16400	22800	36500

The level of harmonic voltage distortion on a system that can be assigned to an electricity consumer will be affected to the harmonic current drawn by the consumer beside the impedance of the system at the various harmonic frequencies. Table 1.2 shows the current distortion limits in IEEE Std 519 (Hoevenaars et al. 2003). According to the table, IEEE Std 519 uses the ratio of short circuit to establish potential influence on the voltage distortion and customer's size on the system. The short circuit ratio I_{sc} / I_L is the ratio of the short circuit current (I_{sc}) at the point of common coupling with the utility, to the customers maximum load or demand current I_L. According this, the lower ratios or higher impedance system will result lower current distortion limits to keep voltage distortion at reasonable levels. Table 1.2 also defined that the total demand distortion of current limits as well as individual current limits. The current is more severe for short circuit ratio indicates a high impedance power system or a large customer or both. The ratio of the root-sum-square value of the harmonic current to the maximum demand load current can be calculated as (Hoevenaars et al. 2003):

$$I_{TDD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \dots}}{I_L} \times 100\% \qquad (1.1)$$

Where :

I_L maximum demand load current

Table 1.2: Current Distortion Limit

	Individual Harmonic Order					**Max Current Harmonic (%)**
I_{sc}/I_L	**<11**	**11≤h<17**	**17≤h<23**	**23≤h<35**	**35≤h**	**TDD**
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

1.3 Motivation of Research

The ac to dc conversion performed by conventional diode and thyristor rectifiers are widely used in many applications such as household electric appliances, battery charging, electronic ballast and dc motor drives. Those rectifiers can be considered as harmonic current source and delivers generally a similar amount of harmonic currents to the system. The harmonics give negative impact to the power quality of the electrical system. Therefore, the pulse width modulated (PWM) ac to dc power converter might become best candidate to offer good power factor and nearly sinusoidal input currents. Recent researchers have introduced several control technique for PWM ac-dc converter. With the increasing of power quality demand, it is become compulsive to study the control technique of PWM converter with the impact of harmonic in this system. The significance of this study is to obtain almost sinusoidal input currents, unity power factor operation and controllable dc link output voltage under the conditions of balanced, unbalanced and distorted three phase grid voltage.

1.4 Problem Statement

Conventionally, the rectifier or AC to DC converter connected to the grid power system is developed using thyristor or power diode as power electronic switches. This conventional rectifier contributes to the harmonic and reactive current which will be injected back to the grid system and cause the disturbance at transmission and distribution line. In order to achieve high performance ac to dc converter by producing almost sinusoidal input currents, unity power factor operation and provides controllable dc-link output voltage, the suitable topology of the AC to DC converter must be applied to replace conventional diode bridge and thyristor rectifiers. According this, in this thesis, the universal bridge rectifier is applied to reduce the power quality of the converter.

This research is ignited by the problems that occur in obtaining almost sinusoidal input currents, unity power factor operation and providing controllable dc-link output voltage under ideal and non-ideal operating conditions such as unbalanced, distorted and disturbed grid supply connected to the three phase ac-dc converter. There are a few control techniques for the three phase AC to DC converter proposed by some researchers (Razali