UNIVERSITI PUTRA MALAYSIA

DESIGN OF DELTA MODULATED AC - DC CONVERTERS

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By

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TABLE OF CONTENTS

LIST OF FIGURES

Abstract of this thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the requirements for the degree of Master of Science.

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June 1999

Chairman: Ir.Dr. Norman bin Mriun.

Faculty: Engineering

An analysis and implementation of delta modulation (DM) technique in the control of ac-dc converters is studied here in this project. The DM technique offers advantages of easy implementation, continues converter voltage control, and a direct control on the line harmonics. A simple circuit of the delta modulator is proposed, designed and fabricated in the laboratory. This proposed modulation scheme, fundamentally differs from conventional PWM technique, by virtue of its self carrier generating ability. Results of the parametric variation of the modulator are reported. Simulated and experimental results of the single phase DM ac-dc converters validate the analytical results

Abstrak tesis ini dikemukakan kepada Senate Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGHURAIAN DELTA MODULATION AC-DC CONVERTERS

Oleh

NAEEM MOHAMED SALEEM HANNOON
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Pengerusi: Ir.Dr. Norman bin Mriun.

Fakulti: Kejuruteraan

Projek ini melibatkan analisa dan implementasi teknik "Delta Modulation (DM)" dalam pengawalan "ac-dc converter". Teknik DM ini mempunyai beberapa kelebihan termasuk:

1. Mudah untuk mengimplemenatasi
2. Pengawalan voltan pengubahsuai (voltage converter) yang tetap (continuous), dan
3. Pengawalan terus harmonic kitar (direct control of line harmonics).

Satu litar asas "delta-modulator" di cadangkan. Litar ini kemudiannya direka dan dibina dalam makmal. Teknik modulasi yang dicadangkan pada asanya berbeza dari teknik modulasi PWM (Pulse-Width Modulation) kerana teknik ini mempunyai kebolehan menjanakan penghantaran-sendiri (self-carrier generating ability).

Keputusan variasi parametrik delta-modultor dikemukakan. Juga dikemukankan adalah keputusan simulasi dan kerja-makmal DM satu-phasa ac-dc converter yang mengsahkan keputusan yang diperolehi secara analitikal.

CHAPTER I

INTRODUCTION

Phase controlled converters that have been used for some time are rugged, simple, easy to control and require little maintenance. These converters are very useful specially when the only switching device available was thyristor. The thyristors were difficult to switch off as they required extra commutation circuit for this purpose. But the phase controlled converters have certain serious disadvantages. For low voltages thyristors were difficult to switch off as they required extra commutation circuit for they have low power factor and also they generate large number of undesirable harmonics. Moreover, as the output voltage is decreased, the input power factor decreases, necessitating the ac source to supply reactive power. The harmonics generated tend to pollute the power network and cause interference with other equipment in close proximity. In dc drives, the ripple causes overheating and a general derating of the motor. To compensate the poor performance and enhance the conversion efficiency, various methods have been proposed. Principle scheme for power factor improvement include:

1. Reactive compensation
2. Multiphase rectification
3. Sequential control
4. Pulse Width Modulation (PWM) technique

Reactive Compensation [1,2]

Basically, this method is a filtering approach, utilizing shunt inductor-capacitor (LC) filters at the ac side and a smoothing reactor in series at the output dc stage. The LC filter located at the harmonic source is tuned to resonance at low order characteristic harmonics. The filter serves as a low impedance path for the harmonic current to flow, virtually eliminating their presence in the ac system. Although the scheme results in a definite improvement in the current waveform, it has the following disadvantages:

(1) Separate filter is required for every major harmonic component, or alternatively, continuous tuning is essential to eliminate troublesome harmonic order.

(2) Due to the large magnitude of current and low harmonic component, large size inductors and capacitors are required.

(3) The filter causes voltage fluctuations, and it results in increased losses.

Multiphase Rectification [2,3]

Since harmonic currents are a function of converter pulses, improvement in power factor can be obtained by increasing the number of output pulses. In general, an n pulse converter generates harmonic components of order n_{k+1}, where k is any integer. As for example, a six pulse converter contains harmonics of orders $5^{th,}$ $7^{th,}$ $11^{th...}$ and correspondingly, a twelve pulse converter pulse is characterized by $11^{th,}$ 13^{th}, 23^{th}, ...harmonic orders. This procedure, using a higher number of phases for low order harmonic cancellation is referred to as phase multiplication. Multiphase-rectification is restricted to high voltage dc transmission (HVDC) system where the cost of additional power apparatus and complex circuitry are justified.

Sequential control [4,5]

Improvement in power factor is achieved by cascading two converter bridges and using sequential control. In this process, one bridge is maintained in full advance (rectifying) or full retard (inverting) and the other bridge is controlled. Since one converter operates as a diode bridge, the cascade connection simulates a semi-converter in both the motoring as well as the regenerating modes, resulting in an improvement in displacement angle. The sequential control method is complicated, expensive and only partially effective, and hence it has found limited uses.

PWM Techniques

Optimum performance achievable by pulse width modulation techniques has revolutionized the field of static ac-to-dc converters. Implementation of these techniques has been facilitated by the advent of power transistors offering outstanding characteristics of high power handling capabilities, fast switching and most significantly, the absence of commutation circuitry in converter topologies. Consequently, conventional thyristor-based converters are gradually being replaced by solid state PWM controlled transistor converters. The line commutation methods offers little flexibility in controlling thyristor switching due to the natural commutation of thyristors by line voltages and subsequent conduction of thyristors on different phases. Hence, the phase angle control technique is more or less restricted as the only control parameter in thyristor turn-on instants with turn-off dictated by converter operation. In contrast, the forced commutation principle allows thyristor commutation at any desired instant by providing each thyristor with its own commutation circuit. In other words, the use of forced commutation increase the versatile of the converter and permits a direct control of thyristor switching to improve performance. Initially, control schemes incorporating forced commutation were based on a single pulse approach to symmetrically trigger thyristor pairs per half cycle. Various single pulse control schemes have been reported in the literature [5-7] and moreover, when used in conjunction with the aforementioned schemes, resulted in a general improvement in converter performance. However, it was soon realized that maximum power factor and reduction in low order harmonics could be achieved by using multiple pulses per half cycle. This opened the venue for PWM technique, where thyristor switchings are governed by certain modulation laws such that the ac waveform closely resembles a sinusoid.

PWM techniques have gained considerable attention in recent years due to the optimum performance attainable with a simple converter topology. The salient features of a PWM controlled ac/dc converters are:

- High operating power factor
- Unity displacement factor
- Negligible lower order harmonics
- Controllability

- Reduced filter size

Limitations of the process are:

- Complex control circuit
- Auxiliary commutation circuits
- Increased losses due to high switching frequency

Survey of PWM

Recently, the delta modulation technique has gained considerable attentions as potential PWM scheme for control of power converters. Most of the literature on the subjects pertains to the implementation of inverters and adjustable speed ac drives.

Ziogas [8] has implemented a free running rectangular wave delta modulator to control a voltage source inverter. Rahman, et al [9,10] have made use of the inherent V/f (voltage/frequency) characteristics of the symmetrical hysterisis delta modulator to control the speed of induction and permanent-magnetic synchronous motors. Manias, et al [11] have suggested its use in current control of a switch mode rectifier (SMR), though provision for controlling the output voltage is not accounted by the modulation circuit. Its use in uninterruptible power supplies (UPS) for controlling both rectifier stage as well as inverter switching has also been reported.

An optimal control strategy incorporating a multistage delta modulator has been reported by Rahman, et al [12] to improve the performance of a single phase inverter. The modulation system consists of a rectangular wave delta modulator followed by an active filter network, the output of which is fed to another rectangular wave delta modulator.

Kheraluwala, et al [13] have employed the sigma delta modulator for a resonant dc link inverter. The sampled data nature of the delta modulation strategy has been exploited to realize the switchings at the zero crossings of the link voltage. For PWM control of a rectifier by the delta modulation technique, the modulator must be instrumental in providing the following features:

- continuous control of the output voltage over the entire operating range,
- reduce and/or eliminate lower order harmonics,
- minimize output voltage ripple,
- ease of implantation.

To meet the first criterion, it is necessary to have indirect control of the pulse widths of the modulated pulses such as the ratio of "on" pulses to "off" pulses determine the output voltage. Clearly, the family of linear delta modulators are unable to satisfy this requirement due to the fact that the pulses are a function of sampling frequency and a present step size.

One approach in overcoming this limitation in linear delta modulators is to adopt a different scheme of controlling the output voltage. Rather than having a filter of present characteristics, the time constant associated with the "on" pulse is maintained different from that of the "off" pulse. Consequently, control of the output voltage is achieved by continuously changing the two time constants. Needless to say, the procedure substantially complicates the circuit implementation. Rectangular wave delta modulator has the inherent ability to track the reference signal within a well defined boundary established by hysteresis threshold levels. The modulator can therefore be used for either voltage or current control depending on the reference signal. Switching frequency and hence harmonic control can be achieved in three unique ways:

(1) by adjusting integrator parameters,

(2) by changing the amplitude of the reference signal, and

(3) by controlling the hystresis threshold levels.

The use of adaptive schemes for converter applications debatable considering that the modulator is responsible for encoding a well defined sinusoidal signal of constant frequency. Again, the adaptive scheme must incorporate a hysteresis comparator. Undoubtedly, adaptive delta modulators provide superior performance but at the expense of a substantially complex circuit. The same quality performance can be obtained by a single rectangular wave delta modulator using a simple filter network

In Light of the argument presented, rectangular wave delta modualtor is capable of meeting the controlled rectifier criteria. The intrinsic feature of the asynchronous modulator is classified as am adaptive PWM technique. As such, the modulator serves dual purpose of encoding a typical sinusoidal reference signal as well as controlling the output voltage.

Aim

The main purpose of this project is to study and implement the delta modulated control of a single phase rectifier. The dc output voltage of the converter must be controlled in magnitude, this is achieved by pulse width modulation PWM of the converter switcher.

Objectives

The main objectives of this thesis is to:

1. design the logic circuit and a control scheme of the modulator by using Pspice simulation package
2. fabricate circuit and testing the modulated parameters,
3. compare the performance of the new circuit with available circuits.

CHAPTER II

LITEARATURE REVIEW

Introduction

Pulse Width Modulation have been used for many years not only for controlling the amplitude of output voltage but also for adjustment freqeuncy and its harmonic content. The demerits of these are low power factor and generation of undesirable harmonics as mentioned earlier.

To compensate poor performance and enhance conversion efficiency of either ac-to-dc or whatever, this technique was suggested. The technique can be categorized into two manner i.e. analog and digital techniques. In the former technique, the switching angels occurs at crossing of two waveforms, as a result the pulse width modulation waveform occur in a harmonic content. While the latest technique can be separated when the switching angles are chosen to directly affect the harmonic content and this lead to eliminating some harmonic and minimizing the figure of current distortion.

The pulse width modulation is regarded as a high frequency energy processing operation performance on the converter switched output voltage or current waveform to optimize one performance criterion. The pulse width modulation operation reproduces a synthesized waveform as a composition of pulses of variable width and constant amplitude.

Most of the common known methods for generating pulse width modulation control signal is base on comparison between a desired signal (reference or modulation) with a sawteeth carrier wave. Since the pulse width modulation is a standard tool from communication theory, the following prior results can be drawn:

1. If the switching frequency is much larger than the power frequency, the low frequency component of output voltage is determined by the modulation function,
2. Fourier components near the switching frequency will have as high as amplitude as those near the wanted frequency,
3. Low pass filtering can recover the modulating function, since it represents the low frequency component:

However, the high power rating necessary for those elements makes the situation undesirable. An appropriate digital filter capable of filtering a pwm pulse train. The complexity of switching controller required presents the technical challenge to the potential use of a power processing operation in the electrical power system environments.

The application of a PWM voltage source converter to active power filtering involves arbitrary voltage waveform generation adopted by load variation. To control this, either closed loop or open loop technique can be realized. While the open loop operation is suitable for a fixed loading condition, the closed loop involves the arbitrary waveform synthesis in respond to load variation. This means that in the PWM power processing operations, a current or voltage feedback loop has to be realized to adjust the converter to switching pattern in-order to changes in the time dependent loads.

Some of the most important applications such as motor drives require adjustable frequency. This is also true of backup systems designed to adapt to changing needs and input sources, as well as more generic inverter applications. In these cases, it is not possible to use a resonant filter. What are the alternatives? Frequency adjustment does not seem too promising, since frequency matching is required for energy flow. The duty ratios were held at 50% to avoid any dc output component.

Thc pulse width modulation has been widely used in dc to ac inverter or converter. Optimum performance achievable by Pulse Width Modulation techniques has revolutionized the field of static ac to dc converters. Implementation of these techniques has been facilitated by the advent of power transistor offering outstanding characteristics of high power handling capabilities, fast switching and most significantly, the absence of commutation circuitry in converters topologies.

Consequently, conventional thyristors-based converters are gradually being replaced by solid state PWM controlled transistor converters.

PWM is a signal processing technique used for synthesizing an arbitrary waveform for a particular application. In power electronics circuits and control technology, PWM is regarded as a high frequency energy processing operation performed on the converter switched output voltage or current waveform to optimize one performance criterion. The PWM operation reproduces a synthesized waveform as a composition of pulses of variable width and constant amplitude. The power output then contains harmonic distortion. The converter output waveform harmonic content is commonly chosen as the performance criterion, and in most applications the aim is to minimize it.

Review of PWM Techniques

Various types of PWM techniques exist and can be categorized as

1. Natural Sampling,
2. Uniform sampling,
3. Optimal PWM ,
4. Adaptive control PWM,
5. Hysterisis current controlled PWM.

Natural Sampling

Natural sine PWM technique is one in which sine wave is compared with triangular wave to produce the modulated wave. In this technique , most commonly referred to as Sinusoidal PWM [14,15], has the modulated waveforms containing harmonics as a function of the frequency ratio. The frequency ratio or modulation index is defined as the ratio of the carrier frequency to modulation frequency. The higher the frequency ration, the more distant the dominant harmonics are from the fundamental component. The switching points as shown in Figure 2.1(a), are determined by the crossings of the modulated waveform, typically a sine wave, this has the disadvantages of undefined crossing points of two waves when the frequency of sine wave increases to a certain limit. To eliminate this draw back the sine wave is replaced by stepped sine wave.

Another version of the carrier modulated PWM technique described above, uses a triangular wave and a constant dc reference waveform. In this case, variation in the dc level controls the pulse width. Similar to the sinusoidal PWM method, the harmonic content is a function of the triangular wave frequency [16]. High frequency carrier causes the dominant harmonics to appear in the upper spectrum.

Uniform Sampling

This PWM technique is based on a sample and hold principle. The uniform