CHAPTER 1

INTRODUCTION

1.1 Motivation

The electrical energy processing technology has gained great progress in the past decade. This is mainly due to the large amount necessity of 3C products as well as the progress made in power semiconductor devices. However, for high power processing, the relative development is not so rapid and promising as that used for consumer electronics. Hence, the main motivation of this research is centered round the study of a high performance three-phase AC to DC converter. To achieve high power quality, only active three-phase AC/DC converters are concerned. It is desired to achieve (1) sinusoidal line currents without harmonic pollution, (2) clean DC output voltage, (3) the output voltage can be either stepped up or stepped down continuously, (4) bidirectional power flow capability, (5) integrated single stage converter configuration to achieve better efficiency. Although, for practical applications, at the present time the performance specification of existing products is still quite low standard, the above definition of the high performance for the concerned converter is rather attractive and challenging at least from the viewpoint of academic interest.

1.2 Literature Survey

Recent AC/DC converter researches are oriented to providing good input power factor, low line current distortion to satisfy different harmonic standards [1-4], and with possible regeneration capability [5-12]. To meet above requirements, most existing results are concerned with boost type converters [13-35]. In present literature, there exist many different topologies of boost type converter. There are one-active-switch operations under discontinuous current mode from [13] to [16]; six-active-switch operations from [17] to [26] and the others are four-active-switch operations from [27] to [35]. A one-active-switch boost rectifier was first proposed by Ziogas et al. [13] in 1991. The rectifier is operated in discontinuous conduction mode and the switching frequency is load dependent. Six-active-switches was proposed first by Wernekinck in 1987 [17]. There is a full-bridge converter. In 1993, Pan et al. proposed four-active-switch to reduce the numbers of the active switch [31]. However, since these topologies are boost type, they are not suiting for step down conditions. Due to this disadvantage, some three-phase buckboost type rectifiers have been proposed [36-41]. The drawbacks of the buckboost rectifiers are pulsating input and output currents, the higher conduction losses induced by the series connection of devices, and the high rms switch current. Also, the high voltage stresses of the switch makes it impractical for high power operation [36].

Hence recently, Pan et al. proposed a single stage three-phase boostbuck converter to overcome the above disadvantages [12]. They proposed an equivalent duty cycle for the generalized zero voltage space vectors such that control of AC and DC parts of the converter circuit can be integrated to achieve the ideal characteristics. Namely, the converter can achieve clean sinusoidal input current, unity power factor, adjustable output dc voltage, fixed switching frequency, and being insensitive to input voltage distortion. Also, depending on how many modes are chosen and which class of generalized zero-voltage space vectors is selected to increase the equivalent dc duty cycle, different control strategies can be chosen. Besides, the boostbuck converter does not need a lockout circuit and the control strategy can be easily implemented by using an EPROM [11].

However, there are still some problem existed. First, since the six active switches normally operate randomly [12, 42] so as to reduce the resulting control error [42], it is very difficult to find an analytic dynamic model for feedback controller design. Next, for some applications, bidirectional power flow capability is required for regeneration operation. Third, the equivalent dc duty ratio for the generalized zero-voltage space vectors in [12] is time varying. In view of the above drawbacks, it is the main purpose of this thesis to propose a constant equivalent duty ratio (D_0) control strategy for the proposed converter with bidirectional power flow capability. In addition, to achieve lower capacitor voltage rating and faster settling time, it is desired to be able to apply the maximum D_0 control.

1.3 Contributions of This Dissertation

Major contributions of this dissertation may be summarized as follows. First, the author proposed an active three-phase step up/down AC/DC converter with bidirectional power flow capability to achieve the previously defined high performance characteristic. Second, based on the generalized zero voltage space vectors concept and the distributed D_0 control strategy, the author derived a closed form duty cycle control law and successfully proved the feasibility of the conjecture of constant D_0 control strategy. Third, based on the closed form duty cycle control law and the state space averaging technique, the author derived the model of the proposed converter. The DC model and the small signal model may be expressed by both the mathematical equations and the equivalent circuit forms. The transfer functions of the small signal model are also derived for reference. Fourth, due to existence of one degree of freedom, namely choice of D_0, of the proposed converter, the author proposed a maximum constant D_0 controller for the concerned converter to lower the intermediate capacitor voltage for practical applications. An analog type prototype is also constructed to demonstrate the validity of the proposed theory. Finally, in order to further reduce the switching number of the active switches as well as reduce the switching on/off transient, the author proposed a dead-band controller. It is found that the switching number of each active switch in the bridge is reduced by one sixth and also the intermediate capacitor voltage can be further reduced.

1.4 Outline of Contents

The remaining contents of this dissertation may be outlined as follows. For completeness, a time varying d_0 controlled three-phase AC/DC converter is first reviewed and served as starting basis. The generalized zero voltage space vectors concept proposed by Pan et al. [12] is reviewed and also adopted in the proposed converter for integrating the AC subcircuit and the DC subcircuit to obviate cascading of two converter stages. Then, in chapter three, a closed form duty ratio control law is derived based on the assumption of existence of the constant D_0 control strategy. It turns out that such solution does exist and the conjectured constant D_0 control is indeed feasible. Based on the closed form solution mathematical models of the proposed converter are then derived. It is interesting to see that despite the random switching actions in the previous literature, the steady state behavior remains in great harmonics as governed by the derived models.

Due to the existence of one degree of freedom, namely constant D_0 in chapter three, hence, it is naturally worth searching for an optimal solution. In chapter four, a distributed D_0 control strategy is proposed to achieve the maximum constant D_0 control. An analog controller is also proposed and a prototype is constructed to verify the validity of the proposed control strategy.

In order to further enhance the converter performance, namely to reduce the switching number of the active switches, a dead-band control strategy is proposed in chapter five. Detailed theoretical basis is presented and an analog controller is also proposed. Since the implementation is quite similar to that of the chapter four, only some simulation results are given for illustrations. Finally, some conclusions are offered in the last chapter and some topics are suggested for future study.