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FPGA based variable frequency AC to AC power conversion

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ABSTRACT

AC/AC variable frequency power conversion system is proposed which makes use of a cycloconverter in newer form, ac–ac matrix converter. An attempt has been made to operate this matrix converter both in conventional low frequency ac–ac converter, cycloconverter and new high frequency ac–ac converter, cycloinverter. The ability to directly affect the frequency conversion of power without any intermediate stage involving DC power is a huge advantage of the system. The undesirable harmonic components in the output of the matrix converter have been minimized using an advanced modulation technique called as trapezoidal modulation technique. The technique offers several advantages compared to other modulation techniques in terms of easy and fast real-time waveform generation with higher fundamental output voltage. The converter is simulated using well known software package MATLAB. Simulations results are presented for both cycloconverter as well as for cycloinverter. It has been found that for cycloinverter operation the total harmonic distortion (THD) is more as compared to cycloconverter mode of operation. The simulated results are also validated with experimental results by implementing the trigger controller circuit to generate trapezoidal modulated trigger signal for matrix converter on field programmable gate array (FPGA). Peripheral input–output and FPGA interfacing has been developed through Xilinx 9.2i using very high speed integrated circuit hardware description language (VHDL). The circuit has been tested qualitatively by observing various waveforms on digital storage oscilloscope (DSO). The operation of proposed system has been found satisfactory.

1. Introduction

Traditionally ac–ac power conversion using semiconductor switches is done in two different ways: (1) in two stages (ac–dc and then dc–ac) as in dc link converters or (2) in one stage (ac–ac) cycloconverters. Majority of the cycloconverters are naturally commutated and the maximum output frequency is limited to a value that is only a fraction of source frequency [1]. As a result the major applications of cycloconverter are low speed AC motor drives with frequency from 0 to 20 Hz [2]. With recent device advancement, newer forms of cycloconverters are being developed and drawing more research interest. These new cycloconverters use self-controlled switches and are known as ac–ac matrix converters. These converters may also be used for high frequency ac–ac conversion and known as cycloinverter. Cycloinverters are ideal in induction heating and in aircraft for use in the ground power unit to power the airplane while it is on the ground [3]. The output of the matrix converter is however rich in harmonics [4]. Various modulation techniques employed to reduce the harmonics are sinusoidal pulse width modulation (SPWM) [5], space vector pulse width modulation (SVPWM) [6,7], staircase case pulse width modulation (SCPWM) [8] and delta modulation [9]. An advanced modulation technique, named as trapezoidal modulation technique, has been proposed in this paper where sinusoidal modulating signal is replaced by a trapezoidal wave. The trapezoidal wave is suitable for on line computation and its waveform varies from a rectangular wave to a triangular wave. The technique offers several advantages compared to other modulation techniques in terms of easy and fast real-time waveform generation with higher fundamental output voltage [10–14].

Many digital and transistor logic circuit (such as microprocessor and microcontroller) can develop PWM [15]. The performance of these devices is however limited because these are made with generic hardware, leaving software as the only method to create application-specific functions by the designer [16]. In comparison, FPGAs [17] give designers the freedom to create custom functions, completely adapted to their specific application requirements, by enabling customization of both hardware and software at very low cost [18]. In this paper a digital controller has been designed and implemented on FPGA to generate the trigger pulses for a frequency conversion system using hardware description language

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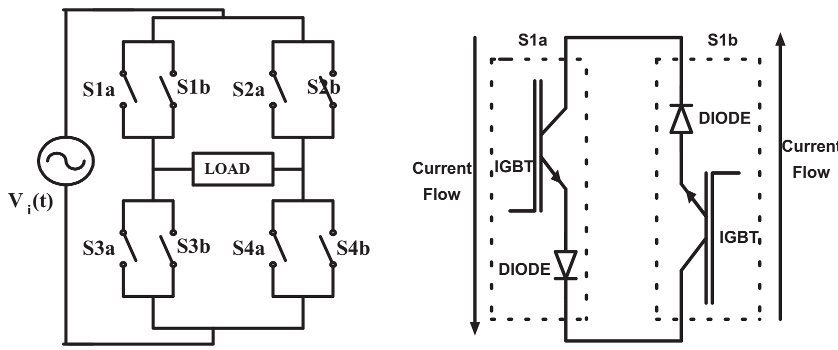


(a) Power circuit. (b) Common emitter configuration.

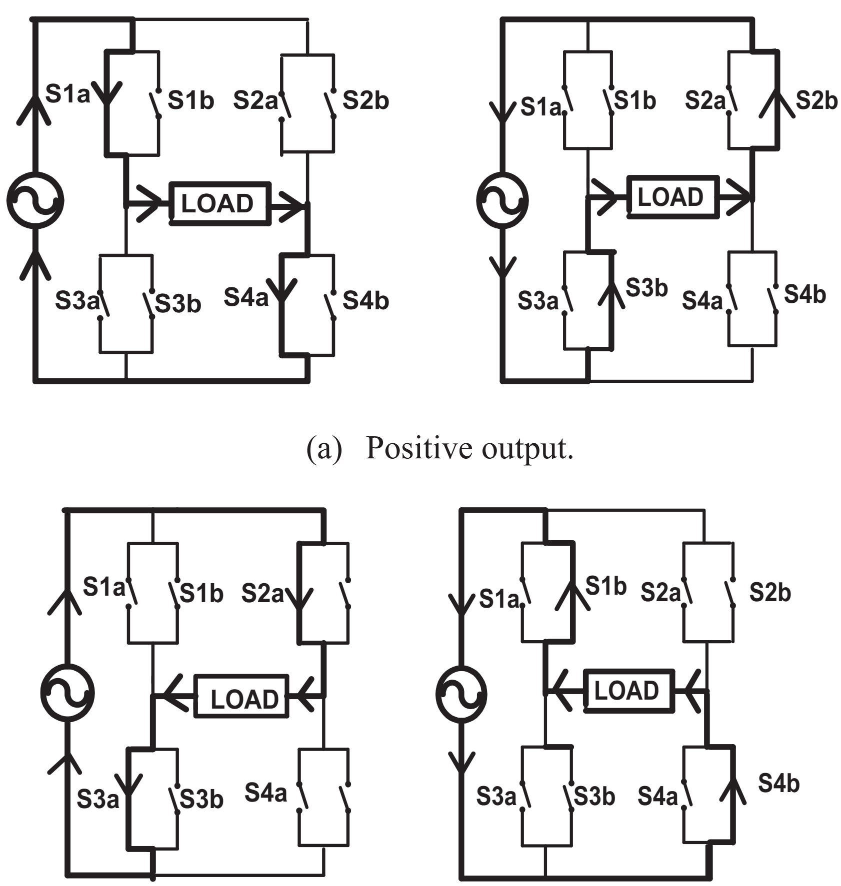
Fig. 1. Frequency converter.

VHDL. Trigger requirements are obtained for single-phase matrix converter which is operated both as cycloconverter as well as cycloinverter [19].

2. Principle of operation

Fig. 1(a) shows the proposed frequency power converter that requires four bi-directional switches capable of blocking voltage and conducting current in both directions. In the absence of bidirectional switch module, the common emitter anti-parallel insulated gate bipolar transistor (IGBT), with diode pair as shown in Fig. 1(b) is used. The diodes provide reverse blocking capability to the switch module. The IGBT is used due to its high switching capability and high current carrying capacity desirable for high-power applications [20]. The output can be synthesized by suitable toggling of the switches subject to the conditions that ensures the switches do not short-circuit the voltage sources, and do not open-circuit the current sources [21].

The converter will operate in cycloconverter mode to produce positive output when switches S1a and S4a conduct for positive input cycle while for negative input cycle switches S3b and S2b will conduct as shown in Fig. 2(a). The negative half output of



(a) Positive output.

(b) Negative output.

Fig. 2. Cycloconverter operation.