

A Novel Multilevel DC – AC Converter from Green Energy Power Generators Using Step-Square Waving and PWM Technique

F E Fajingbesi^{1,2*}, N S Midi¹ and S Khan¹

¹Department of Electrical and Computer Engineering, International Islamic University Malaysia

²Department of Physics Electronics and Earth Science, Fountain University Osogbo Nigeria

E-mail: *fawwazfajingbesi@yahoo.com

Abstract. Green energy sources or renewable energy system generally utilize modular approach in their design. This sort of power sources are generally in DC form or in single cases AC. Due to high fluctuation in the natural origin of this energy (wind & solar) source they are stored as DC. DC power however are difficult to transfer over long distances hence DC to AC converters and storage system are very important in green energy system design. In this work we have designed a novel multilevel DC to AC converter that takes into account the modular design of green energy systems. A power conversion efficiency of 99% with reduced total harmonic distortion (THD) was recorded from our simulated system design.

1. Introduction

The need and use of green (renewable) energy systems are rapidly increasing across the globe occupying an increasing share in the global power generation market in order to attain an emission free environment and hopefully restore the grave extent of damage caused by the old systems to nature and environment. However the downsides of this source are majorly the instability in the natural sources (Wind & Solar). Green energy generators are mostly DC and are modular in nature. In order to be compatible into grid systems this modular sources have to be efficiently synthesized into one single source hence the research on multilevel modular converters [1-11]. Multilevel Modular converter are now a common place in both industrial and general grid electronics since the inception in 2001 and major research achievements have been recorded [1-17]. They offer high voltages with low harmonics mostly without any need for major reactive devices such as transformers and inductors. Many designs topologies have since been proposed each having its merits and downside with the H-Bridge been the bases for most design.

2. System overview

This work has presented a novel multilevel DC converter from modular energy sources seen in green energy system consisting of less reactive element to offer greater reduction in size, power loss and total harmonic distortion (THD). In figure 1, the block diagram illustrating the cascading concept of adapting multiple modular source to achieve higher output voltage is illustrated using our multilevel DC converter design shown in figure 2. The novel design seen in figure 2 consist of a multilevel DC converter and an Inverted multilevel DC converter. Each single multilevel DC converter consist of four MOSFET switch and two Capacitor with a power source.



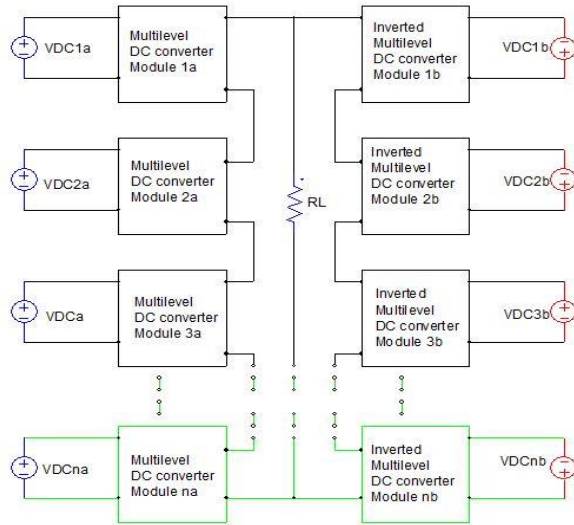


Figure 1. Multilevel DC power converter module system configuration

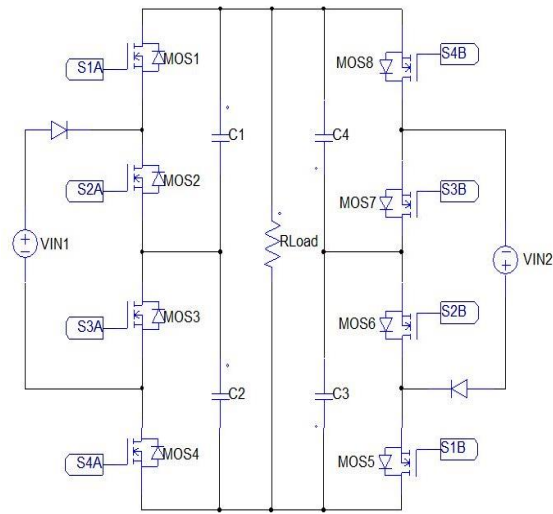


Figure 2. Multilevel DC converter circuit

The two separate block of this novel multilevel converter shown in figure 2 are switch intelligently in a complementary fashion to produce a positive and negative cycle multilevel DC output as seen in Figure 10. There are several possible output from this system based on the switching configuration. In our work we have chosen a 3 state system where the output moves from off state to V_{IN} then to $2V_{IN}$ and back to V_{IN} then off producing the positive half cycle. The transition for producing the negative half cycle is also achieved using by the inverted DC converter module section similar to the positive cycle process. For the cascaded input parallel output series shown in fig 1. The output is dependent on the PWM timing configuration govern by the novel PWM switching Output algorithm below

$$\text{if } (PWM_{1A \& 1B} == PWM_{2A \& 2B})$$

$$\text{Then } R_{L(P-P)} = 4 \times V_{IN} ;$$

$$\text{No. of Steps} = 2 ;$$

$$\text{Else if } (PWM_{1A \& 1B} \gg PWM_{2A \& 2B})$$

$$\text{Then } R_{L(P-P)} = 4 \times V_{IN}$$

$$\text{No. of Steps} = 4 ;$$

Therefore one can conclude for any N^{th} number of cascade with PWM signal time scaled by a factor $E = E \pm 1$, then the number of steps is given by $2N$ and the peak to peak voltage is given by $2N \times V_{IN}$. The advantage of higher step have been seen in several literature as they offer not only higher stable voltage but also extreme reduction in THD [1–11], [15]. Therefore by combining cascades with equal PWM and those with time scaled PWM the novel converter can achieve higher steps and amplitude for modular sources.

3. PWM Switching States

Each module of this multilevel converter consist of four MOSFET switch whose gating signal are systematically design using PWM technique. The switching state of each transistor in achieving the three fundamental operating mode earlier discussed in section II is summarized in the table 1. S_{1A}

represents the first switch in Module 1A and S_{1B} represent the last switch in the inverted Multilevel converter Module 1B (*labeling from top to bottom*)

Table 1. Converter switching state

V_{OUT}	S_{1A}	S_{2A}	S_{3A}	S_{4A}	S_{1B}	S_{2B}	S_{3B}	S_{4B}
V_{IN}	1	0	0	1	0	0	0	0
$2V_{IN}$	1	0	1	0	0	0	0	0
	0	1	0	1	0	0	0	0
V_{IN}	1	0	0	1	0	0	0	0
$-V_{IN}$	0	0	0	0	1	0	0	1
$-2V_{IN}$	0	0	0	0	1	0	1	0
	0	0	0	0	0	1	0	1
$-V_{IN}$	0	0	0	0	1	0	0	1

When the converter is in switching state for mode 1, (only switches S_{1A} and S_{4A} are on and all others are off), then

$$V_{OUT} = V_{IN1} \quad (1)$$

After a time τ the PWM frequency change and S_{1A} S_{3A} and S_{2A} S_{4A} are switched on as pairs complementarily with 50% duty cycle for a time $\tau + 1$ and hence

$$V_{C1} = V_{IN1} \text{ and } V_{C2} = V_{IN1} \quad (2)$$

$$V_{OUT} = 2V_{IN1} \quad (3)$$

After this switching state, the PWM frequency is returned back to its original state for another time τ where S_{1A} and S_{4A} are only on hence the output voltage falls back to

$$V_{OUT} = V_{IN1} \quad (4)$$

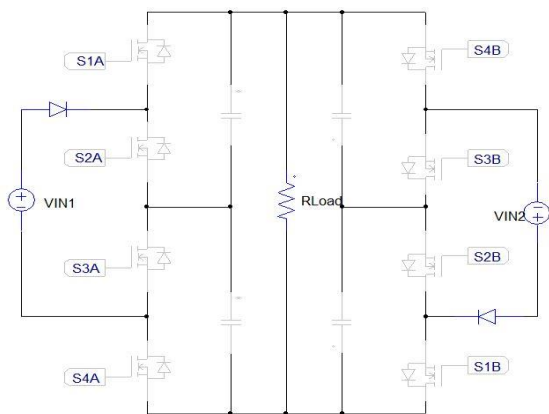
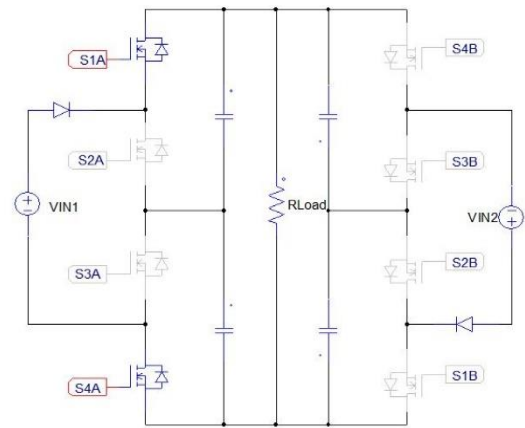
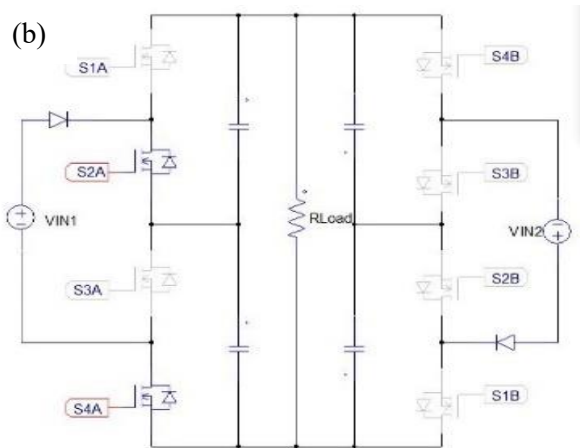
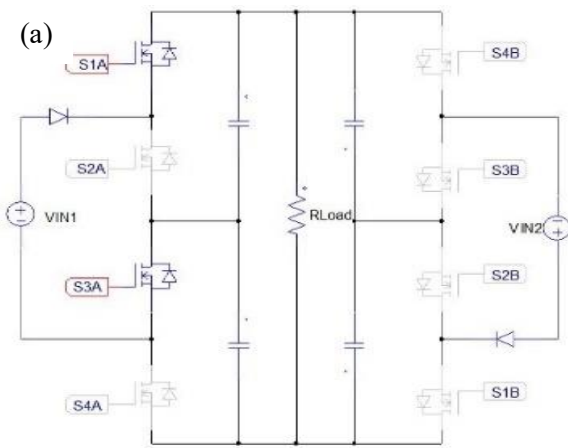
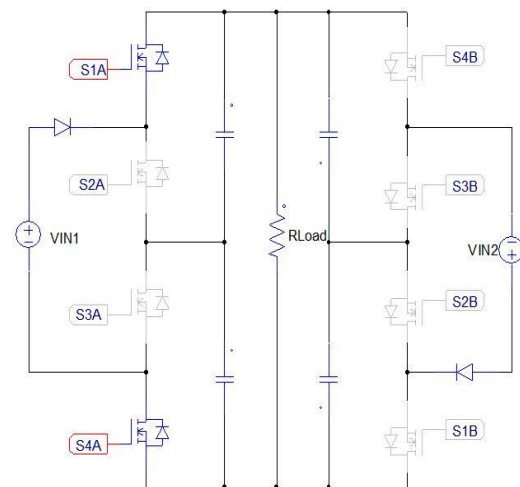
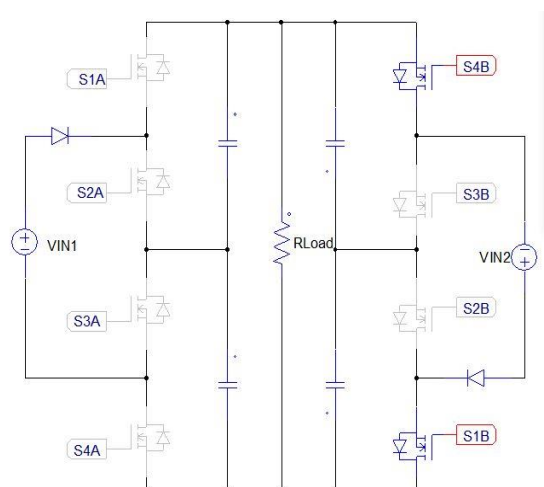
At the end of this cycle the inverted multilevel switch are then activated and the process is repeated producing the sequence from

$$-V_{IN2} \text{ to } -2V_{IN2} \text{ to } -V_{IN2} \quad (5)$$

The result of this is a positive and negative cycle of multilevel DC signal in time domain. The graphical illustration of the switching is illustrated in the next section

4. Result and Discussions

We have designed a novel multilevel DC converter for integrating modular energy sources (green renewable energy). The system is based on CMOS PWM gated switch. The switching states are given graphically in figure 3 to 11 below.

**Figure 3.** Converter at a $t < 0$ – all switch off**Figure 4.** $S1_A$ and $S4_A$ receive PWM signal**Figure 5.** Transition state to twice V_{IN} : PWM operate at High f . (a) $S1_A$ and $S3_A$ receive PWM signal for half time period. (b) $S2_A$ and $S4_A$ receive PWM signal for the second half time period**Figure 6.** Transition state back to V_{IN} **Figure 7.** Transition state from V_{IN} to $-V_{IN}$

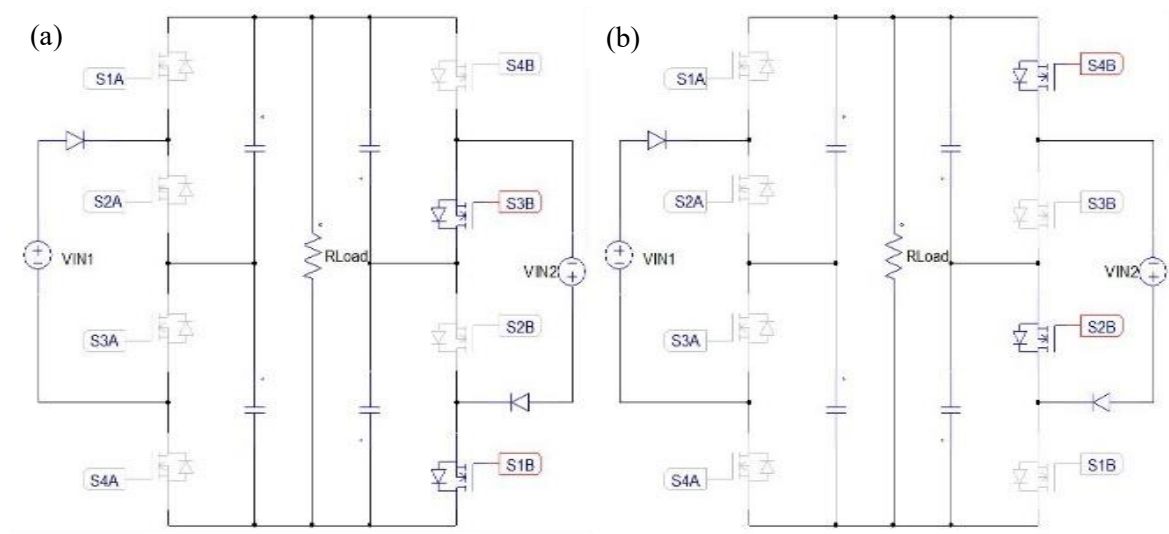


Figure 8. Transition state to twice $-V_{IN}$: PWM operate at High f . (a) $S1_B$ and $S3_B$ receive PWM signal for half time period. (b) $S2_B$ and $S4_B$ receive PWM signal for the second half time period

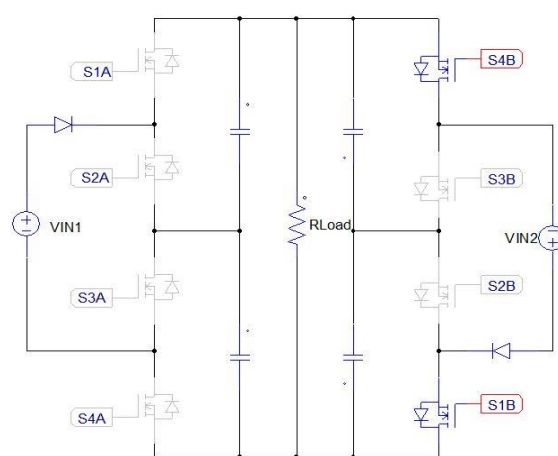


Figure 9. Transition state back to $-V_{IN}$

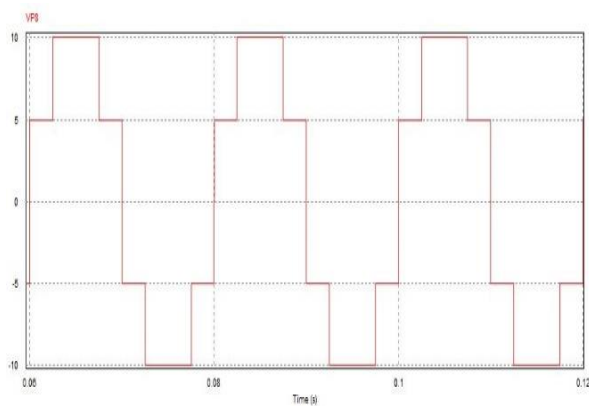


Figure 10. Multilevel full cycle output wave

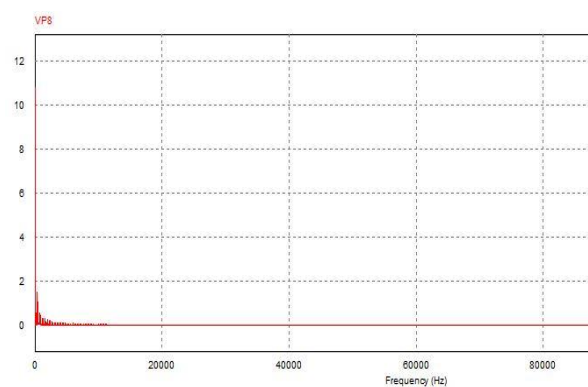


Figure 11. FFT of output wave

5. Conclusion

In this work, we have studied past designs of multilevel converters and now proposed a novel converter that take into account the modular structure of today's rising green renewable energy sources. The simulated efficiency of our converter system is 99% and with high total harmonic distortion (THD) reduction. The design is so simple yet efficient and the core of it is in the PWM switching, timing and delays. The base module can be cascaded to obtain higher steps and peak amplitudes. The future of this converter includes prototyping, adding simple first order low pass filters for real time testing and evaluation.

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