Modeling and Simulation of a Single Phase Matrix Converter with Reduce Switch Count as a Buck/Boost Rectifier with Close Loop Control

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Abstract **-** This Paper focused on Buck/Boost Rectification by Single Phase Matrix Converter with fewer numbers of switches. The conventional matrix converter consists of 4 bidirectional switches, i.e. 8 set of IGBT/MOSFET with anti parallel diodes. In this proposed matrix converter, only six switches are used. The switch commutation arrangements are also carried out in this work. The gate pulses to the switches are provided by the PWM techniques. Step up or step down DC outputs can be obtained by using suitable switching algorithm. The PSIM simulation results are provided to validate the feasibility of this proposed method.

Key words **-** *Single Phase Matrix Converter (SPMC) with Reduce Switch Count, Controlled Rectifier, Close Loop Buck/Boost Chopper Operation.*

I. INTRODUCTION

The usage of switch-mode power supplies (SMPS) is increased with the development of advanced semiconductor devices. The SMPS and other power switching circuits are used within the modern commercial and industrial environment. The four different conversions of supply are grouped to form SMPS. They are AC-AC, AC-DC, DC-DC and DC-AC conversions. In this AC-DC conversions are used in many portable applications. The converted DC supply has to be change according to the load connected to it. This is achieved by DC-DC chopper. Widely using DC-DC choppers are Buck (step down) and Boost (Step up).

The Matrix Converter (MC) topology was first introduced by Gyugyi in 1976 [2]. It is mainly used for AC-AC conversion. Other name for MC is PWM cycloconverter. It provides the all-silicon solution for AC-AC conversion by removing the DC link, which is used in conventional rectifier-inverter based system. Other advantages of MC are good input power quality, potentiality of increasing power density, reducing size and cost, bidirectional energy flow. The single phase matrix converter (SMPS) was first identified by zuckerberger in 1997 [1] as the direct single phase AC-AC converter. The MC is also capable of rectifying [5], inverting [4], and chopping [6].

The conventional SMPS consists of 4 bidirectional switches. Each switch is capable of blocking voltage and conducting current in both directions. The bidirectional switch is not readily available in market. So it is formed by connecting two IGBT with anti-parallel diode pair in series. Totally 8 switches are used in conventional SPMC. When we consider the SPMC for rectifier operation there is 2 switches which are unused for all purpose including safe commutation strategy [5] & [10]. Reduce switch count SPMC is obtained by removing the unused switches. The rectifier operation with this reduced SPMC was analyzed in [14]. This proposed paper deal with the realization of reduced switch count single phase matrix converter as a buck/boost controlled rectifier.

II. CONVENTIONAL BUCK/BOOST RECTIFIER

The conventional buck/boost rectifier topology is the combination of two different SMPS. First one is AC-DC SMPS by means of Diode bridge rectifier and next one is DC-DC conversion with the help of step down or step up chopper circuit. This is shown in the figure 1 and 2. The alternate rectifier is shown in the figure 3, provides the regenerative operation using the free wheeling diodes arranged in anti-parallel to the switch.

This rectifier with buck boost operation can also be obtained by using SPMC.

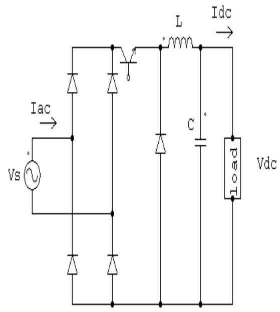


Fig. 1: Buck Rectifier

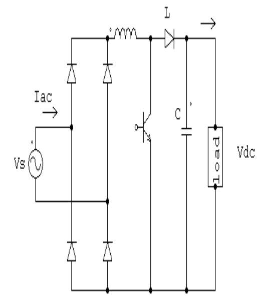


Fig. 2: Boost Rectifier

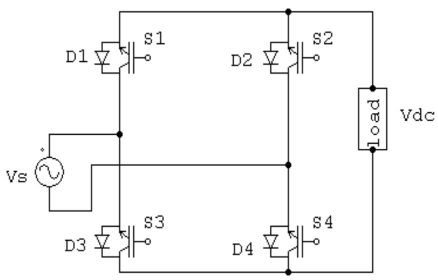
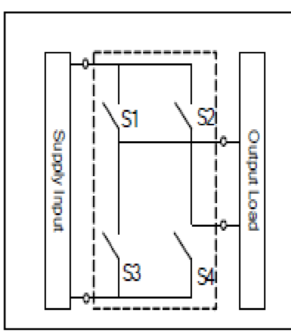


Fig. 3: Bridge Control Rectifier

III. SINGLE PHASE MATRIX CONVERTER

The conventional SPMC is shown in the figure 4. It consists of 4 bidirectional switches. There is no discrete semiconductor device for bidirectional switch and hence the common emitter anti-parallel IGBT, diode pair is used. The IGBT were used because of its high switching capabilities and high current carrying capacities. A single bidirectional switch is shown in the figure 5.



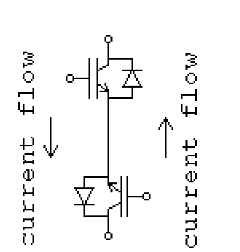
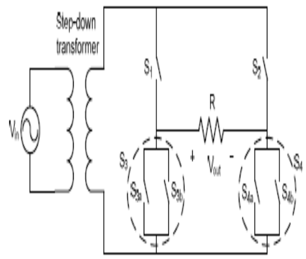


Fig.4: SPMC Topology Fig.5: Bidirectional Switch

IV. REDUCED SWITCH COUNT SPMC (RSC-SPMC) AS BUCK/BOOST RECTIFIER

The unused switches in the conventional SPMC are removed for rectifier operation and the same is shown in the figure 6.



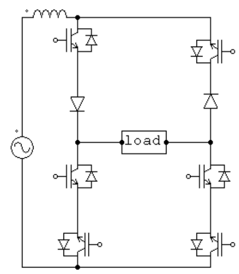


Fig. 6: RSC-SPMC Fig. 7: Buck/Boost RSC-SPMC

The figure 7 shows the arrangement of RSC-SPMC for Buck-Boost rectification. With this topology, both buck and boost operation can be carried out by using the required switching strategies

A. *Pulse Width Modulation (PWM)*

The PWM pulse is generated by comparing triangular carrier signal and DC reference signal. The modulation index m_a is getting changed by adjusting the amplitude of the reference and carrier signal, Hence the duty cycle of the gate pulse is varied to synthesize the required DC output from AC supply. The PWM pulse generation is shown in the figure 9. When the reference signal is higher than the carrier the pulse will generate.

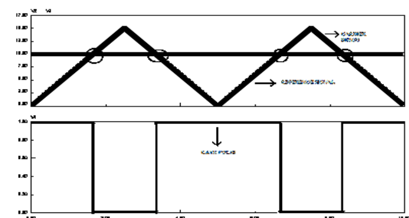


Fig. 8

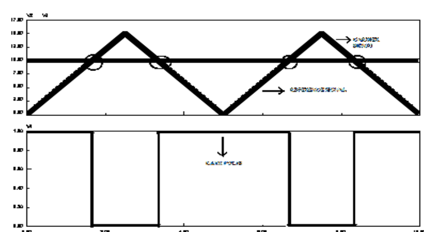


Fig. 9: PWM Pulse Generation

B. Commutation

The PWM switching in this converter, results with voltage spikes due to change in current in the inductor load, Hence in SPMC, systematic switching sequences are required to perform the work of freewheeling diode in conventional controlled rectifier that could be provided a path for current to dissipate during switches turn off. It will reduce the stress across the switches.

C. Modes of Operation

The two different switching strategies for 1) buck and 2) boost operation with RSC-SPMC is as described below:

1) Buck Converter: It consists of 4 modes of operation. For positive cycle, mode 1 and mode 2 are carried out, whilst mode 3 and mode 4 are carried out for negative cycle of the input supply. The respective modes of operation are shown in the figures 10-13.

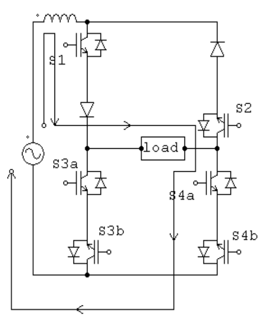


Fig.10: Mode 1

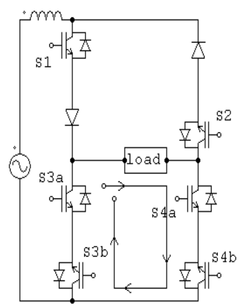


Fig. 11: Mode 2

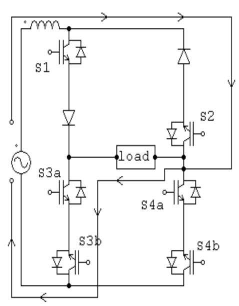


Fig. 12: Mode 3

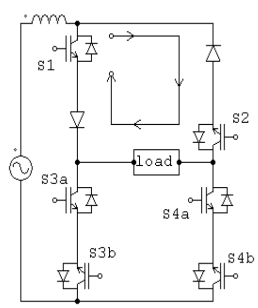


Fig. 13: Mode 4

The switching strategies for all modes of buck converter with RSC-SPMC topology are given in table 1 and the respective waveforms are shown in the figure 14. The output voltage is controlled by using the PI control method. The Buck rectifier with gate pulse generation and close loop arrangement is shown in the figure 21.

Table 1: Switching Strategies for Buck Converter

Switches	Positive cycle		Negative cycle	
	Mode 1	Mode 2	Mode 3	**Mode 4**
S1	ON	OFF	OFF	**OFF**
S2	OFF	OFF	ON	**OFF**
S3b	OFF	ON	ON	**ON**
S4a	**ON**	**ON**	**OFF**	**ON**

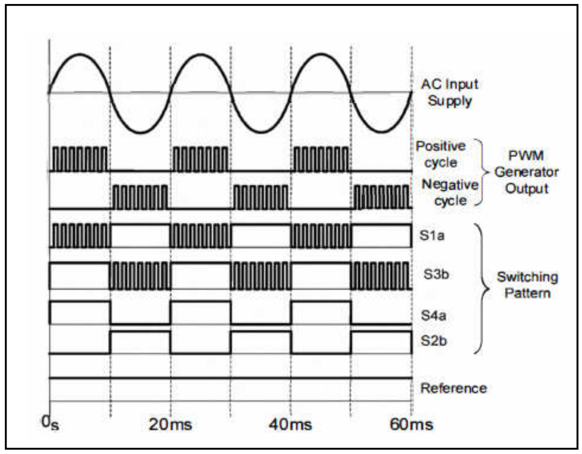


Fig. 14: Switching Pattern for Buck Converter

2) *Boost Converter* : The output DC voltage is greater than that of the input voltage. To get this output, there are 4 modes of operation. For positive cycle, first and second modes are in operation while third and fourth modes are for negative cycle. In mode 1, S1 and S3a switches are conducting to charge the inductor. In mode 2, S1 and S4a switches are conducting to supply the load. The energy stored in the inductor is discharge to the load. So load voltage is boosted in this mode. In mode 3, S2 and S4b switches are used to charge the inductor and in mode 4, S2 and S3b are used to supply the load. The modes of operations are shown in figures 16-19.

The switching algorithm for the boost RSC-SPMC is given in table 2 and the waveforms are shown in the figure 15.

The Boost rectifier with gate pulse generation and close loop arrangement is shown in the figure 20.

Table 2: Switching Strategies for Boost Converter

Switches	**Positive cycle**		**Negative cycle**	
	Mode 1	Mode 2	Mode 3	**Mode 4**
S1	ON	ON	OFF	**OFF**
S2	OFF	OFF	ON	**ON**
S3b	OFF	OFF	OFF	**ON**
S4a	OFF	ON	OFF	**OFF**
S3a	ON	OFF	OFF	**OFF**
S4b	**OFF**	**OFF**	**ON**	**OFF**

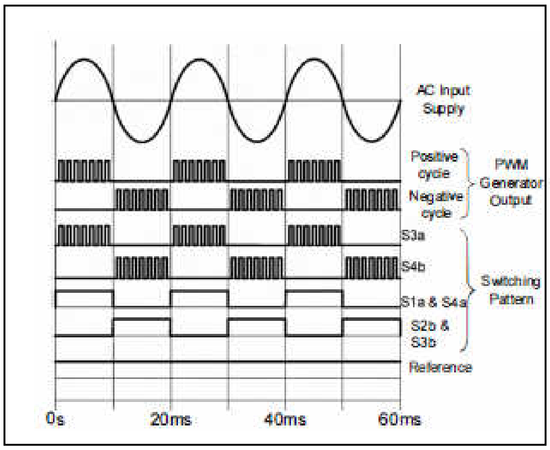


Fig.15 : Switching Pattern for Boost Converter

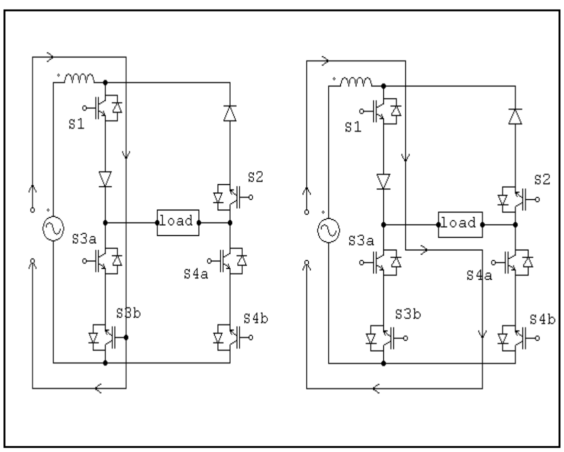
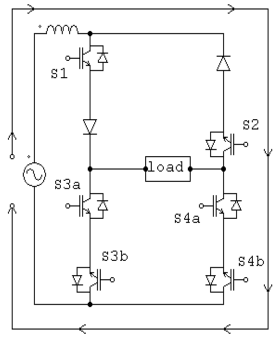


Fig. 16: Mode 1 Fig. 17: Mode 2



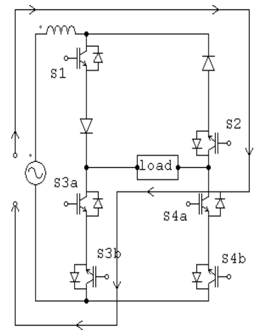


Fig. 18: Mode 3 Fig. 19: Mode 4

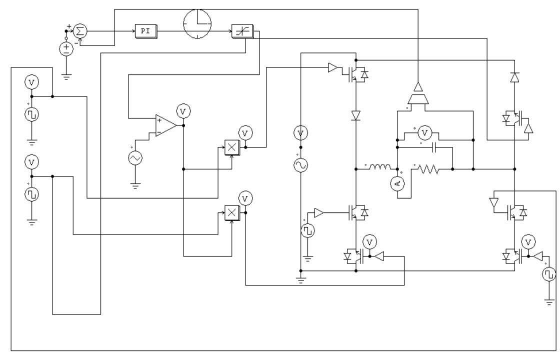


Fig. 20: RSC-SPMC Buck Converter with Close Loop Boost Rectifier

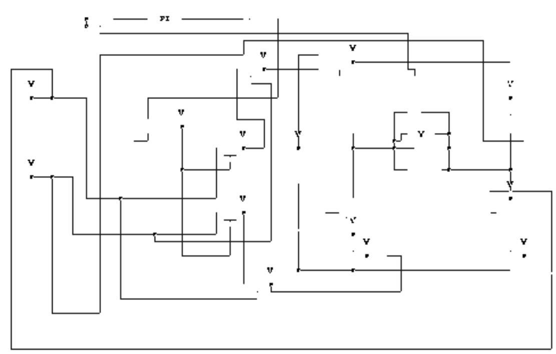


Fig. 21: RSC-SPMC Close loop Buck Rectifier

V. SIMULATION RESULTS

The verification of the buck and boost operation with SPMC is done in the PSIM simulation software. The simulation diagram of Buck and Boost rectifiers are shown in the figure 22 and 23 respectively. The switching algorithm is get differ for both topology while the power circuit is same.

The input power supply is 100 V AC and the load parameters are R = 300 Ω and C = 1000 μF. The switching frequency is 5 KHz. The IGBT with parallel diode is used as a power switch.

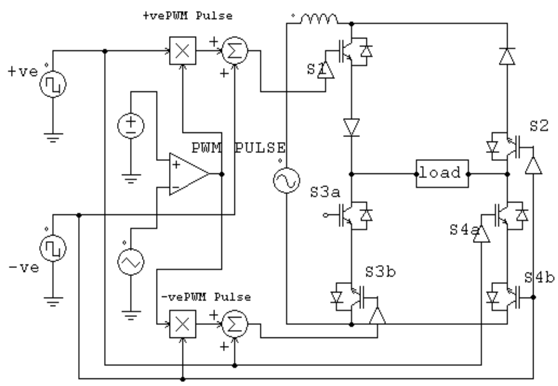


Fig. 22 : Simulation Circuit for Buck Converter

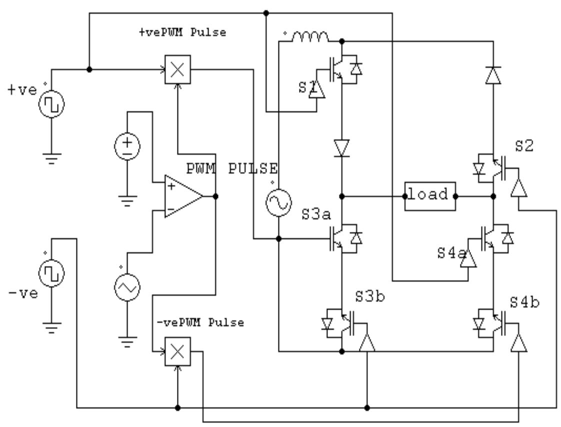


Fig. 23 : Simulation Circuit for Boost Converter

The figure 24 and 25 shows the boost rectification output. By varying the modulation index, the amplitude of the output can be change. For m_a = 0.5, the output is less than 150V, while m_a = 0.8, the output is greater than 150V. Figure 26 and 27 are shows the output of close loop boost converter.

The figure 28 and 29 verify the buck rectification, here also by varying the m_a, the DC output can be change. For m_a = 0.5, the output is less than 50 V while m_a = 0.8, the output is 90V. Figure 30 and 31 are shows the output of close loop buck converter.

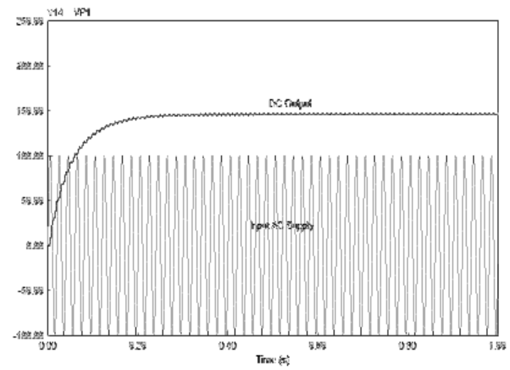


Fig. 24: Boost Output – Input is 100V AC and the Output is 145V DC for m_a – 0.5

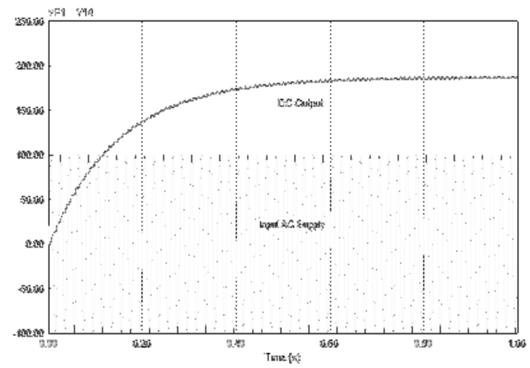


Fig. 25: Boost Output – Input is 100V AC and the Output is 180V DC for m_a – 0.8

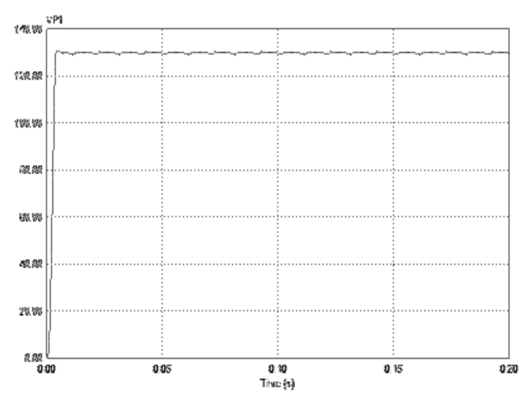


Fig. 26 : Close Loop Boost Converter Output – Input is 50V AC and Output is 130 V DC

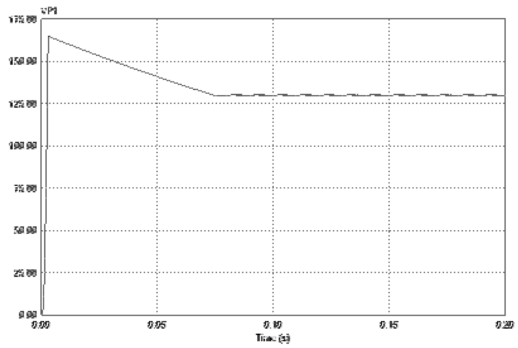


Fig. 27: Close Loop Boost Converter Output – Input is 80V AC and Output is 130 V DC

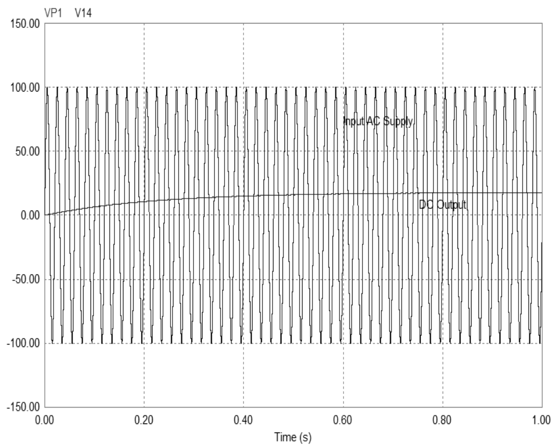


Fig. 28: Buck Output – Input is 100V AC and the Output is 20V DC for m_a – 0.5

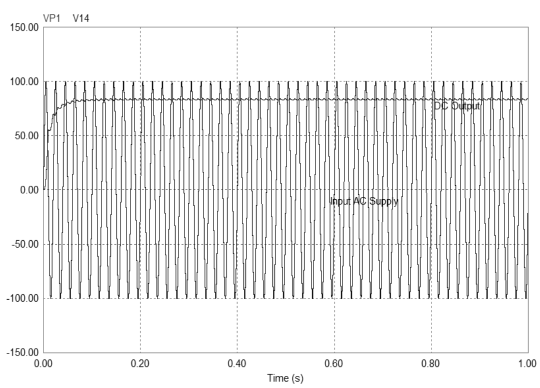


Fig. 29 : Buck Output –Input is 100 V AC and Output is 90 V DC for m_a – 0.8

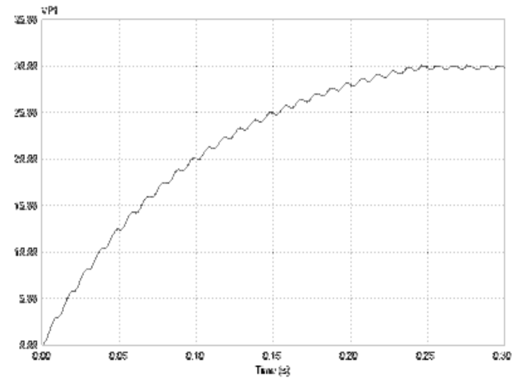


Fig. 30: Close Loop Buck Converter Output – Input is 70V AC and Output is 30 V DC

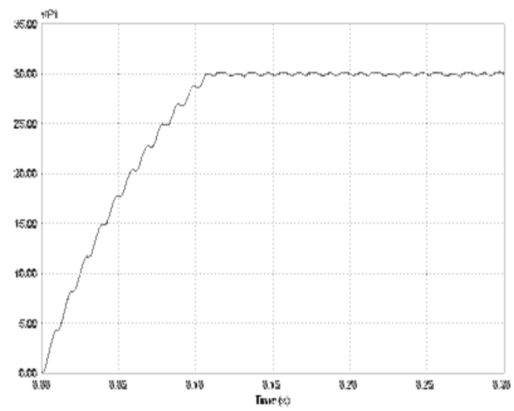


Fig. 31: Close Loop Buck Converter Output – Input is 100V AC and Output is 30 V DC

VI. CONCLUSION

Successful investigation of SPMC as a Buck or Boost controlled rectifier with reduced switch count is outlined. The PSIM simulation outputs were observed to confirm the predicted performance of the proposed topology. Required outputs were obtained by using the suitable switching algorithm with PWM technique. This SPMC can be finding application in wind energy system. The output of smallest wind energy system is maybe three phases or single phase ac signal. Mostly we prefer three phase output since it reduces line loss, and runs with less vibration, but in some cases single phase is sufficient such as wind turbine (with power rating less than 1kw) used to charge batteries for sailboats, cabins, and small homes. In that case, this proposed matrix converter can be use.

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