# Diode-Clamped Based Indirect Matrix Multilevel Converter Topology

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**Abstract—This paper presents a novel sparse matrix converter configuration that needs no bulky energy storage capacitors or inductors, and employs only unidirectional power semiconductor switches. The source side bridge is switched at the line frequency and therefore, this allows the use of the low speed high power rating switches. This feature and the use of diode-clamped multilevel topology at the output stage make this new matrix converter suitable for medium to high power applications and improves the output voltage quality. Compared to the existing multilevel matrix converter topologies, the proposed topology requires no flying or extra capacitor, a smaller number of switches and a simpler modulation strategy. Simulation results for a 220v/60Hz input source and 20KVA load show that the proposed AC/AC topology has input unity displacement power factor, high (0.95 to 0.88) input power factor for different load Conditions and controllable output voltage at a desired frequency.**

## I.INTRODUCTION

Different circuit topologies have been developed to convert AC power at one frequency to AC power at another frequency. In conventional methods, the AC power is first rectified and then is converted back to AC power at a different frequency. An alternative approach is the Matrix Converter (MC) technology [1], where the input AC power is directly converted to output AC power using a matrix of bidirectional switching elements, Fig. 1. Both topologies can provide controllable sinusoidal output voltages and input currents. Compared to the conventional back to back converter, the MCs are compact, more reliable, and do not needs an extra voltage control strategy for the DC-link capacitor. Due to complicated modulation algorithms and the utilization of the bidirectional switches, conventional MCs have not been widely adopted. With respect to the early modulation techniques, a conceptually different control technique was introduced in 1983 [2] which led to the invention of the two stage direct power conversion topology. Based on this modulation technique a new class of converter topologies was invented which was simpler. These converters are also known as ”indirect MC (IMC)”, ”dual bridge MC” or ”sparse matrix converter” , [3]–[7]. These advances have made matrix converters more feasible and practical. Nevertheless, the application of matrix converters is still limited to low and medium voltage levels. Multilevel converter topologies, on the other hand, are well known solutions for medium and high power applications. Among various multilevel topologies, the most important ones are [8]: Diode-Clamped Multilevel Converter (DCMC) [9], Flying Capacitors Multilevel converters (FCMC) [10] and Cascaded Multilevel Converters (CMC). Therefore, various combinations of these topologies, known as Multilevel Matrix Converters (MMC), have been developed for high power direct AC to AC power conversion. The first attempt for developing MMCs incorporates the CMC topology, and was reported in [11]. The other approach uses the FCMC topology to form a MMC [12]. Although both techniques are innovative and interesting, they utilize excessive number of capacitors that also need to be balanced. This contradicts one of the MC objectives which was the elimination of capacitors from the converter topology. On the contrary, this paper presents a novel MMC that employs diode clamped multi-level topology in a sparse matrix converter configuration that does not utilize extra capacitors and also the cumbersome voltage balancing strategies are not necessary anymore. Similar to conventional converter topologies, the proposed topology uses unidirectional switches and consequently uses less switches than the two previously MMCs.

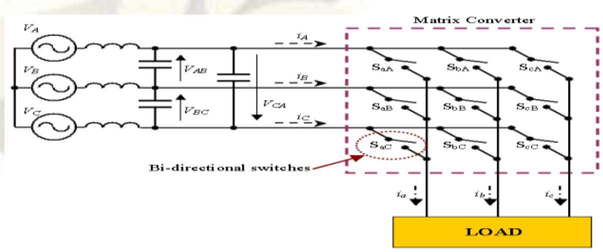
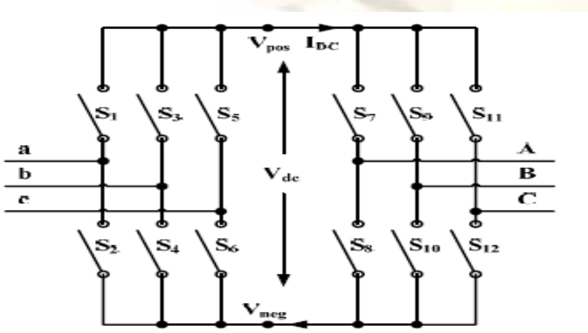



Figure 1. Conventional indirect matrix converter topology.

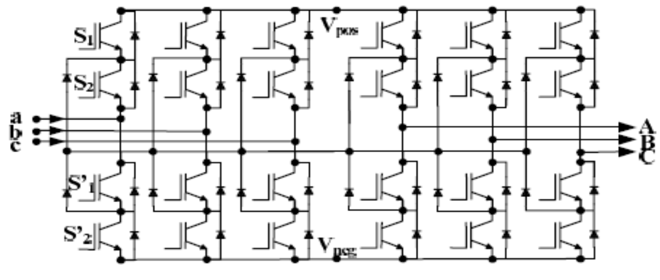
A point worth mentioning would be that since the source-side bridge is switched at the source frequency, switching losses are limited to the lowest possible level. Furthermore, the modulation strategy used for this topology is simple and similar to the conventional converters and does not have the complexity of the existing MMCs. Simulation results show that the proposed AC/AC topology has input unity displacement power factor, high (0.95 to 0.88) input power factor for different load conditions and controllable output voltage at a desired frequency. The simulations are carried out for a 220v/60Hz input source and 20KVA load at 100Hz.

## II. BASIC MATRIX CONVERTER TOPOLOGY AND INDIRECT MATRIX CONVERTERS (IMC)

Since the multilevel matrix converters are based on basic MC and IMC topologies, these basic topologies are reviewed in this section. The basic 3φ −3φ matrix converter topology is shown in Fig. 1. This configuration of bidirectional switches enables the connection of any of input phase a, b, or c to any of output phase A, B or C at any instant. Different modulation techniques such as triangular wave voltage command modulation [13] and space vector modulation (SVM) [14], [15] were developed for matrix converters. The indirect modulation technique was a conceptually different technique introduced in 1983 [2], which divided the MC into two parts. With the two partitions, it resembled the conventional back to back topology, but instead it uses the idea of a fictitious DC-link rather than a real rectified DC- link. The objective of the modulation strategy is to synthesize the output voltages from the input voltages and the input currents from the output currents. Thus, the matrix converter is described by an equivalent circuit combining current source rectifier and voltage source inverter connected through virtual dc link as shown in Fig. 2(a). The inverter stage has a standard 3φ - 3φ voltage source inverter topology consisting of six switches, $S_7 - S_{12}$and rectifier stage has the same power topology with another six switches, $S_1 – S_6$. Both power stages are directly connected through virtual dc-link and inherently provide bidirectional power flow capability because of its symmetrical topology.




(a)



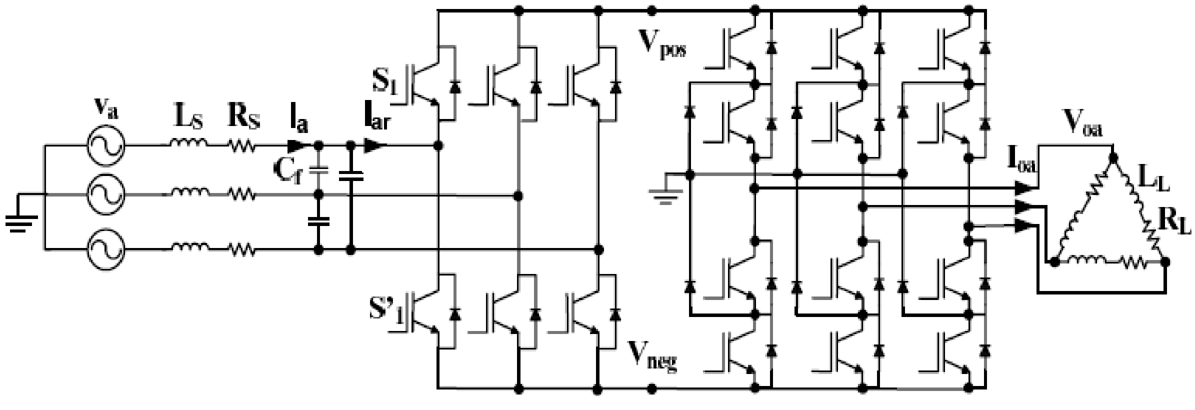

(b)

Figure 2. (a) Indirect Matrix Converter (b) One possible Multilevel matrix converter topology

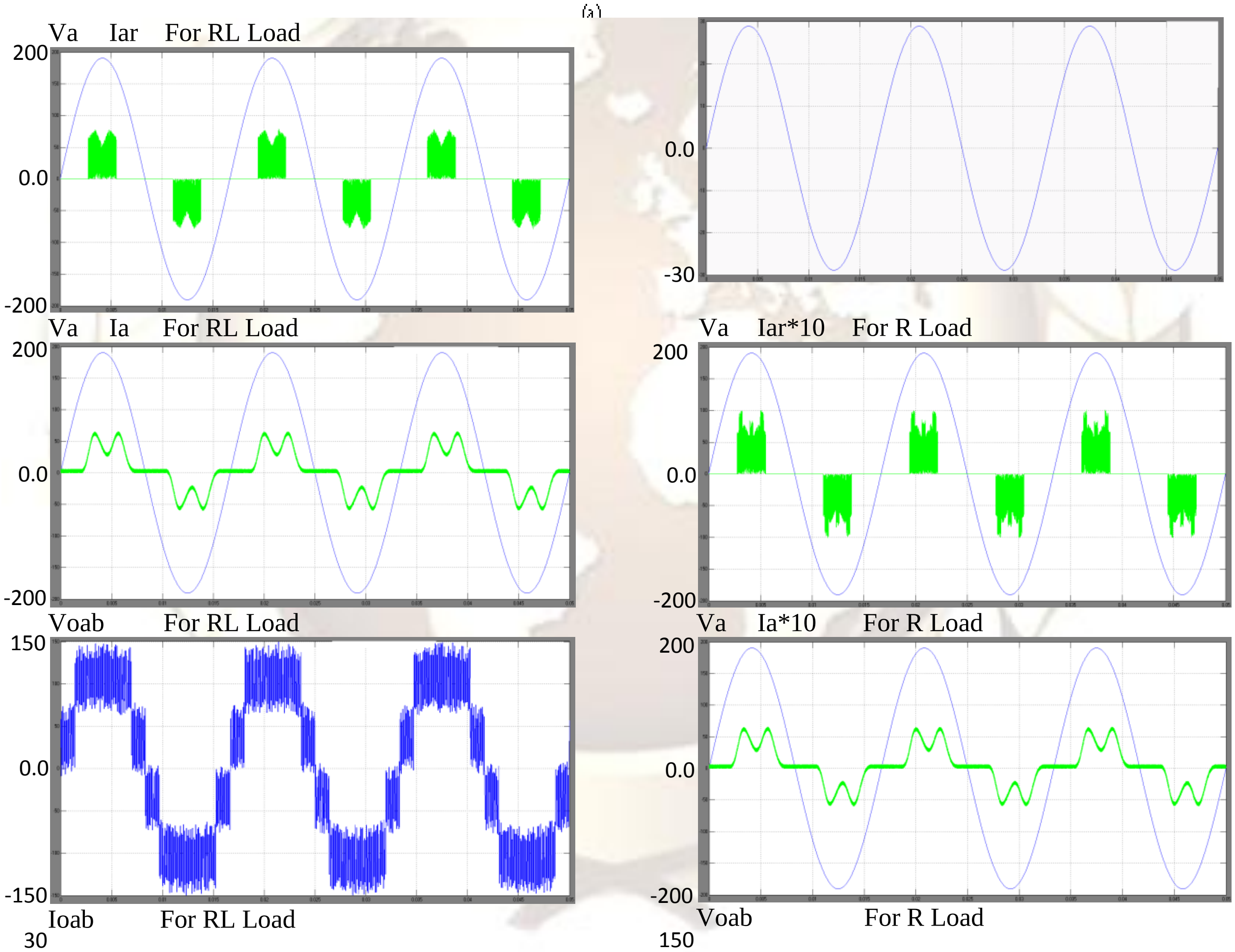
The main idea is to decouple the control of the input current and output voltage. This is done by two steps; first, by using SVM the rectifier is switched to form the input current, to keep the input power factor close to unity and to generate dc voltage at the dc bus. Secondly, based on this dc voltage the inverter is switched to generate controllable output voltages, [2], [14]. Having found the switching patterns for the equivalent circuit, it is quite straightforward to find the equivalent switching functions for the conventional matrix converter shown in Fig.1, [2]. Although the equivalent circuit shown in Fig.2(a), was originally used to find the modulation strategy for the conventional matrix converter, this concept can be physically implemented as a matrix converter topology for direct conversion. These types of converters are also known as ”indirect MC (IMC)”, ”dual bridge MC” or ”sparse matrix converter”. Different topologies are derived from this concept. For the IMC a conventional (two-quadrant switch) voltage-source type inverter is fed by a four-quadrant switch current-source type rectifier which is able to operate with positive and negative DC current for unipolar DC link voltage as required by the inverter stage. Since the dc link voltage is unipolar, the number of switches in the topology can be reduced, [4]. Another IMC topology is a hybrid of the matrix converter and the conventional back to back converter, [16]. In this configuration the bidirectional switches of the IMC topology are replaced with unidirectional ones.

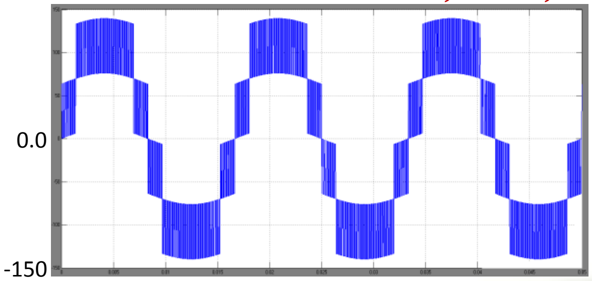
## III. EXISTING MULTILEVEL MATRIX CONVERTER TOPOLOGIES

To increase the power level, achieve higher efficiency, and provide better output voltage quality, the multilevel concepts have been adapted to develop multilevel matrix converter topologies. The first attempt was inspired by CMC topology [11] which utilizes conventional matrix converter with four-quadrant switch cells. The other multilevel matrix

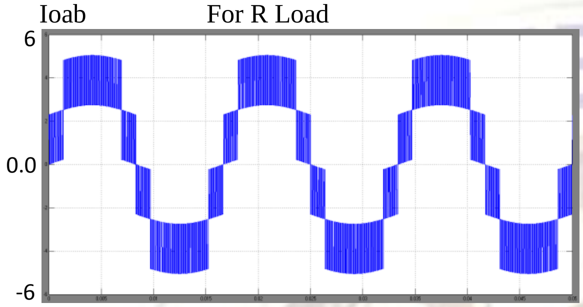

Va
Ls
Rs
Ia
Iar
Cf
S1
S'1
Vpos
Vneg
Voa
Ioa
LL
RL

(a)

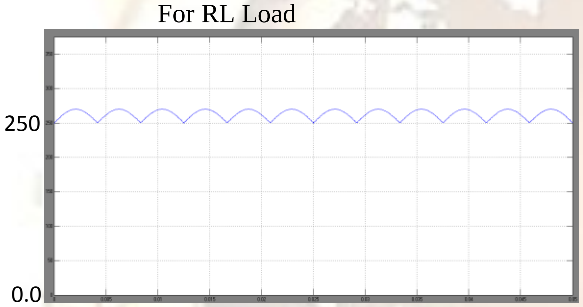

Va Iar For RL Load
200
0.0
-200
0.0
-30
Va Ia For RL Load
200
0.0
-200
Va Iar*10 For R Load
200
0.0
-200
Voab For RL Load
150
0.0
-150
Va Ia*10 For R Load
200
0.0
-200
Ioab For RL Load
30
Voab For R Load
150




Ioab For R Load

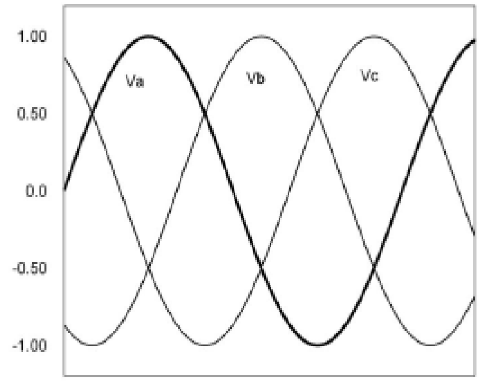


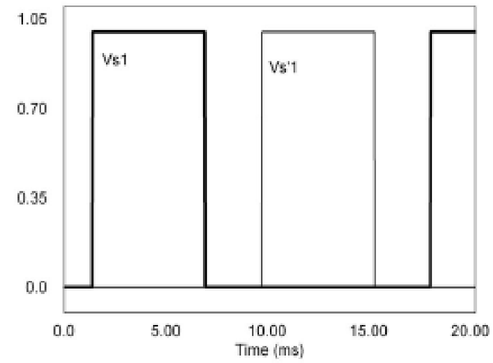

Vpos – Vneg
For RL Load




(b)

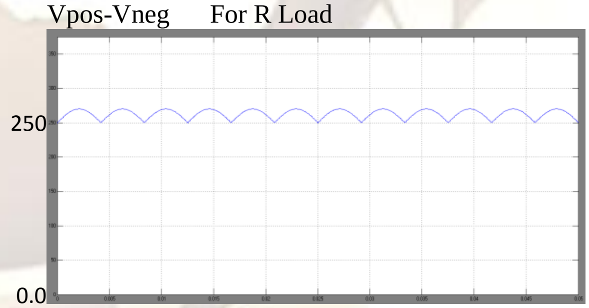
converter introduced in the literature [12] is a hybrid of the FCMC idea and the Matrix converter topology. Although both techniques are innovative and interesting, they incorporate capacitors that need to be balanced and consequently complicates the control process. On the contrary, in the conventional MCs the use of capacitors were avoided to allow a more compact form and greater longevity. Moreover, the other two existing multilevel matrix topologies, [11], [12], use 36 switches in addition to six and nine capacitors respectively, while the proposed topology in this paper uses only 24 switches.




Another shortcoming of the FCMC matrix converter is that the input current waveforms and input power factor are not controlled even thought it is one of the main objectives of the matrix converters.

Vpos-Vneg For R Load




(c)

Fig 3(a) indirect multilevel matrix converter topology (b) simulation results for R=5Ω $L_L$=3mH (c) simulation results for R= 50Ω$L_L$=0mH.

## IV. DIODE-CLAMPED BASED MULTILEVEL MATRIX CONVERTERS

Considering the IMC topologies mentioned in section II, other implementations of multilevel matrix converters are possible. For this purpose, the inverter and the rectifier stages can be replaced with the multilevel converter circuit as shown in Fig. 2(b). The neutral point of the two converters are connected together and instead of two buses three current passes exist between rectifier and inverter stages. On the other hand, to avoid spikes and high current surges, the input voltage sources should not be short circuited and the output current should always find a path to flow.

But satisfying these rules for the three buses makes the modulation very complicated and it can be shown that under some circumstances for higher number of levels it is not possible to comply with the rules. However, another configuration is possible which does not have the aforementioned problems. If the input current rectifier stage remains as a two level converter, the result would be a simpler topology as shown in Fig. 3(a). In Fig. 3(b), the rectifier stage is switched at the line frequency, and because low frequency, high power and high voltage switches are available in the market with reasonable prices, there is no need to substitute this stage with multilevel converter. It is worth mentioning that the neutral point of the multilevel stage is connected to ground to keep it at zero voltage and the two positive and negative buses are supplied by the two level rectifier stage. As demonstrated in Fig. 3(b),4, the rectifier stage is synchronized with the source voltage. Therefore, the fundamental harmonics of the input currents are in phase with the corresponding source voltages. Utilizing basic SVM techniques for multiplexed inverters, the output stage can be controlled to generate controllable AC voltage wave
forms with a desired frequency. To prevent a short circuit at the input stage and an open circuit at the output stage certain precaution must be taken. To avoid an open circuit, the rectifier stage is switched at the zero vector period of the multilevel inverter stage. The short circuit problem occurs if more than two switches among upper or lower switches are turned on. However, this is prevented by using the simple switching pattern illustrated in Fig. 4, because as soon as an upper switch is turned off, another upper switch will be turned on.

## V. SIMULATION RESULTS

The simulation results in Fig. 3 confirms the operation of the proposed multilevel matrix converter. Using the circuit in Fig. 3(a), computer simulation are carried out for two different sets of R-L loads. The circuit parameters used in simulation are shown in Table I.

TABLE I
SYSTEM PARAMETERS FOR SIMULATION

| *Parameter* | *Values* |
|---|---|
| $L_s$ | $30\mu$ |
| $R_s$ | $0.1\Omega$ |
| $C_f$ | $10\mu$ |
| $V_{input}$ | $220V_{l-l}(rms)$ |
| $f_{input}$ | 60Hz |
| $f_{out}$ | 100Hz |
| $f_{sw}$ | 10KHz |

It is shown in Fig. 3 that the displacement power factor for the input stage is almost unity for the two different operating points. The input current total harmonic distortion is much better than that of the diode rectifier with dc-link capacitor, but worse than that of the PWM boost converter. However, this level of distortion is usually acceptable for most of the applications. The efficiency of the proposed topology is higher, because of the less reactive components and the lower switching frequency at the rectifier stage.

## VI. CONCLUSION

This paper presents, a new AC/AC power converter that is suitable for high power applications. The proposed multi-level matrix converter topology is based on diode clamped multilevel converter at the output stage and input rectifier using unidirectional switches. Therefore, compared to other existing MMCs, it utilizes the least number of switches and minimizes switching losses. Because of the multilevel output waveforms, the output power quality is significantly improved. This topology does not require bulky DC-link capacitors, heavy input inductors or highly controlled flying capacitors and only uses small input filter capacitors. Principle of operation and characteristics of the converter were investigated and its feasibility is illustrated by simulation results for a 20KVA load. It is shown that for different loads, the output voltage is controllable at the desired frequency and the unity displacement power factor is achieved at the input stage. In conclusion it is worth mentioning that the proposed MMC topology is based on three level diode-clamped converter and further research is required for higher number of levels.

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