

## AC-AC POWER CONVERTERS – OVERVIEW AND APPLICATION

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*A direct AC – AC conversion has many attractive features. This paper discusses most applied converter topologies in industrial electronics-voltage regulators, induction motor drives, wind power conversion systems and other. A comparison between two of recently used types of converters (matrix and with DC-link) is given. Matrix converters are considered in more details, with their characteristics such as four-quadrant operation, unity power factor and high-quality waveforms.*

**Keywords:** AC-AC conversion, power converters, matrix converters.

### 1. INTRODUCTION

AC-AC power converters has many applications such as power regulators, induction motor drives, direct conversion systems in wind generators and many others. They are devices, which use a semiconductor switches in a different configuration of connection. These converters are unidirectional or bi-directional power flow compatible in function of used electric configuration, elements and application. In today of power applications high-power MOSFET or IGBT- switches are used, driven by various commutation strategies and modulation techniques. The main aim is to obtain an high-quality power conversion, minimum losses, high efficiency and low cost.

A different converters topologies are known since 70-th and 80-th years of the last century. Some of them has an thyristor implementation with natural commutation. A today's used elements requires some kind of high performance commutation strategies to comply with the application requirements.

In the present AC-AC converters are divided on two basic topologies (Fig.1):

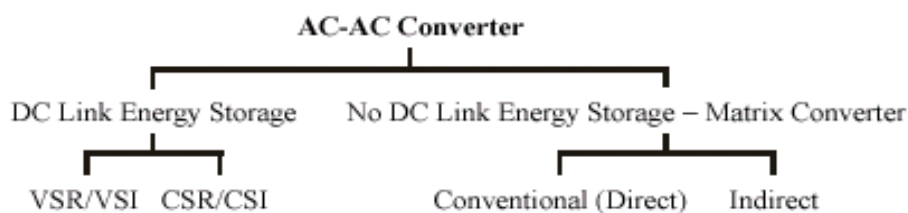


Fig.1.Different converter topologies

### 2. FEATURES OF BASIC CONVERTERS TOPOLOGY

DC-Link Converters-In basic configuration they have two sections-a rectifier stage and an inverter stage. A typical configuration use large and expensive energy storage intermediate elements such as inductors and capacitors. This is a main disadvantage of these type converters. A rectifier bridge and an inverter bridge uses unidirectional or bi-directional switches and detached way of commutation. Depen-

ding of used energy store elements there are two main configurations, called DC current link (inductor-CSR/CSI) or DC voltage link (capacitor-VSR/VSI) Modification of some converter topologies may include diode bridge clamp circuits, thyristor choppers and other additional elements. A basic circuit is shown on Fig.2:

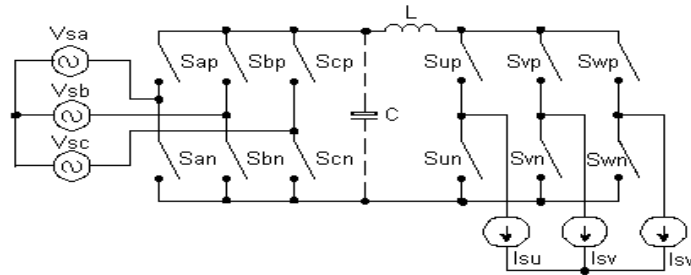


Fig.2.DC-Link Converter Topology

Because energy store elements are needed, for the purpose of direct conversion systems, requirements for their characteristics are strict and complex. These converters are also needed of additional filter elements for the output and input. The quality of output waveforms, harmonics and phase displacement of current depends on stability of the DC link voltage, commutation of rectifier/inverter stage and other. Power factor correction circuits is usually recommended. In attempt to obtain improved input and output characteristics some authors suggest upgraded DC-link converters (resonant link converter, HF link converter) [4,5].

Matrix converters: this type of converters has a simple structure and many attractive features. Its main advantages are adjustable (including unity) power factor, bi-directional power flow and possibility of a compact design due to the lack of large energy storage elements compared to a conventional AC/DC/AC converters. Furthermore reactive elements on the input and output can be replaced with small AC-filter elements due to low harmonic distortion of waveforms. Matrix converters can regenerate energy back into the mains from the load side, where the mains current is sinusoidal and the displacement factor seen by the mains can be adjusted by proper modulation irrespective of the type of load.

One of major disadvantages of this topology is large number of switches, usually with bi-directional configuration. This requires a complex and different comutation strategy, including more isolated driver circuits and complicated switching algorithm.

Basic topology of this type converter is shown on Fig.3:

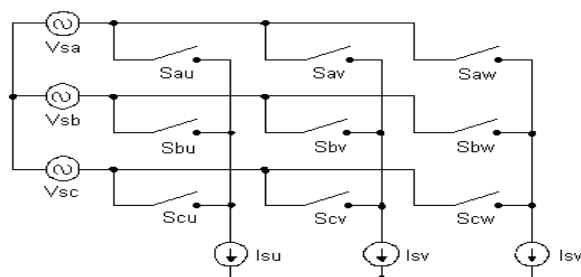


Fig.3: Conventional Matrix Converter

Because of difficult commutation and modulation strategies, needed for proper operation, matrix converters has not been widely adopted in industry. There are a number of publications, discuss an alternative topologies, presented by some authors like J.Kolar, L.Wei, T.Lipo and other [8,9].The main aim is to reduce number of switches and driver circuits, as well as to simplify modulation and commutation strategies. These converters are called “indirect”, ”dual-bridge”, ”sparse matrix” and other. As a result the application of these topologies is somewhat limited, but suitable for some cases. Characteristics of these converters are investigated and discussed in papers, and they will not be presented with more details here. In part, next table shows properties of some matrix topologies:

TABLE I.  
CONVERTER TYPE PROPERTIES

Converter Type	Transistors	Diodes	Isolated Drivers
Conventional	18	18	6
Indirect	18	18	8
Sparse Matrix	15	18	7
Ultra Sparse	9	18	7

A comparison between two basic topologies of AC-AC conversion is shown in Table 2. Different converters has application, depending of their features and disadvantages. In present, the matrix converters offer attractive all-silicon solution of energy conversion. With proper modulation strategies they propose better performance when sinusoidal input currents or true bi-directional power flow is required. No large energy storing elements are needed. Thus following section will discuss in more details properties and application of matrix converters.

TABLE II  
COMPARISON OF DIFFERENT CONVERTER TOPOLOGIES

Topology	Transistors	Fast diodes	Rectifier diodes	Large electrolytic capacitors	Large Inductors
Matrix	18	18	0	0	0
DC-link	12	12	0	1	3

### 3. MATRIX CONVERTERS-TECHNOLOGY AND APPLICATION

As discussed before, with proper commutation and modulation strategies applied to matrix converters can be reached high quality waveforms and high efficiency of power conversion.

Reliable current commutation between switches in matrix converters is more difficult to achieve than in conventional converters since there are no natural free wheel path. It has to be active controlled at all times with respect to two basic rules:

- avoid short circuit in the input
- avoid open circuit in the output

These two critical conditions may cause overcurrents and overvoltages due to stored inductive energy, and may damage the converter.

Two simplest forms of safety commutation is called as follows “overlap commutation” and “dead-time commutation”.

In overlap commutation, the incoming cell is fired before the outgoing cell is switched off. This would normally cause a line-to-line short circuit but extra line inductance slows the rise in current so that safe commutation is achieved. This is not desirable method since the inductors used are large and expensive. The switching time for each period is also greatly increased, which may cause control problems.

Dead-time commutation uses a period where no switches is turned on, causing a momentary open circuit of the load. Snubbers or clamp circuits are then needed across the commutation cells to provide the path for the load current. This method is undesirable since energy losses in additional circuits in every switching period. Bi-directional nature of commutation cells further complicates the snubber design. Clamping devices also have large dimensions, which remove advantage of matrix converters to be smaller.

A more reliable method of commutation, which obeys the above rules, uses a multi-step commutation strategy, in which current direction of current flow can be controlled. In basics principles of multi-step commutation allow with proper algorithm to be provided path for inductive load currents without additional free wheeling diodes and other. Depends on switch-ing state periods there are two types: four-step or two-step commutation. This method of driving the semiconductor devices often is also called semi-soft switching [6,7]. An example circuit and state diagrams are shown at Fig.4 and Fig.5:

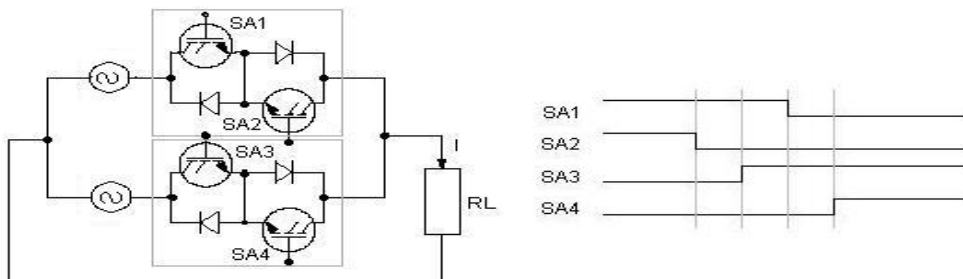


Fig.4:2 phase to single phase matrix converter Fig.5:Switching state diagram for 4-step commutation

Modulation strategies in matrix converters has important part in achieving a high efficiency of power transfer and wide range of application. The output waveforms are formed by selecting each of the input phases in sequence for defined periods of time. The output voltage consists of segments made up from three input voltages. The input currents consist of segments of three output currents plus blank periods during which the output current freewheels through the switch matrix.

The modulation problem is usually posed assuming a sinusoidal output voltage and sinusoidal input current is required as follows. Given a set of input voltages and an assumed set of output currents:

$$[v_i(t)] = V_m \begin{bmatrix} \cos(\omega_i t) \\ \cos(\omega_i t + 2\pi/3) \\ \cos(\omega_i t + 4\pi/3) \end{bmatrix} \quad [i_o(t)] = I_{out} \begin{bmatrix} \cos(\omega_o t + \phi_o) \\ \cos(\omega_o t + \phi_o + 2\pi/3) \\ \cos(\omega_o t + \phi_o + 4\pi/3) \end{bmatrix} \quad (1)$$

Find a modulation matrix  $M(t)$  such that:

$$[v_o(t)] = qV_m \begin{bmatrix} \cos(\omega_o t) \\ \cos(\omega_o t + 2\pi/3) \\ \cos(\omega_o t + 4\pi/3) \end{bmatrix} \quad [i_i(t)] = qI_{out} \begin{bmatrix} \cos(\omega_i t + \phi_i) \\ \cos(\omega_i t + \phi_i + 2\pi/3) \\ \cos(\omega_i t + \phi_i + 4\pi/3) \end{bmatrix} \quad (2)$$

There are 2 basic solutions to this problem derived by Venturini [10]:

$$[M1(t)] = \frac{1}{3} \begin{bmatrix} 1+2q\cos(\omega_m t) & 1+2q\cos(\omega_m t - 2\pi/3) & 1+2q\cos(\omega_m t - 4\pi/3) \\ 1+2q\cos(\omega_m t - 4\pi/3) & 1+2q\cos(\omega_m t) & 1+2q\cos(\omega_m t - 2\pi/3) \\ 1+2q\cos(\omega_m t - 2\pi/3) & 1+2q\cos(\omega_m t - 4\pi/3) & 1+2q\cos(\omega_m t) \end{bmatrix}$$

in this case:  $\omega_m = (\omega_o - \omega_i)$  (3)

$$[M2(t)] = \frac{1}{3} \begin{bmatrix} 1+2q\cos(\omega_m t) & 1+2q\cos(\omega_m t - 2\pi/3) & 1+2q\cos(\omega_m t - 4\pi/3) \\ 1+2q\cos(\omega_m t - 2\pi/3) & 1+2q\cos(\omega_m t - 4\pi/3) & 1+2q\cos(\omega_m t) \\ 1+2q\cos(\omega_m t - 4\pi/3) & 1+2q\cos(\omega_m t) & 1+2q\cos(\omega_m t - 2\pi/3) \end{bmatrix}$$

in this case:  $\omega_m = -(\omega_o + \omega_i)$

First equation in Eq.(3) yields  $\phi_i = \phi_o$  giving the same phase displacement at the input and output of the converter whereas the second equation yields  $\phi_i = -\phi_o$  giving reversed phase displacement at the input. Combining the two solutions provides the means for input displacement factor control:

$$[M(t)] = \alpha_1 [M1(t)] + \alpha_2 [M2(t)] \quad \alpha_1 + \alpha_2 = 1 \quad (4)$$

Setting  $\alpha_1 = \alpha_2$  gives unity input displacement factor regardless of the load displacement factor. Other possibilities exist, through choice the ratio of above coefficients, to have a leading displacement factor (capacitive) at the input with lagging (inductive) load and reverse. Using this solution the maximum value of input/output transfer ratio ( $q$ ) of converter can achieve 50%. For  $\alpha_1 = \alpha_2$  the modulation functions can be expressed as follows:

$$m_{kj} = \frac{t_{kj}}{T_{seq}} = \frac{1}{3} \left[ 1 + \frac{2v_k v_j}{V_{in}^2} \right] \quad K = A, B, C \text{ and } j = a, b, c \quad (5)$$

Limitation of transfer voltage ratio is shown in Fig.6. The maximum output voltage can be improved to 86% of input voltage by including third harmonics of the input and output frequencies. The output voltage target waveforms now make full use of the input voltage envelope, as shown in Fig.7. In this case the equation becomes:

$$m_{kj} = \frac{1}{3} \left[ 1 + \frac{2v_k v_j}{V_{in}^2} + \frac{4q}{3\sqrt{3}} \sin(\omega_i t + \beta_k) \sin(3\omega_i t) \right] \quad (6)$$

$\beta_k = 0, 2\pi/3, 4\pi/3 \quad K = A, B, C \text{ and } j = a, b, c$

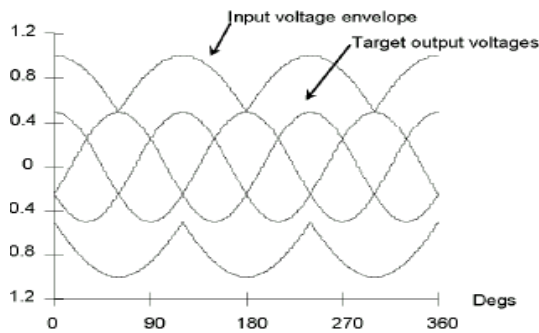


Fig.6

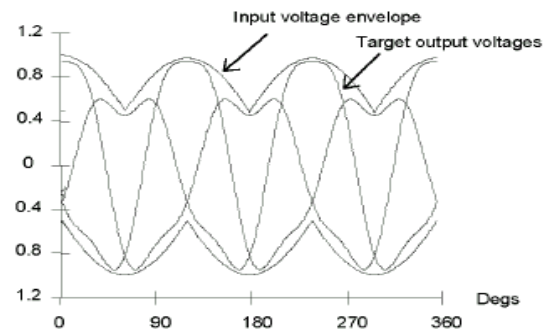


Fig.7

#### 4. CONCLUSION

This paper has described basic AC-AC converter topologies. A comparison in brief between two of most used in recent configurations of circuits was shown. The device losses from a matrix converters is reduced due to small or no filter and energy storage elements. With some of the novel semi-soft commutation strategies it is also possible to show that at higher switching frequencies the matrix converters can be more efficient than the conventional DC-link circuits. Using a proper modulation strategies and commutation techniques, in present often controlled by microprocessors, matrix topologies will begin and become an attractive alternative to conventional regulators in applications where sinusoidal input currents or true bi-directional power flow are required.

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