# A Review of Model Predictive Control Strategies for Matrix Converters

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**Abstract: Matrix converters are a well-known class of direct AC-AC power converter topologies that can be used in applications in which compact volume and low weight are necessary. For good performance, special attention should be paid to the control scheme used for these converters. Model predictive control strategy is a promising, straightforward and flexible choice for controlling various different matrix converter topologies. This work provides a comprehensive study and detailed classification of several predictive control methods and techniques, discussing special capabilities they each add to the operation and control scheme for a range of matrix converter topologies. The paper also considers the issues regarding the implementation of model predictive control strategies for matrix converters. This survey and comparison is intended to be a useful guide for solving the related drawbacks of each topology and to enable the application of this control scheme to matrix converters in practical applications.**

## Nomenclature

| | | |
|---|---|---|
| $\boldsymbol{v_s}$ | Source voltage | $[v_{sA}\ \ v_{sB}\ \ v_{sC}]^T$ |
| $\boldsymbol{i_s}$ | Source current | $[i_{sA}\ \ i_{sB}\ \ i_{sC}]^T$ |
| $\boldsymbol{v_i}$ | Input voltage | $[v_A\ \ v_B\ \ v_C]^T$ |
| $\boldsymbol{i_i}$ | Input current | $[i_A\ \ i_B\ \ i_C]^T$ |
| $\boldsymbol{v_{dc}}$ | DC-link voltage | |
| $\boldsymbol{i_{dc}}$ | DC-link current | |
| $\boldsymbol{v_o}$ | Output voltage | $[v_a\ \ v_b\ \ v_c]^T$ |
| $\boldsymbol{i_o}$ | Output current | $[i_a\ \ i_b\ \ i_c]^T$ |
| $\boldsymbol{v_o^*}$ | Output voltage reference | $[v_a^*\ \ v_b^*\ \ v_c^*]^T$ |
| $\boldsymbol{i_s^*}$ | Source current reference | $[i_{sA}^*\ \ i_{sB}^*\ \ i_{sC}^*]^T$ |
| $\boldsymbol{i_o^*}$ | Output current reference | $[i_a^*\ \ i_b^*\ \ i_c^*]^T$ |
| $\boldsymbol{R_f}$ | Input filter resistance | |
| $\boldsymbol{L_f}$ | Input filter inductance | |
| $\boldsymbol{C_f}$ | Input filter capacitance | |
| $\boldsymbol{L_o}$ | Load inductance | |
| $\boldsymbol{R_o}$ | Load resistance | |

## 1. Introduction

The Matrix Converter (MC) is a power converter topology in which an AC-source is directly connected to an AC-load without the presence of bulky energy storage devices. Hence, this configuration is appropriate for applications in which the converter volume and weight must be minimized. The MC topology presents many advantages over the conventional cascaded rectifier-inverter structure such as controllable power factor at the source side, sinusoidal waveforms at the load and input side with low harmonic content and natural, bi-directional power transfer [1].

A considerable number of modulation and control techniques have been proposed for MCs in the literature. As stated in [2], the first modulation methods where Venturini [3] and Roy's [4] strategies, which appeared to involve complex mathematical approaches. However, the Pulse-Width Modulation (PWM) strategy is one of the most straightforward methods used for matrix converters [5]-[6]. Also, the Space Vector Modulation (SVM) [7]-[8] and Direct Torque Control (DTC) [9]-[10] present good performance when applied to electrical motor drives in the industrial applications. However, these methods suffer from relative complexity.

Other methods for controlling matrix converters include direct power control [11]-[12], fuzzy control [13]-[15], neural networks [16]-[17] and genetic algorithms [18]-[19]. Some leading strategies like Model Predictive Control (MPC) have been newly proposed in order to simplify the control of MCs and provide fast and satisfactory performance in both transient and steady states [20]-[46]. For establishing a straightforward, intuitive and flexible control strategy, this last method considers the nonlinear discrete nature of power electronic circuits and drives. At each sampling instant *k*, this method employs a mathematical model of the system to predict its behavior at the upcoming sample time. Then, a predefined cost function based on the desired control objectives is defined to select the optimal switching vector.

One notable advantage of MPC is the relative simplicity of its control concept compared to the traditional complex and non-intuitive 3-D modulation strategies that have a considerable number of existing switching vectors. [47] Compares the Fuzzy Logic Control (FLC) and Finite Set - Model Predictive Control (FS-MPC) methods, and the results show that the FS-MPC dynamic response is slightly better than that of the FLC. Therefore, MPC offers more advantages than the traditional linear and nonlinear control methods; including the capability to control different objectives at the same time, high controller bandwidth and a shortened control loop cycle time. Fig. 1 summarizes and classifies the most recognized modulation and control methods used for matrix converters. The most well-known MPC variations with their various control objectives are also shown in this figure.

The primary purpose of this work is to provide a comprehensive report of the essential contributions that the MPC scheme makes to various MC configurations including several control objectives implemented using the MPC strategy. The paper is organized such that the most noteworthy capabilities and advantages that MPC contributes to the MC control scheme are well clarified and the issues related to this control approach are easy to understand.

## 2. Different Predictive Control Variations Applied to MCs

There are several MPC schemes with a variety of control objectives that have been applied to MC topologies in the referenced papers. Fig. 1 depicts the sub-classification of the most popular schemes, i.e. Predictive Current Control (PCC) and Predictive Torque Control (PTC). Other implementations, such as Predictive Voltage Control (PVC) [39], [40], [43]-[44] and Predictive reactive/active Power Control (PPC) [20], [41] can be found in the literature as well, but they are not analysed in detail here. Moreover, other variations have been presented which cannot be directly included in the classifications of Fig.1. For example, the method proposed in [48] substitutes the conventional cascaded design with only a predictive controller by which the motor speed and currents are regulated, defining an appropriate cost function. In this section, the PCC and PTC schemes and the different control capabilities that they contribute to MC control schemes are reviewed in detail.

### *2.1. Predictive Current Control (PCC)*

The block diagram of the PCC scheme for matrix converters is depicted in Fig. 2. The basic PCC strategy is formulized firstly. In the basic PCC scheme, only the output current is controlled, and arbitrary values are considered as its reference. As the converter and load models should be used in this method for predicting the upcoming amount of the control variable, an uncomplicated load model is considered:

$$\frac{di_o}{dt} = \frac{1}{L_o}V_o - \frac{R_o}{L_o}i_o \qquad (1)$$

By discretising (1) using the forward Euler's approximation:

$$i_o(k+1) = \frac{T_s V_o(k+1) + L_o i_o(k)}{L_o + R_o T_s} \qquad (2)$$

in which $T_s$ represents the sampling time. A cost function as defined in (3) is used for calculating the difference between the load current references, $I_o^*$, and their corresponding predicted values, $I_p^*$:

$$g(k+1) = |i_a^* - i_a^p| + |i_b^* - i_b^p| + |i_c^* - i_c^p| \qquad (3)$$

Several capabilities can be added to this basic scheme by including the reactive power minimization term in this cost function and considering special references for the output current or input reactive power. Different modified PCC schemes are listed in TABLE 1 "see Appendix 1". This table

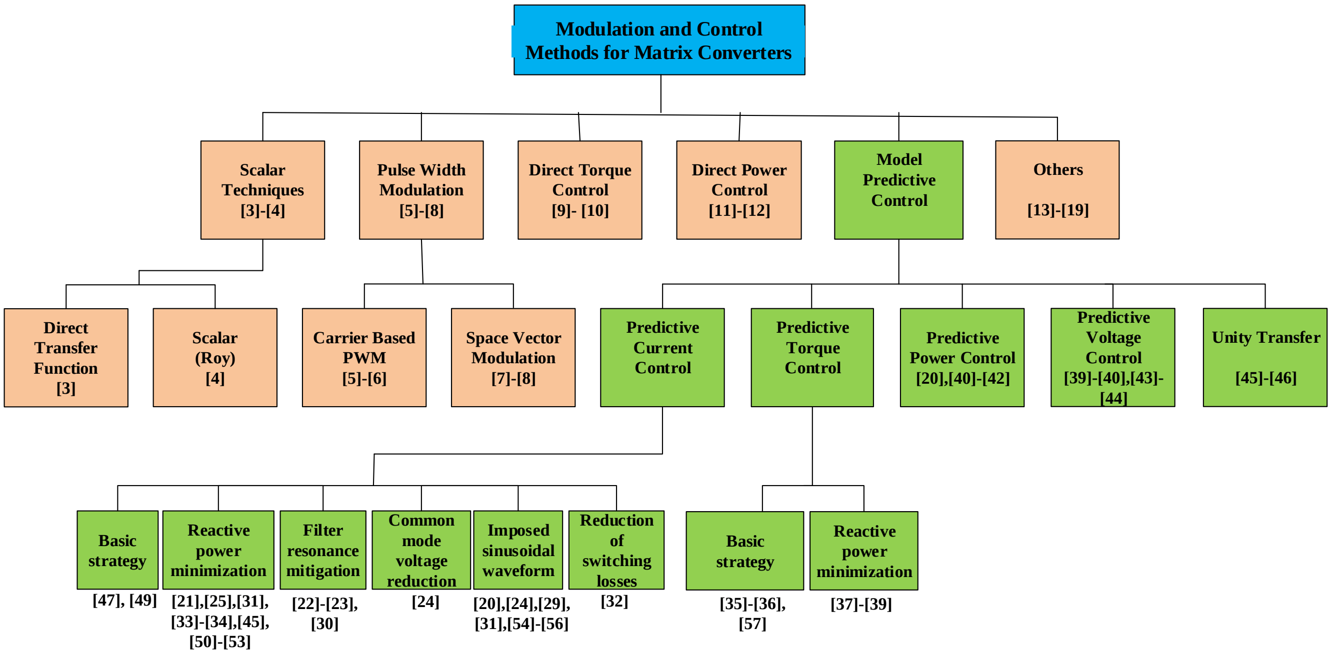


***Fig. 1.*** *Classification of different control and modulation strategies for MCs.*

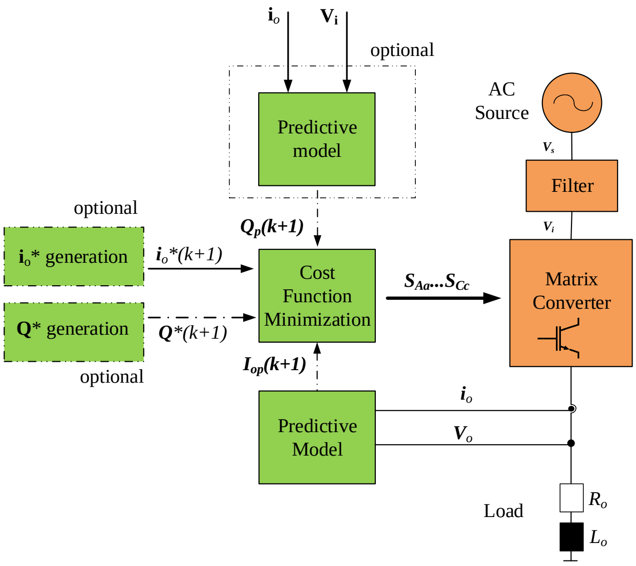


*Fig. 2. PCC scheme block diagram for matrix converters.*

specifies for each method whether any special values must be applied as the output current and reactive power references. A brief description of each method is provided below.

*2.1.1 PCC with reactive power minimization:* The input currents will be highly distorted in the basic PCC, which is a major drawback. To improve the source current response and achieve unity power factor, another term is included in the cost function (4) so as to consider the source-side instantaneous reactive power minimization as well [21], [25], [31], [33]-[34], [45], [50]-[53].

$$g(k+1) = \Delta i_o + \gamma_q \Delta q \tag{4}$$

in which $\Delta i_o$ represents the three-phase load current control term and $\Delta Q = |Q^* - (V_{s\alpha} i_{s\beta} - V_{s\beta} i_{s\alpha})|$ is included for input reactive power minimization. Also, $\gamma_q$ is the weighting factor ([58] presents some guidelines for selecting this value).

*2.1.2 PCC with active damping:* In the MPC scheme, only one vector may be selected as optimal, and applied for several sampling instances. In this way, an unfixed switching frequency along with a wide spectrum are achieved. This changing frequency, which may be accompanied by source voltage fluctuations, can generate a resonance in the source-side filter that results in a highly distorted input current. Since the source and load sides of the MC are directly connected and have no isolation, this distortion can be transferred to the output current. To overcome this problem, [22]-[23], [30], and [59] propose an input-filter resonance mitigation scheme called active damping, which precludes the drawbacks of passive damping such as the decrease in the overall efficiency. The basic principle of this approach is to employ a virtual resistor at the source side for reducing the harmonic content without affecting the value of the main frequency component. In this strategy, a specific output current reference is generated in order to fulfil the above requirements.

*2.1.3 PCC with imposed sinusoidal current reference:* In another approach for minimizing the reactive power's instantaneous value, only the main frequency reference waveform is tracked at the input side. According to the results in [20], [24], [29], [31], and [54]-[56], this approach achieves a performance that is superior to that of the instantaneous reactive power minimization method. It results in simultaneously lower THD values at the source and load side currents, attenuating input filter resonance, and hence increasing the life span of the capacitor. Eq. (5) shows the cost function used in this method:

$$g(k+1) = \Delta i_o + \gamma_i \Delta i_s \tag{5}$$

where $\Delta i_s = |i_{sA}^* - i_{sA}^p| + |i_{sB}^* - i_{sB}^p| + |i_{sC}^* - i_{sC}^p|$ is the source current error. The source current reference waveforms and their amplitudes can be determined as follows:

$$\begin{aligned} i_{sA}^* &= I_s \sin(\omega_s t + \theta) \\ i_{sB}^* &= I_s \sin(\omega_s t - \frac{2\pi}{3} + \theta) \\ i_{sC}^* &= I_s \sin(\omega_s t + \frac{2\pi}{3} + \theta) \end{aligned} \tag{6}$$

Here:

$$I_s = \frac{-\lambda V_s + \sqrt{(\lambda V_s)^2 - 4\lambda R_f R_o I_o^{*2}/\eta}}{-2\lambda R_f} \tag{7}$$

with $\lambda = 1 - 8\pi^2 f_s{}^2 C_f L_f$. Based on the input reference currents in (6), the required reactive power could be calculated and used in the cost function (5).

## A. PCC-based implementation of Field Oriented Control (FOC)

A different PCC approach is presented in [33] for controlling an asynchronous motor with a predictive current control scheme, including the minimization of instantaneous reactive power value. Two stages are present in this method: the first, a predictive phase performing PCC and second, a classical stage providing input reference currents for the first stage based on the Field Oriented Control (FOC) method. In this strategy, the defined cost function is the same as (4). For improving the efficiency of the drive system, two different steps are suggested. These approaches are based on modifying the cost function by adding the number of commutations occurring during transients between the actual switching states, or by directly adding the value of the switching losses [32]. The corresponding modified cost functions are, respectively:

$$g(k+1) = \Delta i_o + \gamma_q \Delta q + \gamma_{sw} n \tag{8}$$

$$g(k+1) = \Delta i_o + \gamma_q \Delta q + \gamma_{sl} \sum_{i=1}^{18} \Delta i_c^{(i)} \, \Delta v_{ce}^{(i)} \tag{9}$$

Here, $n$ is the number of commutations that occur when applying the optimal vector, and $\Delta i_c^{(i)}$ and $\Delta v_{ce}^{(i)}$ are respectively the changes in the collector current and collector-emitter voltage of the $i^{th}$ switch. It should be taken into account that 18 is the number of switches in the direct matrix converter topology.

### 2.2. Predictive Torque Control (PTC)

This control method has been presented in several papers such as [35], [41], and [57], and its implementation diagram is shown in Fig. 3. As in PCC, the PTC scheme includes choosing the optimal actuation among all the possible MC voltage vectors at every sampling period so as to minimize a predefined cost function ($g$). In order to compute $g$, the stator flux $\psi_s$ and the electromagnetic torque $T_e$ are predicted for the upcoming sampling time employing a discrete mathematical model of the induction motor. As depicted in Fig. 3, the proportional-integral control scheme is employed to generate the electromagnetic torque reference value $T_e^*$. For the aforementioned strategy, the differences between the flux and torque predicted and reference values are included in the cost function:

$$g = \Delta T_e(k+1) + \gamma_\psi \Delta\psi(k+1) \quad (10)$$

in which $\gamma_\psi$ is the flux magnitude weighting factor.

A term similar to that seen in PCC, can be also included in the cost function for reducing the instantaneous value of the reactive power and hence, enhance the converter performance at the source side. Here, the cost function is defined as:

$$g = \Delta T_e(k+1) + \gamma_\psi \Delta\psi(k+1) + \gamma_q \Delta q_s(k+1) \quad (11)$$

Where $\gamma_q$ and $\gamma_\psi$ are the weighting factors for the input reactive power and stator flux terms, respectively. Furthermore, in the variation proposed in [60], the corresponding term in (9) is added to (11) in order to achieve higher efficiency than that of the conventional PTC scheme. As concluded in [36]–[39], the PTC strategy provides eminently rapid dynamic behaviour for $T_e$. In addition, its control is independent of the stator flux. It simultaneously provides unity displacement power factor in both regeneration and motoring conditions with a simple and effective algorithm. All these considerable features make PTC an attractive choice for replacing the Direct Torque Control (DTC) scheme when employing MCs.

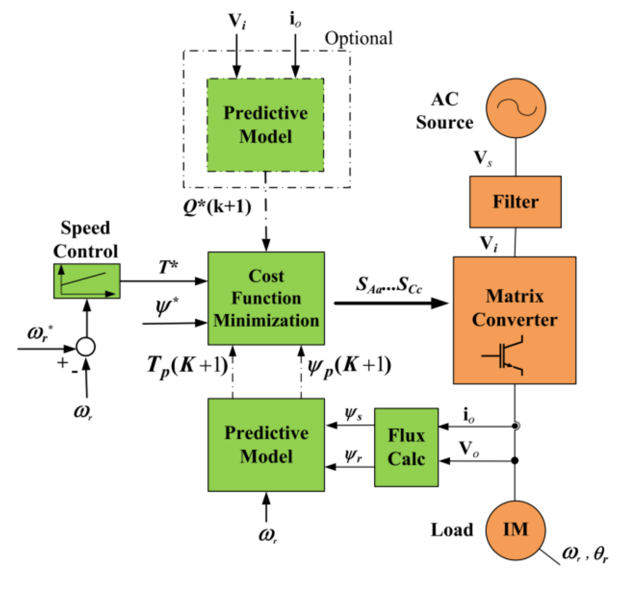


***Fig. 3.*** *PTC scheme block diagram for matrix converters.*

## 3. MPC contributions to different matrix converter configurations

As stated in literature, many different matrix converter structures exist, among which the Direct Matrix Converter (DMC) is the most common. Compared to DMC, the number of switching devices, applications and operation constraints may differ for other structures. Here, a short but comprehensive review is provided about the different MC topologies for which MPC has been implemented. The main focus will be on how MPC improves the operation and control scheme of each topology.

### 3.1. DMC

Direct Matrix Converter (DMC) is the most common topology to which predictive strategy has been applied. Fig. 4 shows the DMC topology in which a configuration of bidirectional switches is placed between the input source and the load with no extra DC-link device. The source is equipped with a filter in order to eliminate overvoltages that result from the rapid commutation of $i_i$ waveforms and to remove high-order components of $i_s$ [1]. There are two operational constraints for the DMC that should be considered: 1) due to the behavior of the inductive load, its current should not be interrupted, and 2) since a capacitive filter is employed at the source side, a short-circuit of any two input lines must be avoided. Under these constraints, 27 switching states are acceptable and should be evaluated at every sampling instant during the MPC implementation in order to choose a vector that minimizes the cost function.

Several research works, such as [22], [29]-[31], [32]–[33], [37], [38], [40], [43], [45], [50], and [54]-[55], have discussed controlling this converter with an MPC scheme for a wide range of industrial areas including motor drive and grid-connected applications. This control scheme contributes several advantages to the DMC. For instance, the complicated transformations and modulations that are necessary in traditional PWM and SVM methods are eliminated, the

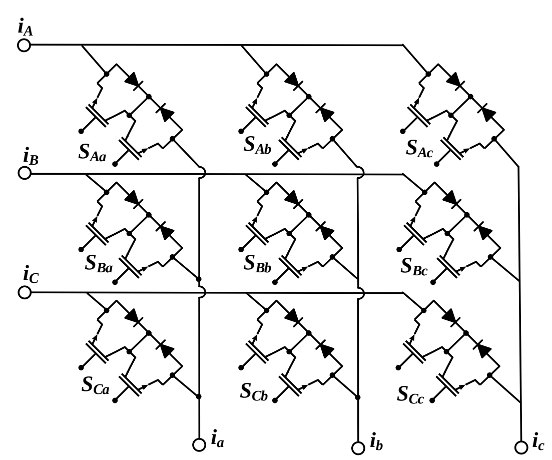


***Fig. 4.*** *Power circuit of the DMC configuration.*

correct operation of DMC is guaranteed and, unlike in traditional methods, all the available switching states (including rotating vectors) are employed. However, due to the requirement of controlling the both input and output sides of the converter and the presence of a considerable number of switching states, a notable challenge in implementing MPC for the DMC is the weighting factor selection. In [61], an indirect MPC scheme is suggested for separating the control of the input and output variables by considering a fictitious DC-link and thus eliminating the use of weighting factors. Several capacities could be added to this method such as mitigating input filter resonances [62]. MPC has also been applied to some variations of DMC such as Single-Phase MC (SPMC) [43]-[44], its cascaded configurations for high power applications [63] and a three-to-five leg DMC [20]. The main challenge in implementing MPC for the latter converter is the notable computational burden, which is due to the considerable number of applicable voltage vectors (243 different vectors); therefore, appropriate steps should be taken to overcome this problem. Also, a novel and attractive modified topology is a modular multilevel matrix converter; which adds several advantages to the conventional DMC such as simple scalability and superior-quality inputs and outputs. MPC has been applied to this topology in order to extend its range of frequency operation in variable speed drives [64].

### *3.2. Indirect Matrix Converter (IMC) and other variations*

Fig. 5 shows the indirect matrix converter configuration as another MC topology. Despite the fact that its modulation and commutation patterns are simpler than those of DMC, the main challenge here is assuring a non-negative voltage value at the virtual DC-link while at the same time, achieving an input unity Displacement Power Factor (DPF). The MPC scheme has also been applied to this topology in several papers including [14], [23]-[26], [28], [34], [36], [49], and [51], which cover a variety of areas such as shunt active power filters, renewable energy applications and motor drives in aerospace and military applications. Among various control objectives considered in these papers are resonance mitigation at the source filter [23], [25], [28], tracking output reference currents, and obtaining nearly sinusoidal current waveforms at the input line (thus eliminating the attenuation caused by the load nonlinearity) [51]. The rectification stage generates nine voltage vectors while the inversion stage generates eight, resulting in 72 valid switching states for this converter. Since only positive DC-link voltage values are permitted, the valid switching states are reduced to 24, all of which must be examined in the defined cost function at every sample time. Additionally, by appropriately synchronizing the vector changes of the input side with the application of zero states at the inversion stage, the MPC scheme inherently achieves soft switching.

As mentioned in [65]-[66], there are different modified IMC configurations with a lower number of semiconductor devices, and thus existing switching vectors, that are derived from the conventional IMC for specific applications. MPC has also been implemented in some of these topologies including a Sparse Matrix Converter (SMC) (Fig. 6) [21], topologies with more semiconductor devices such as IMC with 4 [27] and 6 legs [35], and a Hybrid IMC (HIMC) (Fig. 7) [46]. SMC requires the generation of a superlative voltage value at the virtual DC-link, the retention of sinusoidal current waveforms and unity DPF at the input side as well as the synchronization of the rectifier and inverter switches. The method proposed in [21] combines MPC with Space Vector Pulse Width Modulation (SVPWM) to achieve a fixed switching frequency performance. Since MPC is only responsible for controlling the load currents, only eight switching states need to be considered and checked. Next, the selected switching state provides a reference waveform, which is then fed to the modulation subsystem. In this way, the input power factor value approaches unity and the reference waveform is well tracked.

In [67]-[69], the MPC scheme is used for a four-Leg IMC. Here, the control goals include regulating the output current and voltage and decreasing the instantaneous reactive power on the input side. Moreover, MPC has been implemented for a dual-output four-leg MC in [70]. Here, two three-phase output currents are independently controlled by easily optimizing a single cost function. This controller results in a low THD output value, and the zero sequence current is also controlled appropriately. In [71], MPC is applied to a modified three-phase, four-leg MC. A four-switch structure

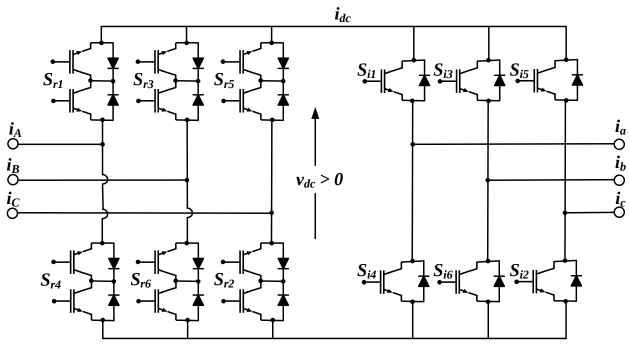


***Fig. 5.*** *IMC topology.*

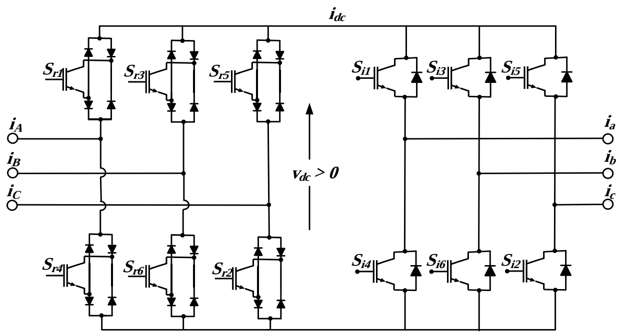


***Fig. 6.*** *Sparse matrix converter topology.*

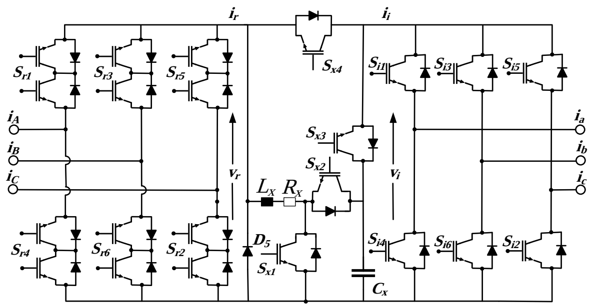


***Fig. 7.*** *HIMC topology.*

that forms a back-to-back topology has been suggested for generating multilevel variable DC-link voltages. A modified switching method for guaranteeing a positive DC-link voltage has also been suggested for the rectifier stage in order to reduce the computational burden. In [35], MPC is applied to a six-leg IMC feeding a multi-drive system that includes two induction machines. Employing this topology for multi-drive systems results in a significant decrease in their weight and size since it eliminates the need to use a different converter for each machine. The main issue here is the increase of the valid switching states that need to be considered in the optimization algorithm at every sampling time. In order for MPC to achieve a satisfactory behavior, the sampling period should obviously be as small as possible. On the other hand, decreasing the sampling frequency is necessary in order to enable the algorithm to evaluate all of the valid vectors in each sample. To overcome this conflict, some recent investigations have considered some kinds of redundancies for the topology so as to decrease the number of vectors that must be evaluated. Moreover, several works on IMC-derived circuits reclassify the switching vectors of the rectification stage based on the fact that the highest voltage value is required at the virtual DC-link in each moment; and thus decreasing the total number of evaluated switching states by a third [72].

It is common knowledge that a major drawback of the matrix converter topology is its limited output voltage value (86% of the input). The authors of [46] propose a hybrid IMC (Fig. 7), which adds an auxiliary voltage source to the DC-link that enables the unity voltage transfer ratio to be achieved even with the presence of intense fluctuations in the input voltage. They also apply an MPC scheme to the additional source. Here, the proportional-integral control scheme generates the reference waveform for the current, and the MPC strategy feeds the PWM block with an appropriate duty cycle value. The scheme proposed in this reference ensures that the power transfer is balanced and the voltage ratio reaches unity. Another approach for overcoming this problem is to incorporate the over-modulation concept to the MPC scheme [73]. This method, which is implemented by using adjustable weighting factors, achieves a voltage transfer ratio of more than 98% for a variety of output frequencies. This method provides a better performance regarding the control of inputs and outputs than the over-modulation DSVM applied to MCs.

## 4. Limitations and drawbacks of the MPC scheme applied to MCs

Although it has been proven that different variations of MPC are very effective in controlling MCs, these methods have some limitations and weaknesses. The main ones are:

- Variable sampling frequency.
- Relatively high computational burden.

To eliminate the abovementioned problems, some solutions are suggested in the literature. After a short discussion on the origin of each issue, the proposed solutions are discussed in this section.

### 4.1. Variable switching frequency

The unfixed switching frequency issue of the MPC strategy is due to the absence of a modulator. In other words, since only a single voltage vector is chosen and applied in each sample, the switching frequency varies and considerable ripple components may be generated. Different strategies are proposed for solving this problem. For example, the Discrete Space Vector Modulation (DSVM) strategy has been combined with predictive control by introducing some virtual vectors generated by an external modulator [74]. In [75], only the MPC scheme is used instead of PI controllers, and a conventional modulator is also employed. Furthermore, a method is suggested in [76] based on the low-frequency components of the predictive strategy's discrete outputs. However, it should be noted that the aforementioned approaches are not as intuitive and simple as the conventional predictive strategy, and they entail complex expressions for calculating switching times. The most common approach for fixing the switching frequency is the Modulated Model Predictive Control (M2PC) strategy. In this method, the features of SVM and conventional predictive strategies are combined and, much like in the SVM method, a sequence of voltage vectors is applied in each sample. Similar to the predictive strategy, the best vector sequence and also the duty cycle of each vector in this sequence are determined by a predefined cost function. In this case, the vector that results in lowest value of the cost function has the highest application time. This method has been used in several references. For example, in [77], the double-sided switching pattern is considered with four active- and three zero-voltage vectors in each sequence. Fig. 8 depicts the principles of this scheme. Each vector's duty cycle can be determined by the aforementioned explanation and the equations in [77]. This strategy has been successfully applied to indirect matrix converters [78]-[79], direct matrix converters connected to an induction motor [80], and to DFIG [81]-[82].

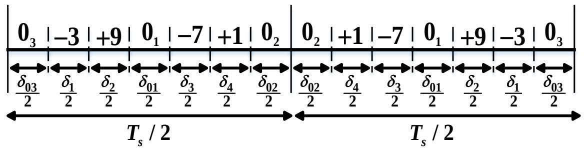


***Fig. 8.*** *Double-sided switching pattern used in [77].*

### 4.2. High Computational Burden

As there are numerous control objectives and switching states in MCs, the computational burden of implementing MPC for this converter is noteworthy. However, Due to parallel process ability of FPGAs, the execution time for multiple control objectives could be kept almost constant by implementing MPC in these devices. This approach provides a cost-effective solution for reducing the computational burden [83].

Moreover, several strategies are suggested for decreasing the number of possible switching states. In [84], an algorithm is proposed that preselects the switching states by evaluating the sectors of the input current and output voltage vectors. In this approach, only 11 states are evaluated, and the implementation of MPC with a long prediction horizon becomes possible. In addition, reduction of the sampling period is made possible by decrease of the computational burden, which further improves the control objectives' behavior. In [85], another method is proposed; which decreases the computational burden by avoiding current prediction and further reducing the candidate states. This approach requires just 10 reactive power predictions and 10 cost function evaluations during each sampling time. Reference [86] proposes a similar approach. Here, the candidate states are reduced by using two predefined look-up tables. These look-up tables are formed according to the sign of torque deviation and the positions of the input voltage and stator flux vectors.

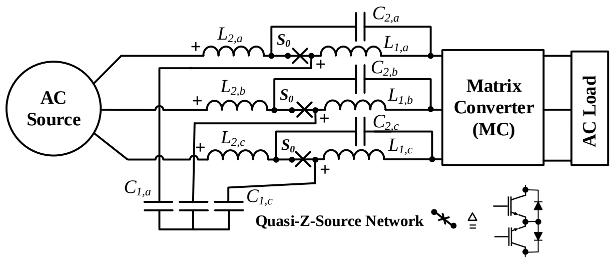


***Fig. 10.*** *Quasi-Z-source MC [92]*

## 5. Practical and industrial applications

Although MPC has been implemented for different MC topologies, and the benefits and advantages are clear, its industrial applications have not been widely addressed and reported in the literature. Some reasons could be the complexity of the model-based optimization and the computational burden, which requires employing relatively powerful and expensive microprocessors. However, the MPC scheme can provide additional functionalities such as open-switch fault diagnosis, which can be an advantage in certain industrial applications. In [87], a fault identification method that includes two stages and is executed without additional voltage sensors is proposed. In the initial stage, detection of the defective leg is done by comparing reference and estimated values of load voltages. The load voltage reference waveform is acquired using the source voltage and the switching vectors. Next, the location of the defective device is determined by identifying the defective switching vector legs. In [88], fault identification is done by monitoring load currents and evaluating the switching state to detect the faulty switch. Since the predictive strategy uses a fixed switching vector during each sample, the identification of the open switch's exact location is certainly easier. Likewise, a fault-tolerant scheme is proposed for the modular multilevel MC in [89]. This paper's main idea is to use MPC in order to determine the reduced 8-branch topology configuration by optimizing branch currents after the fault occurrence.

Several investigations have also been conducted in order to control MCs with MPC in practical applications. [90] Employs MPC to control MCs used as Solid State Transformers (SSTs). Here, two three-to-single-phase matrix converters are connected in cascade in order to achieve a direct, transformerless and bidirectional AC-AC conversion between two AC grids (Fig. 9). This structure provides several benefits such as reduced weight and volume as well as the absence of storage elements. The traditional modulation and control schemes for this structure require extra controllers for power management. The MPC is employed in order to manage the power exchange appropriately. It also achieves fast dynamics and voltage matching between the grids without additional computations or control loops [91].

Another area in which MC has been used is Wind Energy Conversion Systems (WECS). A quasi-Z-source MC (Fig. 10) is employed in [92] for this application, and it is controlled in both normal and Low Voltage Ride-Through (LVRT) modes by a modified MPC scheme. In the proposed scheme, the zero states are deliberately inserted into the control pulses. The application of this modified MPC to this topology results in significantly lower grid current ripples and also enhances the LVRT capability of the WECS. In [93], a stability analysis of the above WECS is carried out, and it is shown that the operation will be stable for the whole range.

In [94], MPC is used in order to control a capacitorless MC-based STATCOM (Fig. 11) for compensating lagging power factors. The proposed structure uses MPC to control the input and output currents in such a way that a phase-shift of 180 degree is created between them. By this method, the reactive power is injected to the grid without the need for electrolyte capacitors.

## 6. Conclusion

This paper provides a comprehensive review about matrix converter various structures and applications which MPC different variations are used to control them. A variety of constraints and challenges related to each topology when it is controlled by the predictive approach have been described in detail. According to the study, each topology has its special requirements and issues, especially when several control goals must be accomplished for a single load or when several motors must be controlled with a single MC. It is revealed that MPC could be considered as an attractive

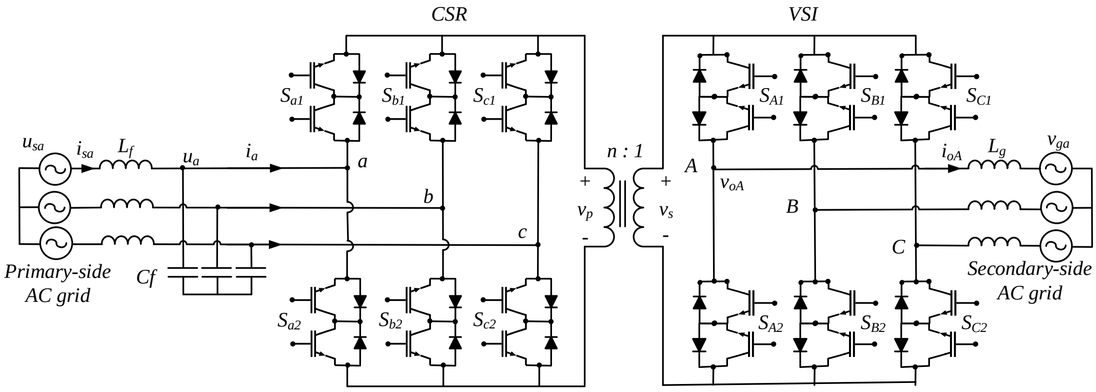


***Fig. 9.*** *MC-based SST structure [90]*

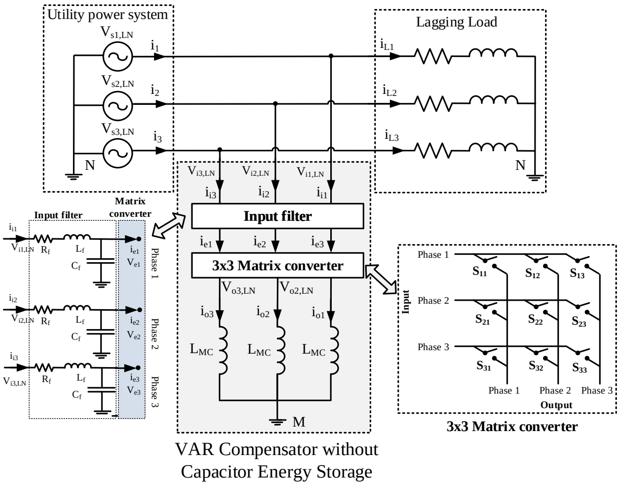


***Fig. 11.*** *MC-based STATCOM [94].*

solution with notable advantages like flexibility and versatility in the control scheme. However, the implementation of MPC for matrix converters may suffer from some disadvantages such as a high computational burden and a variable switching frequency. Using approaches that avoid an unfixed switching frequency and resonance while also reducing the computational load can further enhance the benefits of MPC. This paper is intended to be used by the researchers in this field to comprehend model predictive control's numerous contributions to matrix converters and to help them solve the issues in future trends.

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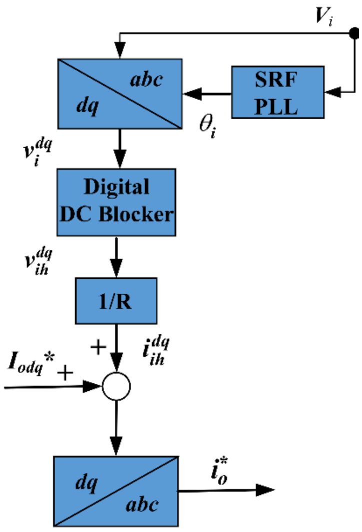
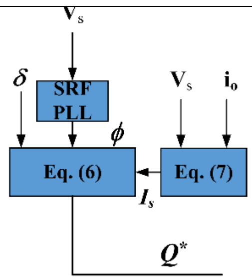
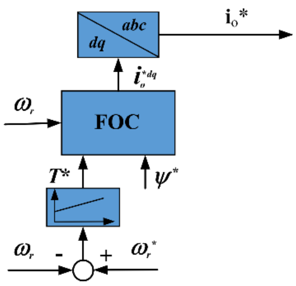
## 8. Appendices

**TABLE 1** Different PCC modifications applied to MCs

| *Method* | *Prediction of input reactive power* | *Special $i_o^*$ generation scheme* | *Special $Q^*$ generation scheme* |
|---|---|---|---|
| **Basic PCC** | Not Needed | Not Needed | Not Needed |
| **PCC with Q minimization** | Necessary | Not Needed | Not Needed |
| **PCC with active damping** | Necessary |  | Not Needed |
| **PCC with imposed sinusoidal source current** | Necessary | Not Needed |  |
| **FOC+PCC** | Necessary |  | Not Needed |