

Reactive Power Control of Permanent-Magnet Synchronous Wind Generator With Matrix Converter

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Abstract—In this paper, the reactive power control of a variable-speed permanent-magnet synchronous wind generator with a matrix converter at the grid side is improved. A generalized modulation technique based on singular value decomposition of the modulation matrix is used to model different modulation techniques and investigate their corresponding input reactive power capability. Based on this modulation technique, a new control method is proposed for the matrix converter which uses active and reactive parts of the generator current to increase the control capability of the grid-side reactive current compared to conventional modulation methods. A new control structure is also proposed which can control the matrix converter and generator reactive current to improve the grid-side maximum achievable reactive power for all wind speeds and power conditions. Simulation results prove the performance of the proposed system for different generator output powers.

Index Terms—Matrix converter, permanent-magnet synchronous generator (PMSG), reactive power control, singular value decomposition (SVD) modulation, variable-speed wind generator.

I. INTRODUCTION

A MATRIX converter is a direct ac/ac frequency converter which does not require any energy storage element. Lack of bulky reactive components in the structure of this all silicon-made converter results in reduced size and improved reliability compared to conventional multistage ac/dc/ac frequency converters. Fabrication of low-cost and high-power switches and a variety of high-speed and high-performance digital signal processors (DSPs) have almost solved some of the matrix converter drawbacks, such as complicated modulation, four-step switching process of bidirectional switches, and the use of a large number of switches [1]. Therefore, its superior benefits, such as sinusoidal output voltage and input current, controllable input power factor, high reliability, as well as a small and packed structure make it a suitable alternative to back-to-back converters.

One of the recent applications of matrix converters is the grid connection of variable-speed wind generators [2]–[14]. Vari-

able-speed permanent-magnet synchronous (PMS) wind generators are used in low-power applications. The use of a matrix converter with a multipole PMSG leads to a gearless, compact, and reliable structure with little maintenance which is superior for low-power microgrids, home, and local applications [13], [15]–[17].

The wind generator frequency converter should control the generator-side quantities, such as generator torque and speed, to achieve maximum power from the wind turbine, and the grid-side quantities such as grid-side reactive power and voltage to improve the system stability and power quality (PQ) [17]–[19]. Unlike conventional back-to-back converters in which a huge dc-link capacitor makes the control of the generator and grid-side converters nearly independent [20], a matrix converter controls the generator and grid-side quantities simultaneously. Therefore, the grid-side reactive power of a matrix converter is limited by the converter voltage gain and the generator-side active or reactive power [21].

One necessary feature for all generators and distributed generators (DGs) connecting to a grid or a microgrid is the reactive power control capability. The generator reactive power can be used to control the grid or microgrid voltage or compensate local loads reactive power in either a grid-connected or an islanded mode of operation [19], [20]. In this paper, the grid-side reactive power capability and control of a PMS wind generator with a matrix converter is improved. For this purpose, in Section II, a brief study of a matrix converter and its singular value decomposition (SVD) modulation technique, which is a generalized modulation method with more relaxed constraints compared to similar modulation methods is presented.

In Section III, the SVD modulation technique is used to model different modulation techniques and study the reactive power capability of a matrix converter. It is shown that in some modulation techniques, such as Alesina and Venturini, the grid-side reactive current is synthesized only by the reactive part of the generator-side current. In other modulation techniques, such as indirect methods or direct and indirect space vector modulation (SVM) methods, the grid-side reactive current is synthesized only by the active part of the generator-side current. To increase the matrix converter reactive current gain, the SVD modulation technique is used such that both active and reactive parts of the generator-side current can contribute to the grid-side reactive current.

It is shown in Section IV that the generator free reactive power capacity can be used to increase the grid-side reactive power. A new control structure is also proposed which can control the generator and matrix converter reactive power to increase the controllability of the grid-side reactive power at any

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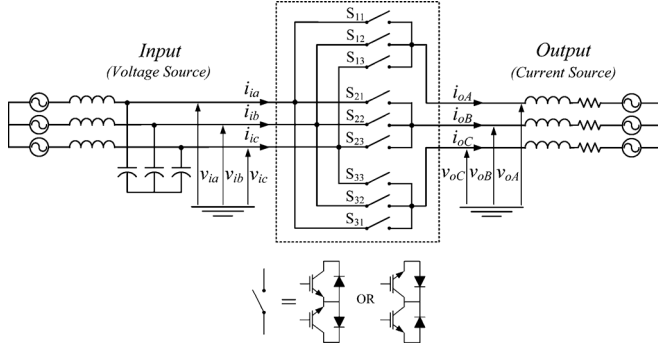


Fig. 1. Typical three-phase matrix converter schematic.

wind speed and power. The proposed control structure is simulated with a simple adaptive controller (SAC) on a gearless multipole variable-speed PMS wind generator, and the results are presented to verify its performance under different operating conditions. The simulations are performed using PSCAD/EMTDC software.

II. MATRIX CONVERTER

Fig. 1 shows a typical three-phase matrix converter. In a matrix converter, the input and output phases are related to each other by a matrix of bidirectional switches such that it is possible to connect any phase at the input to any phase at the output. Therefore, the controllable output voltage is synthesized from discontinuous parts of the input voltage source, and the input current is synthesized from discontinuous parts of the output current source or

$$\begin{aligned}
 V_{o,ABC} &= \mathbf{S}V_{i,abc} \\
 I_{i,abc} &= \mathbf{S}^T I_{o,ABC} \\
 \mathbf{S} &= \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{pmatrix} \\
 \begin{cases} s_{kj} \in \{0, 1\} \\ s_{k1} + s_{k2} + s_{k3} = 1 \end{cases} & \quad k, j = 1, 2, 3 \\
 V_{i,abc} &= \begin{pmatrix} v_{ia} \\ v_{ib} \\ v_{ic} \end{pmatrix}, \quad I_{i,abc} = \begin{pmatrix} i_{ia} \\ i_{ib} \\ i_{ic} \end{pmatrix} \\
 V_{o,ABC} &= \begin{pmatrix} v_{oA} \\ v_{oB} \\ v_{oC} \end{pmatrix}, \quad I_{o,ABC} = \begin{pmatrix} i_{oA} \\ i_{oB} \\ i_{oC} \end{pmatrix} \quad (1)
 \end{aligned}$$

where v_{oj} and i_{oj} ($j = A, B, C$) are the output phase voltages and currents, respectively; v_{ij} and i_{ij} ($j = a, b, c$) are the input phase voltages and currents; and s_{kj} is the switching function of switch kj .

Lack of an energy storage component in the structure of a matrix converter leads to an equality between the input–output active power, i.e.,

$$p_i = V_{i,abc}^T \cdot I_{i,abc} = V_{o,ABC}^T \cdot I_{o,ABC} = p_o. \quad (2)$$

A. SVD Modulation Technique

Different modulation techniques are proposed for a matrix converter in the literature [21]–[23]. A more complete modu-

lation technique based on SVD decomposition of a modulation matrix is proposed in [24]. Other modulation methods of a matrix converter can be deduced from this SVD modulation technique. The technique proposed in [24] has more relaxed constraints compared to other methods.

The SVD modulation method is a duty cycle method in which the modulation matrix \mathbf{M} , which is defined in (3), is directly constructed from the known input voltage and output current and desired output voltage and input current, i.e.,

$$\begin{aligned}
 \mathbf{M} &= \frac{Ave\{\mathbf{S}\}}{T_s} = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} \\
 \begin{cases} 0 \leq m_{kj} \leq 1 \\ m_{k1} + m_{k2} + m_{k3} = 1 \end{cases} & \quad k, j = 1, 2, 3 \quad (3)
 \end{aligned}$$

where m_{kj} is the average of s_{kj} over a switching period.

To represent the input and output voltages and currents in space vector forms, all quantities of the input and output of the matrix converter are transferred from the abc reference frame to the $\alpha\beta 0$ reference frame by the modified Clarke transformation of (4). Therefore, the new modulation matrix $\mathbf{M}_{\alpha\beta 0}$ is obtained as

$$\begin{aligned}
 V_{o,\alpha\beta 0} &= \mathbf{M}_{\alpha\beta 0} V_{i,\alpha\beta 0} \\
 I_{i,\alpha\beta 0} &= \mathbf{M}_{\alpha\beta 0}^T I_{o,\alpha\beta 0} \\
 \mathbf{M}_{\alpha\beta 0} &= \mathbf{K} \mathbf{M}_{abc} \mathbf{K}^T \\
 \mathbf{K} &= \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \\
 \mathbf{K}^{-1} &= \mathbf{K}^T \text{ OR } \mathbf{K} \mathbf{K}^T = \mathbf{I}. \quad (4)
 \end{aligned}$$

The last equality means that matrix \mathbf{K} is a unitary matrix or its transpose is equal to its inverse. Considering the condition set by (3) and using (4), the following basic form for the $\mathbf{M}_{\alpha\beta 0}$ is obtained:

$$\begin{aligned}
 \mathbf{M}_{\alpha\beta 0} &= \mathbf{K} \mathbf{M}_{abc} \mathbf{K}^T = \begin{pmatrix} g_{11} & g_{12} & 0 \\ g_{21} & g_{22} & 0 \\ c'_1 & c'_2 & 1 \end{pmatrix} \\
 &= \begin{pmatrix} \mathbf{M}_{\alpha\beta 2 \times 2} & \mathbf{0} \\ \mathbf{0} & 0 \end{pmatrix} + \underbrace{\begin{pmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{C}'_{1 \times 2} & 1 \end{pmatrix}}_{\mathbf{M}_0} \quad (5)
 \end{aligned}$$

where $\mathbf{M}_{\alpha\beta}$ generates $V_{o,\alpha\beta}$ and $I_{i,\alpha\beta}$ from $V_{i,\alpha\beta}$ and $I_{o,\alpha\beta}$, and \mathbf{M}_0 generates $V_{o,0}$ and $I_{i,0}$ from $V_{i,\alpha\beta 0}$ and $I_{o,\alpha\beta 0}$, respectively.

Since, in a three-phase three-wire system, no zero-sequence current can flow, the zero-sequence voltage can be added to the output phase voltages to increase the flexibility of the control logic. Therefore, in all modulation methods, the main effort is devoted to selecting suitable $\mathbf{M}_{\alpha\beta}$ in (6) to control the output voltage and input current and a suitable \mathbf{M}_0 to increase the operating range of the matrix converter, i.e.,

$$\begin{aligned}
 \begin{pmatrix} v_{o\alpha} \\ v_{o\beta} \end{pmatrix} &= \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} \begin{pmatrix} v_{i\alpha} \\ v_{i\beta} \end{pmatrix} \\
 \begin{pmatrix} i_{i\alpha} \\ i_{i\beta} \end{pmatrix} &= \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix}^T \begin{pmatrix} i_{o\alpha} \\ i_{o\beta} \end{pmatrix}. \quad (6)
 \end{aligned}$$

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