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A New Modulation Technique Is Used In Matrix Converter for Reactive Power Control of Permanent-Magnet Synchronous Wind Generator

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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.

Keywords—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]. Variable- 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 mod-ulation 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 con-trol the generator and matrix converter reactive power to in-crease the controllability of the grid-side reactive power at any 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 MATLAB 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.

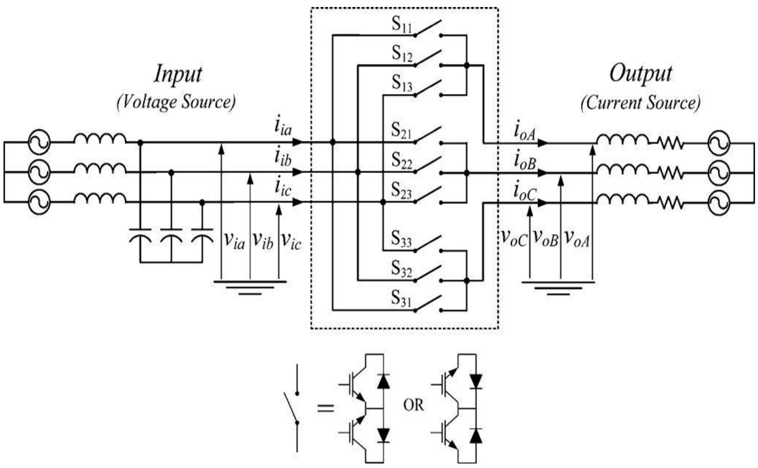

Fig 1: Typical three-phase matrix converter schematic.

$$V_{o,ABC} = \mathbf{S} V_{i,abc}$$

$$I_{i,abc} = \mathbf{S}^T I_{o,ABC}$$

$$\mathbf{S} = \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{pmatrix}$$

$$\begin{cases} s_{kj} \in \{0, 1\} \\ s_{k1} + s_{k2} + s_{k3} = 1 \end{cases} \quad k,\ j = 1, 2, 3$$

(1)

A. SVD Modulation Technique

Different modulation techniques are proposed for a matrix converter in the literature [21]–[23]. A more complete modulation 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 M, which is defined in (2), is directly constructed from the known input voltage and output current and desired output voltage and input current, i.e.

$$M = Ave\{S\}_{T_o} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{32} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}$$

$$\{0 \le m_{kj} \le 1, m_{k1} + m_{k2} + m_{k3} = 1$$

$$where\ k, j = 1,2,3\} \qquad (2)$$

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 αβ0 reference frame by the modified Clarke transformation of (3). Therefore, the new modulation matrix $M_{\alpha\beta o}$ is obtained as

$$V_{o,\alpha\beta o} = M_{\alpha\beta o} V_{i,\alpha\beta o}$$

$$I_{i,\alpha\beta o} = M^T_{\alpha\beta o} I_{o,\alpha\beta o}$$

$$M_{\alpha\beta o} = K M_{abc} K^T$$

$$K^{-1} = K^T\ or\ KK^T = I \qquad (3)$$

The last equality means that matrix K is a unitary matrix or its transpose is equal to its inverse. Considering the condition set by (2) and using (3), the following basic form for the $M_{\alpha\beta 0}$ is obtained

$$M_{\alpha\beta o} = K M_{abc} K^T = \begin{bmatrix} g_{11} & g_{12} & 0 \\ g_{21} & g_{22} & 0 \\ c_1' & c_2' & 1 \end{bmatrix}$$

$$= \begin{pmatrix} M_{\alpha\beta} & 0 \\ 0 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ C_1' & 1 \end{pmatrix} \qquad (4)$$

Where $M_{\alpha\beta}$ generates $V_{o,\alpha\beta}$ and $I_{i,\alpha\beta}$ from $V_{i,\alpha\beta}$ and $I_{o,\alpha\beta}$, and M_o generates $V_{o,0}$ and $I_{i,0}$from$V_{i,\alpha\beta0}$and$I_{o,\alpha\beta0}$, 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 $M_{\alpha\beta}$ in (5) to control the output voltage and input current and a suitable M_o to increase the operating range of the matrix converter, i.e.

$$\begin{pmatrix} V_{o\alpha} \\ V_{o\beta} \end{pmatrix} = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} \begin{pmatrix} V_{i\alpha} \\ V_{i\beta} \end{pmatrix}$$

$$\begin{pmatrix} i_{o\alpha} \\ i_{o\beta} \end{pmatrix} = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix}^T \begin{pmatrix} i_{i\alpha} \\ i_{i\beta} \end{pmatrix} \quad (5)$$

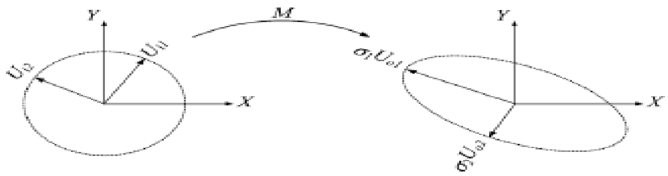

Fig 2: Concept of the SVD of a matrix.

As Fig.2 depicts, the SVD of a matrix means that this matrix will transform the vectors in the direction of $U_{i1,2\times1}$ toward the direction of $U_{o1,2\times1}$ by a gain of σ_1 and vectors in the direction of $U_{i2,2\times1}$ toward the direction of $U_{o2,2\times1}$ by a gain of σ_2 .

.All of the existing modulation methods can be deduced from this simple and general method by choosing suitable q_d, q_q, θ_i and θ_o. On the other hand, Fig.3 shows that if the input and output quantities are transferred onto their corresponding synchronous reference frames, the SVD modulation matrix becomes a simple, constant, and time-invariant matrix (i.eM_{dq}). Therefore, the SVD modulation technique models the matrix converter as a qd transformer in the input–output synchronous reference frame.

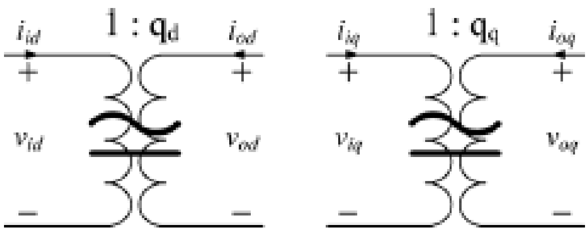

Fig 3: Matrix converter steady-state and dynamic dq transformer model

III. MATRIX CONVERTER REACTIVE POWER CONTROL

The input reactive power of a matrix converter can be written in a general form as [26]

$$\begin{aligned} Q_i &= I_m\{S_i\} = V_{iq}I_{id} - V_{id}I_{iq} \\ &= q_d V_{iq} I_{od} - q_q V_{id} I_{oq} \\ &= Q_{id} + Q_{iq} \end{aligned} \quad (6)$$

Where S_i is the input complex power, Q_{id} is the part of the input reactive power made from I_{od} , and Q_{id} is the part of the input reactive power made from I_{oq}. Therefore, the following strategy of synthesizing the input reactive power of a matrix converter can be investigated.

A. Synthesizing From Both the Active and Reactive Parts of the Output Current

To increase the maximum achievable input reactive current in a matrix converter for a specific output power, its input current should be maximized. M^T Since transforms I_o from the output space onto the input space, to maximize $|I_i|$, the free parameter θ_i must be chosen such that I_o is located as close as possible to the direction over which the M^T gain is maximum, i.e.,

$$max|I_i| = max_m\{|M^T I_o|\}$$

$$\text{Subject to:}\begin{cases} V_o = MV_i \\ |q_d|, |q_q| \le \frac{\sqrt{3}}{2} \\ G_v \le k = |q_d| + |q_q| \le 1 \end{cases} \quad (7)$$

where k is a positive parameter which is used to vary the matrix converter constraint. k can be changed from its minimum possible value (i.e.k=G_v) to its maximum possible value (i.e.,) to change the maximum current gain of the matrix converter (i.e.k=1) to change the maximum current gain of the matrix converter (i.e $G_{c,max}$)and control its input reactive power.

IV. PMS WIND GENERATOR REACTIVE POWER CONTROL

The input reactive power of a matrix converter described in the previous section can be used to control the reactive power of PMS wind generator. PMS wind generator, which is connected to the output of a matrix converter, is simulated to compare the improvement in the matrix converter input or grid-side reactive power using the proposed strategy. The control block diagram of the system is shown in Fig.4, and its parameters are listed in Table I. The simulations are performed using MATLAB software.

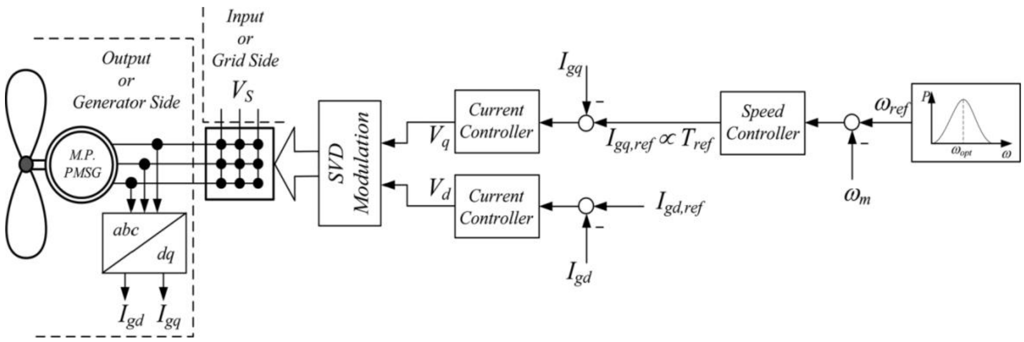

Fig 4: Simplified control block diagram of a PMSG Simulated System Parameters

Source	V_S	530 V
	f_S	50 Hz
Matrix Converter	L_f	0.5 mH
	C_f	9 μf
	f_{SW}	10 kHz
Generator & Turbine	S_g	50 kVA
	E_g	380 V
	n_p	58
	f_g	50 Hz
	R_g	0.1 p.u.
	$L_{dg} \approx L_{qg}$	0.8 p.u.
	H_g	1 sec.
	$P_{W,opt}$	$K_{opt}\omega_m^3$
	K_{opt}	314

To control the generator torque and speed, generator quantities are transferred on to the synchronous reference frame such that the rotor flux is aligned with the d-axis of the dq0 reference frame. Therefore, I_{gq} will become proportional to the generator torque, and I_{gd} can be varied to control the generator output reactive power. Usually, I_{gd} is set to zero to minimize the generator current and losses. However, in this section, the effect of on the input reactive power is also studied, and a new control structure is proposed which can control the generator reactive power to improve the reactive power capability of the system

V. RESULTS

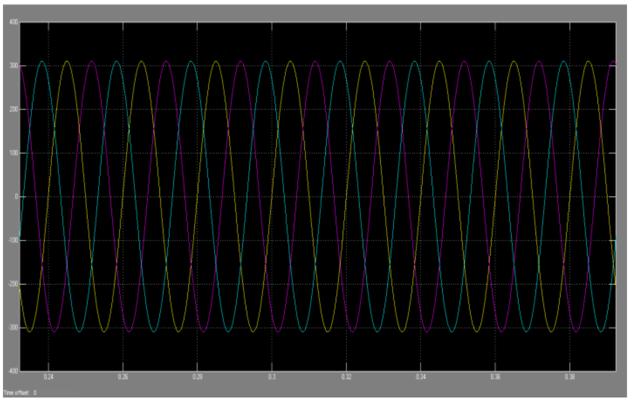

Fig 5: Matrix converter output voltage

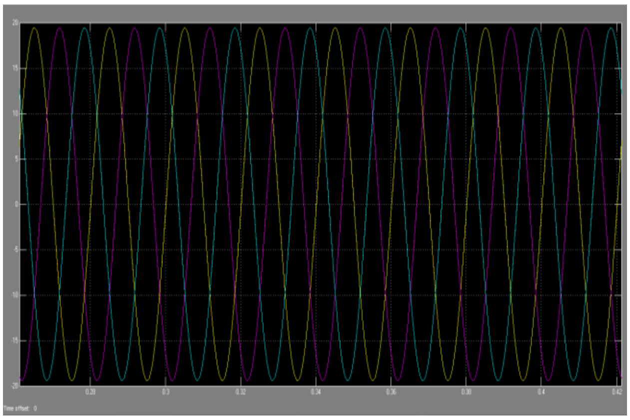

Fig 6: Matrix converter output current

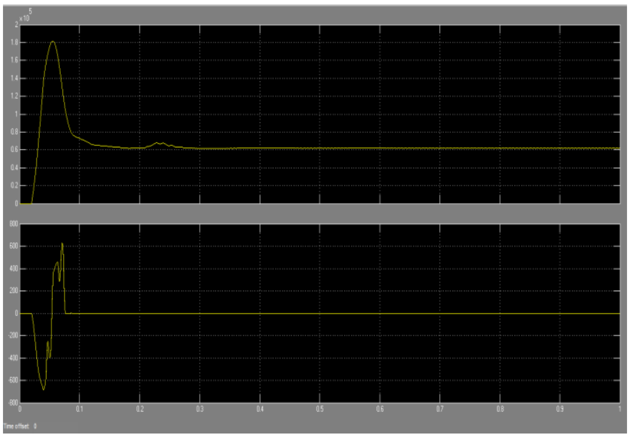

Fig 7: Real and Reactive power at generator side

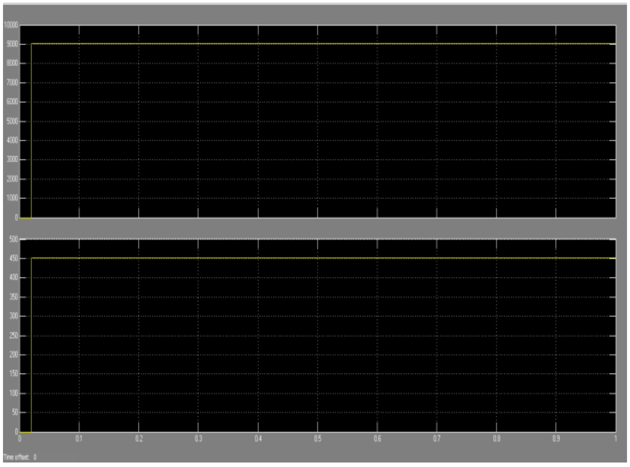

Fig 8: Real and Reactive power at grid side

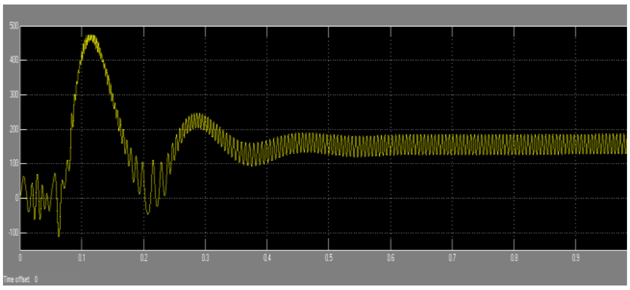

Fig 9: Torque of a generator

VI. CONCLUSION

In this paper, a new control strategy is proposed to increase the maximum achievable grid-side reactive power of a matrix converter-fed PMS wind generator. Different methods for controlling a matrix converter input reactive power are investigated. It is shown that some modulation methods, the grid-side reactive current is made from the reactive part of the generator-side current. In other modulation techniques, the grid-side reactive current is made from the active part of the generator-side current. In the proposed method, which is based on a generalized SVD modulation method, the grid-side reactive current is made from both active and reactive parts of the generator-side current. In existing strategies, a decrease in the generator speed and output active and reactive power, will decrease the grid-side reactive power capability. A new control structure is proposed which uses the free capacity of the generator reactive power to increase the maximum achievable grid-side reactive power. Simulation results for a case study show an increase in the grid side reactive power at all wind speeds if the proposed method is employed.

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