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Direct-Power Control of a Grid-connected Five-phase Permanent-Magnet Synchronous Generator Based on a Five-to Three-phase Matrix Converter

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Abstract. In the paper, a new control of a grid-connected five-phase Permanent-Magnet Synchronous Generator (PMSG) based on a five-to three-phase Matrix Converter (MC) is proposed to reach two main objectives. The first is to develop a [5×3] MC topology to ensure energy conversion from a five-phase wind generator to a three-phase electric grid. Such topology has several attractive aspects over the conventional back-to-back converter, such as a compact size, low cost, small number of power electronic components and absence of a DC-link capacitor. The second objective is to control the active and reactive power injected to the grid from the generator by using a Direct Power Control (DPC) technique whish does not depend on the generator and grid parameters and can be an alternative approach to a field-oriented control in power generation systems. The efficiency of the proposed wind-energy conversion system is simulated by using a MATLAB/Simulink environment.

Keywords: Five-phase Permanent-Magnetic Synchronous Generator (PMSG), Five-to three-phase Matrix Converter (MC), Grid active and reactive power, Direct Power Control (DPC), Wind turbine.

Neposredni nadzor moči v sinhronem petfaznem generatorju s trajnimi magneti

V prispevku je predlagan neposreden nadzor moči v sinhronem petfaznem generatorju s trajnimi magneti, ki temelji na matričnem pretvorniku s petih na tri faze [5 × 3]. Razvili smo novo topologijo za pretvorbo s petfaznega vetrnega generatorja na trifazno električno omrežje. Ta topologija ima prednosti v primerjavi z navadnimi pretvorniki, kot so njena velikost, cena in majhno število močnostnih elektronskih komponent. Opisali smo tudi nadzor delovne in jalove moči, posredovane v omrežje. Predlagani način ni odvisen od parametrov generatorja in omrežja. Učinkovitost predlagane metode smo preverili v simulacijskem okolju MATLAB/ Simulink.

1 INTRODUCTION

In the last decades, the three-phase Permanent-Magnetic Synchronous Generator (PMSG)-based wind turbine has been widely used in wind-power production due to its advantages, such as better reliability, lower maintenance cost and higher efficiency [1-2]. Using a multi-phase PMSG shows other advantages over the three-phase PMSG, such as reduced amplitude and increased frequency of torque pulsation and higher reliability [3]. Therefore, a multi-phase PMSG is very attractive for renewable energy applications [4-8].

Several works on a multi-phase PMSG-based wind turbine with back-to-back converters have been studied recently [4,5]. Nowadays, using MC in controlling AC machines has received much attention due to the advantages of its variable speed drive, such as absence of a DC-link capacitor, sinusoidal input and output waveforms, working close to the unit input-power factor and greater compact size [6-12]. As such, it can be used as an alternative to the DC-link voltage-sourced converter for the wind-energy conversion systems. However, the MC application has been adapted for specific objectives and has not been generalized for the wind-power conversion systems using a multi-phase PMSG generator as in [7-12].

One of the most recent methods to control the wind power is the Direct Power Control (DPC). The method is characterized by its fast dynamic response, simple structure and robust response to parameter variations. In DPC, the active and reactive power are estimated using current measurements and directly controlled with a hysteresis comparator and a switching table similar to the one used in the direct torque control (DTC) applied for the AC machines [14-15].

In this context, the paper investigates the performance of a direct-driven five-phase PMSG-based variable-speed wind turbine connected to an AC grid via a [5×3] MC topology developed to ensure energy conversion from a five-phase wind generator to a three-phase electric grid without using a conventional intermediate circuit (rectifier/inverter). The five-to three-phase MC is controlled as an indirect AC/DC/AC converter by introducing a virtual intermediate direct voltage. The control of the active and reactive power injected to the grid from the generator is achieved by DPC. First, the concept of the proposed five-to three-phase MC and

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application of DPC to a five-phase PMSG are introduced and details of the control strategy are then discussed. Simulation results are presented to validate the performance of the proposed strategy for the whole system.

2 GENERAL SYSTEM DESCRIPTION

As shown in Fig.1, the system analyzed is a variable-speed wind turbine based on a five- phase PMSG and five-to three-phase MC connected to the grid via an RL filter. Due to the low generator speed, the rotor shaft is coupled directly to the generator, which means that no gearbox is needed.

2.1 *Wind-turbine aerodynamic model*

The mechanical power produced by a wind turbine can be expressed as:

$$P_t = \frac{1}{2}\rho A C_p(\lambda,\beta)\, v_w^3 \tag{1}$$

where ρ is the air density, A is the area swept by the rotor blades, R is the turbine blade radius, C_p is the wind-turbine power coefficient, β is the blade pitch angle, v_w is the wind speed and λ is the tip speed ratio defined as:

$$\lambda = \frac{\Omega_m R}{v} \tag{2}$$

where Ω_m is the angular speed of the turbine rotor.

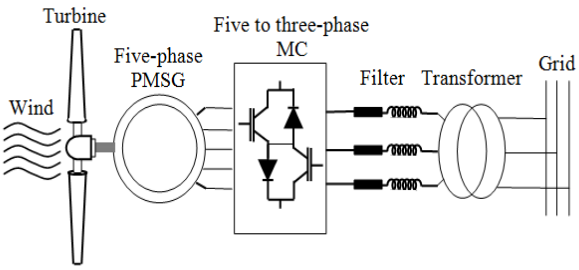

Figure1. Diagram of a grid-connected five-phase PMSG-based on a five-to three-phase MC.

Power coefficient C_p can be approximated as a relationship of tip-speed ratio λ and blade-pitch angle β by the expression [2]:

$$C_p(\lambda,\beta) = C_1 \cdot \left(\frac{C_2}{\lambda_i} - C_3.\beta - C_4\right).\exp\left(-\frac{C_5}{\lambda_i}\right) + C_6.\lambda \tag{3}$$

With:

$$\frac{1}{\lambda_i} = \left(\frac{1}{\lambda + 0.08.\beta} - \frac{0.035}{\beta^3 + 1}\right) \tag{4}$$

And:

C_1 = 0,5176, C_2 = 116, C_3 = 0.4, C_4 = 5, C_5 = 21, C_6 =0,0068.

2.2 *Modeling of a five-phase PMSG*

The stator voltages in the *dq* axis for a the five-phase PMSG in a synchronous rotating reference frame are [4]:

$$\begin{cases} v_{d1} = R_s i_{d1} + \dfrac{d\psi_{d1}}{dt} - \omega_m \psi_{q1} \\ v_{q1} = R_s i_{q1} + \dfrac{d\psi_{q1}}{dt} + \omega_m \psi_{d1} \\ v_{d2} = R_s i_{d2} + \dfrac{d\psi_{d2}}{dt} \\ v_{q2} = R_s i_{q2} + \dfrac{d\psi_{q2}}{dt} \end{cases} \tag{5}$$

The PMSG flux equations in the *dq* axis are:

$$\begin{cases} \psi_{d1} = L_d i_{d1} \\ \psi_{q1} = L_q i_{q1} + \psi_f \\ \psi_{d2} = L_d i_{d2} \\ \psi_{q2} = L_q i_{q2} \end{cases} \tag{6}$$

The electromagnetic torque of a five-phase PMSG is:

$$T_{em} = \frac{5}{2} p[(L_d - L_q) i_d i_q + \psi_f i_{q1}] \tag{7}$$

The mechanical equation of the wind-turbine system is:

$$T_m = T_{em} + K_f \Omega_m + J\frac{d\Omega_m}{dt} \tag{8}$$

where T_m is the mechanical torque of the wind turbine, T_{em} is the electromagnetic torque of the generator, J is the total inertia of the system and K_f is the coefficient of a viscous friction.

2.3 *Five-to three-phase MC*

2.3.1 *Five-to three-phase MC modeling*

A five-to three-phase MC is a single stage converter that connects five inputs to three output phases by using a 5×3 electronic power switch. Each switch is equipped with two anti-parallel-connected IGBTs with fast diodes, as shown in Fig. 2.

The corresponding switching function of each electronic power switch is defined as:

$$S_{mn}=\begin{cases}1 & \text{if } \mathrm{S_{mn}} \text{ closed}\\ 0 & \text{if } \mathrm{S_{mn}} \text{ open}\end{cases} \quad m\in\{A,B,C,D,E\}, n\in\{a,b,c\} \tag{9}$$

As the input phase should never be short-circuited, only one switch can be in the on-state in each leg at any instant:

$$S_{An}+S_{Bn}+S_{Cn}+S_{Dn}+S_{En}=1, \quad n\in\{a,b,c\} \tag{10}$$

The proposed five-to three-phase MC output phase voltages are made of their input-phase voltages:

$$\begin{bmatrix}V_a\\V_b\\V_c\end{bmatrix}=\begin{bmatrix}S_{Aa} & S_{Ba} & S_{Ca} & S_{Da} & S_{Ea}\\ S_{Ab} & S_{Bb} & S_{Cb} & S_{Db} & S_{Eb}\\ S_{Ac} & S_{Bc} & S_{Cc} & S_{Dc} & S_{Ec}\end{bmatrix}\begin{bmatrix}V_A\\V_B\\V_C\\V_D\\V_E\end{bmatrix} \tag{11}$$

2.3.2 Five to three-phase MC control

To minimize complexity of the MC control, it is considered as a two-part converter scheme shown in Fig. 2. The first part is the rectification stage that supplies a constant virtual DC-link and the second part is the inversion stage which is similar to the conventional back-to-back converter (AC/DC/AC) used to generate output voltages of a variable magnitude and frequency [12].

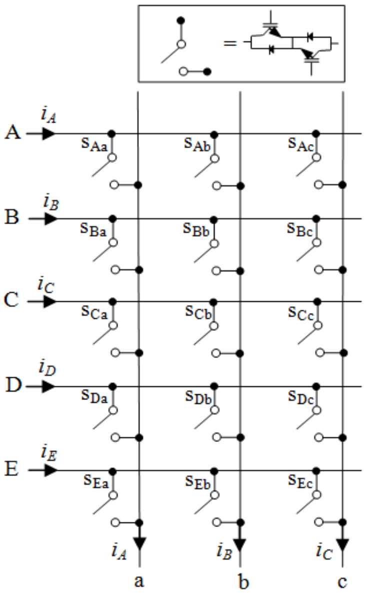

Figure 2. Five-to three-phase matrix converter topology.

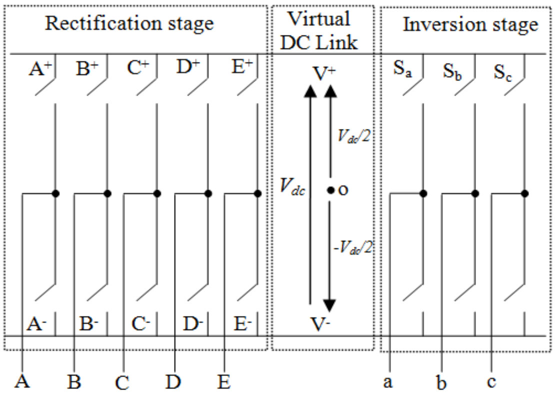

Figure 3. Equivalent [5×3] MC topology.

- *Rectification-stage investigation*

According to Fig. 3, virtual intermediate voltage V_{dc} is:

$$V_{dc}=V^{+}-V^{-} \tag{12}$$

Virtual potentials V^+ and V^- vary as a function of the five-phase inputs and functions of the rectification control:

$$\begin{bmatrix}V^{+}\\V^{-}\end{bmatrix}=\begin{bmatrix}A^{+} & B^{+} & C^{+} & D^{+} & D^{+}\\ A^{-} & B^{-} & C^{-} & D^{-} & E^{-}\end{bmatrix}\begin{bmatrix}V_A\\V_B\\V_C\\V_D\\V_E\end{bmatrix} \tag{13}$$

where m^+ and m^- (m= {A, B, C, D, E}) are the rectification control functions defined by:

$$m^{+}=\begin{cases}1 & \text{if } V_m \text{ is the most postive input phase}\\ 0 & \text{if not}\end{cases} \tag{14}$$
$$m^{-}=\begin{cases}1 & \text{if } V_m \text{ is the most negative input phase}\\ 0 & \text{if not}\end{cases}$$

- *Inversion-stage investigation*

The link between the MC virtual middle potential and the output voltages (see Fig. 3) are:

$$\begin{bmatrix}V_{ao}\\V_{bo}\\V_{co}\end{bmatrix}=\begin{bmatrix}s_a & 1-s_a\\ s_b & 1-s_b\\ s_c & 1-s_c\end{bmatrix}\begin{bmatrix}V^{+}\\V^{-}\end{bmatrix} \tag{15}$$

Where s_n (n= {a, b, c}) are the modulation functions (binary signals) similar to those used in the conventional inverter control.
Substituting Eq. (13) in Eq. (15), gives:

$$\begin{bmatrix} V_{ao} \\ V_{bo} \\ V_{co} \end{bmatrix} = \begin{bmatrix} s_a & 1-s_a \\ s_b & 1-s_b \\ s_c & 1-s_c \end{bmatrix} \begin{bmatrix} A^+ & B^+ & C^+ & D^+ & D^+ \\ A^- & B^- & C^- & D^- & E^- \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \\ V_E \end{bmatrix} \tag{16}$$

Equation (16) can be written as:

$$\begin{bmatrix} V_{ao} \\ V_{bo} \\ V_{co} \end{bmatrix} = \begin{bmatrix} \Gamma_{Aa} & \Gamma_{Ba} & \Gamma_{CA} & \Gamma_{Da} & \Gamma_{Ea} \\ \Gamma_{Ab} & \Gamma_{Bb} & \Gamma_{Cb} & \Gamma_{Db} & \Gamma_{Eb} \\ \Gamma_{Ac} & \Gamma_{Bc} & \Gamma_{Cc} & \Gamma_{Dc} & \Gamma_{Ec} \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \\ V_E \end{bmatrix} \tag{17}$$

where Γ_{mn} are the reference signals defined as:

$$\Gamma_{mn} = m^+ s_n + m^- (1-s_n), m \in \{A,B,C,D,D,E\}, n \in \{a,b,c\} \tag{18}$$

Based on Eq. (17) and the inverter mathematical model given in [13], the MC output voltages are:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} \Gamma_{Aa} & \Gamma_{Ba} & \Gamma_{CA} & \Gamma_{Da} & \Gamma_{Ea} \\ \Gamma_{Ab} & \Gamma_{Bb} & \Gamma_{Cb} & \Gamma_{Db} & \Gamma_{Eb} \\ \Gamma_{Ac} & \Gamma_{Bc} & \Gamma_{Cc} & \Gamma_{Dc} & \Gamma_{Ec} \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \\ V_E \end{bmatrix} \tag{19}$$

The similarity between Eq. (11) and Eq. (19) turns the MC switching into:

$$\begin{cases} S_{ma} = \frac{1}{3}(2\Gamma_{ma} - \Gamma_{mb} - \Gamma_{mc}) \\ S_{mb} = \frac{1}{3}(2\Gamma_{mb} - \Gamma_{ma} - \Gamma_{mc}), \quad m \in \{A,B,C,D,E\} \\ S_{mc} = \frac{1}{3}(2\Gamma_{mc} - \Gamma_{ma} - \Gamma_{mb}) \end{cases} \tag{20}$$

3 DPC OF A GRID-CONNECTED FIVE-PHASE PMSG

The proposed DPC structure of the whole system is presented in Fig. 4. To implement such control, the stator flux and the grid active and reactive power are estimated. The estimated grid powers are compared with their reference values by using two hysteresis comparators and a switching table such as the one used in conventional Direct Torque Control (DTC).

3.1 Stator-flux estimation

To estimate the stator-flux components, stator current i_α and i_β components are measured. They are obtained by applying the Concordia transformation to measured three-phase stator currents i_a, i_b and i_c:

$$\begin{cases} i_\alpha = \sqrt{\frac{2}{3}}\, i_a \\ i_\beta = \frac{1}{\sqrt{2}}(i_b - i_c) \end{cases} \tag{21}$$

Using the flux equation (14), the estimated $\alpha\beta$ components of the stator flux are:

$$\begin{cases} \psi_{\alpha\_est} = L_d i_\alpha \\ \psi_{\beta\_est} = L_q i_\beta + \psi_f \end{cases} \tag{22}$$

From the above two expressions, the estimated module and the phase of the stator flux are:

$$\psi_{est} = \sqrt{\psi^2_{\alpha\_est} + \psi^2_{\beta\_est}} \ , \ \delta_{est} = arctg\left(\frac{\psi_{\beta\_est}}{\psi_{\alpha\_est}}\right) \tag{23}$$

3.2 Grid active-and reactive-power estimation

The active and reactive power injected into the grid is calculated by the following equations:

$$\begin{cases} p_g = \frac{3}{2}(V_{gd} i_{gd} + V_{gq} i_{gq}) \\ Q_g = \frac{3}{2}(V_{gq} i_{gd} - V_{gd} i_{gq}) \end{cases} \tag{24}$$

The dynamic model of the grid-side electric circuits is presented as [2,4]:

$$\begin{cases} v_{gd} = R_g i_{gd} + L_g \frac{di_{gd}}{dt} - \omega_g L_g i_{gq} + v_{cgd} \\ v_{gq} = R_g i_{gq} + L_g \frac{di_{gq}}{dt} - \omega_g L_g i_{gd} + v_{cgq} \end{cases} \tag{25}$$

To ensure a pure active-power exchange from the wind generator and maintain the reactive-power exchange to the grid to guarantee a desirable power factor during the generator function, the *d*-axis of the synchronous reference frame is oriented with the grid-voltage vector [2,4]:

$$\begin{cases} v_{gd} = V_g \\ v_{gq} = 0 \end{cases} \tag{26}$$

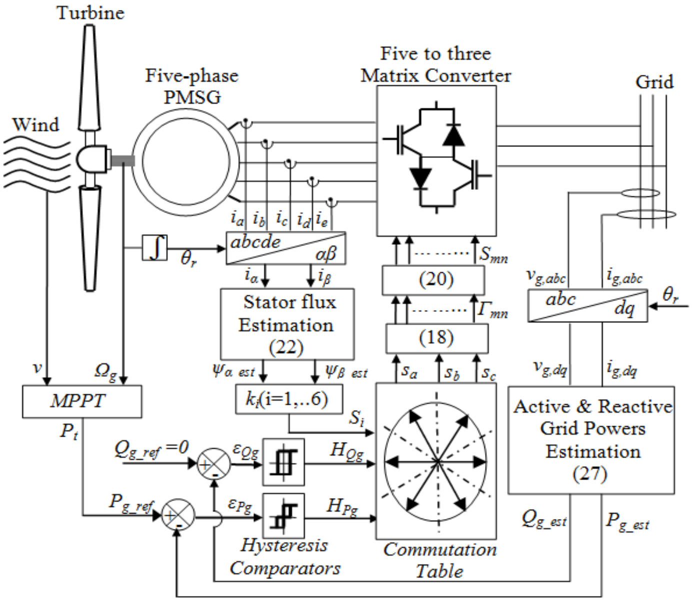

Figure 4. Schematic diagram of the DPC strategy for a five-phase PMSG-based wind turbine.

By substituting Eq. (26) in Eq. (24), the grid active and reactive power are estimated:

$$\begin{cases} P_{g\_est} = \dfrac{3}{2} V_g i_{gq} \\ Q_{g\_est} = \dfrac{3}{2} V_g i_{gd} \end{cases} \tag{27}$$

3.3 *Control of the grid active and reactive power*

The estimated active and reactive power are compared with their reference values in their corresponding hysteresis comparators shown in Fig.4. The comparators outputs and the sector number at which the stator-flux space vector is located are applied to a switching table (Table 1) to select appropriate switching state s_n *(n=a,b,c).* These switch statuses will be applied to the proposed five-to three-phase MC. Eight voltage vectors are selected, two of which determine the zero-voltage vectors and others generate six equally spaced voltage vectors having the same amplitude. According to the DPC functioning principle [14-15], the voltage vector is selected to maintain the active and reactive power within the limits of two hysteresis bands. For this purpose, the evolution space of the stator-flux in the considered reference-frame control is given by [14-15]:

$$-\frac{\pi}{6}+(k-1)\frac{\pi}{3} \le \delta \le \frac{\pi}{6}+(k-1)\frac{\pi}{3},\ k=0,1,2,..,6 \tag{28}$$

Table1. Switching table of the inversion-stage voltage vectors

H_{Qg}	**H_{Pg}**	**Sector**					
		1	**2**	**3**	**4**	**5**	**6**
1	**1**	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	**1**	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_1	V_2	V_3	V_4

4 SIMULATION RESULTS

A grid-connected five-phase PMSG-based wind turbine is investigated using Matlab/Simulink. The parameters of the wind turbine, five-phase PMSG and electric grid used in this investigation are given in the Appendix. To investigate the efficiency of proposed control technique, the average wind speed is 11 m/s with a variation of some 15% as shown in Fig. 5. The turbine rated power is 4.8 kW when functioning in the MPPT mode.

Fig. 6 presents the actual and reference generator speed. As seen, when the wind speed varies, the PI controller makes the five-phase PMSG rotor speed (Ω_m) to follow its reference value ($\Omega g_{\_ref} = \lambda_{opt}.v/R$). The measured and reference generator speed are agreed well proving that MPPT is achieved. The electromagnetic and mechanical torque of the five-phase PMSG change and precisely respond to the wind-speed variations, as shown in Figs. 7 and 8.

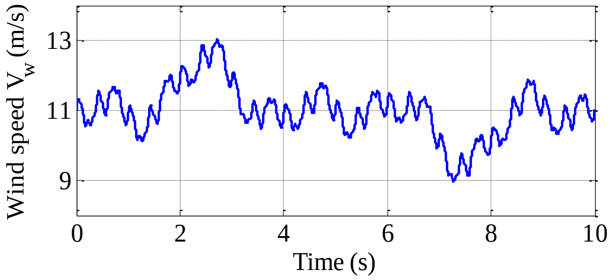

Figure 5. Wind-speed waveform.

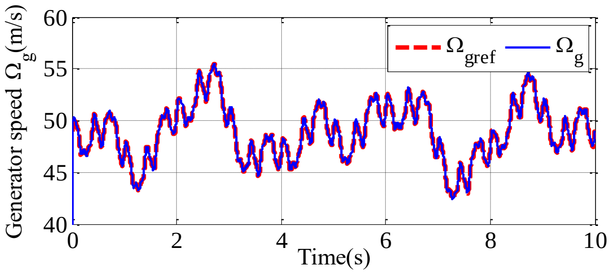

Figure 6. Generator speed & reference.

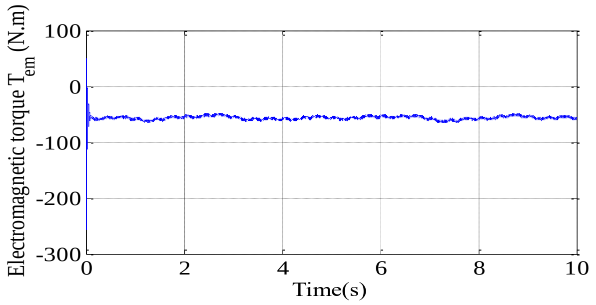

Figure 7. Five-phase PMSG electromagnetic torque.

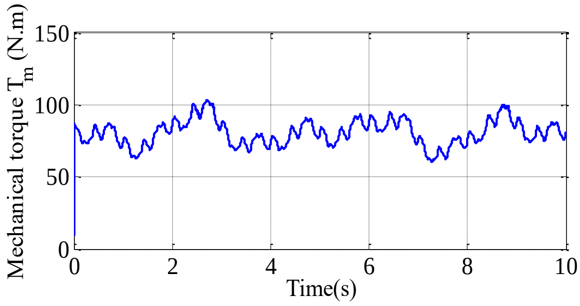

Figure 8. Five-phase PMSG mechanical torque.

Figs. 9 and 10 show the waveforms of the machine *dq*-axis currents. The response of the current vector components (i_{d1}, i_{q1}) varies according to the variations on the wind speed. However, the components (i_{d2}, i_{q2}) are kept at the desired zero value. Fig. 11 displays the three-phase grid-current waveform. The grid current has a sinusoidal form and changes according to the wind-speed variations.

Figs. 12 and 13 show the mechanical power issue from the wind turbine and the active and reactive power injected into the grid. It is clear that the grid active power varies according to the wind-speed variations and follows the mechanical power. The reactive power is kept at zero. Finally, Fig.14 shows the waveform of the grid voltage and current between *0.02 s* and *0.14 s*. It can be seen that the voltage is in phase with the current, which proves that the five-phase PMSG drives with the unit power factor as shown in Fig. 13.

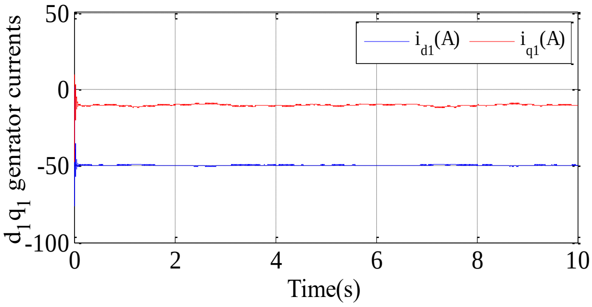

Figure 9. Five-phase PMSG d_1q_1-axis currents.

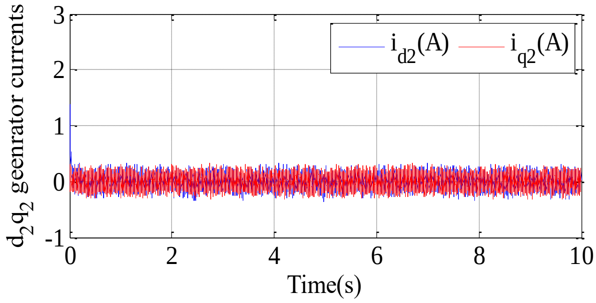

Figure 10. Five-phase PMSG d_2q_2-*axis* currents.

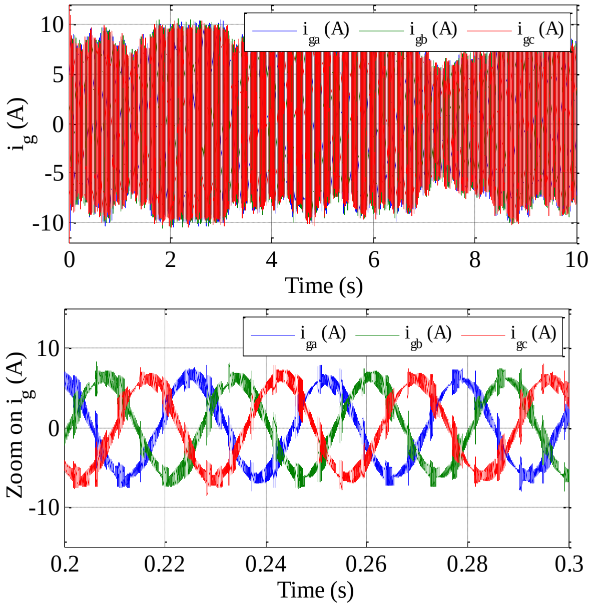

Figure 11. Three-phase grid current i_{ga}, i_{gb} , i_{gc} (A).

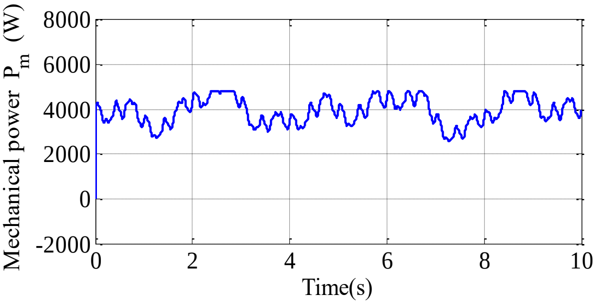

Figure 12. Mechanical power.

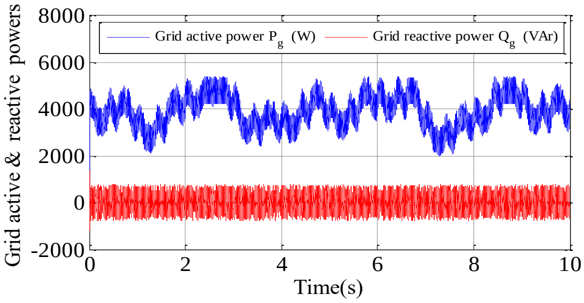

Figure 13. Grid active and reactive power P_g *(W)*, Q_g *(VAr)*.

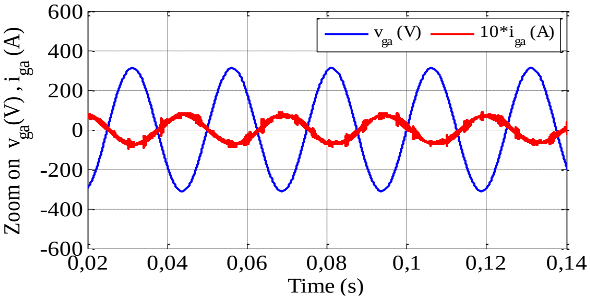

Figure 14. Phase *a* Grid voltage and current (v_{ga}*(V)*, $10\times i_{ga}$ *(A)).*

5 CONCLUSION

The paper presents a novel topology for a grid-connected multiphase wind-energy conversion system employing a five-phase PMSG and a five-to three-phase matrix converter. The proposed topology and the concept are equally applicable to power generation applications. In this study, a simple way to control the five-to three-phase matrix converter by considering a virtual DC link between two conversion stages (rectification and inversion) is used. To control the active and reactive power injected to the grid, the DPC control is investigated. In addition, the generated reactive power of the wind-conversion system is controlled to follow zero. A simulation with the used control algorithms at a suitable wind variation is applied to the whole system. Simulation results show a good performance. Therefore, the objectives of the control method are achieved.

APPENDIX

Table 2. Grid Parameters

Parameter	**Value**
Grid Frequency	50 Hz
Grid resistance	0.015Ω
Grid inductance	0.002H

Table 3. Wind-turbine parameters

Parameter	**Value**
Rotor radius *R*	1.8 m
Power coefficient C_{pmax}	0.41
Air density *ρ*	1.225

Table 4. Five-phase PMSG parameters

Parameter	**Value**
Rated power P_n	4.8 KW
Rated Torque T_n	76 N.m
Pairs poles number *p*	5
Stator resistance R_s	0.425 Ω
Stator *dq*-axis inductances	0.00835H
Inertia *J*	0.01197
Flux linkage ψ_f	0.433 Wb

REFERENCES

[1] Eriksson S., Solum A., Leijon M., Bernhoff H., “Simulations and experiments on a 12 kW direct driven PM synchronous generator for wind power”, *Renewable Energy*, 33(4), pp. 674-681., 2008.

[2] Gajewski P., Pieńkowski K. “Advanced control of direct-driven PMSG generator in wind turbine system”. *Archives of Electrical Engineering*. 65(4), pp. 643-656, 2016.

[3] Freire N., Estima J., Cardoso .A., “A comparative analysis of PMSG drives based on vector control and direct control techniques for wind turbine applications”, *Przegląd Elektrotechniczny*, 88(1), pp. 184-187, 2012.

[4] Rhaili S., Abbou A., Marhraoui S., El Hichami N., “Vector Control of Five-phase Permanent Magnet Synchronous Generator based Variable-Speed Wind Turbine”, *IEEE Xplore*, [Online Available], DOI: 10.1109/WITS.2017.7934647, 2017.

[5] Youssef A., Mahmoud A. Sayed, M. Abdel-Wahab N., Salman G. S.,“MPPT Control Technique for Direct-Drive Five-Phase PMSG Wind Turbines with Wind Speed Estimation”. *International Journal of Sustainable and Green Energy*., 4(5), pp. 195-205, 2015.

[6] Djahbar A., Zegaoui A., Aillerie M., “Multiphase Wind Energy Conversion Systems Based on Matrix Converter”, *AUTOMATIKA*, Vol. 57, no.2, 2016, pp. 396–404.

[7] Rezaoui M.M, Nezli L., Mahmoudi M.O, "High Performances of five–phase induction machine feeding by a [3 × 5] Matrix Converter”, *Journal of Electrical Engineering*, 65(2), pp. 83–89, 2014.

[8] Badiee-Azandehi A., Yousefi-Talouki A., Rezanejad M., “Direct torque control space vector modulation of five-phase interior permanent magnet synchronous motor using matrix converter", *Australian Journal of Electrical & Electronics Engineering*, 12(2), pp.113-124, 2015.

[9] Rezaoui M.M, Nezli L., Mahmoudi M.O, Kouzou a. and Abu Rub H., "A modified PWM three intervals control for a matrix converter in real time”, *Archives of Control Sciences*, 3(1), pp 85–98, 2014.

[10] Yuhendri M., Ahyanuardi A., Aswardi A., “Direct Torque Control Strategy of PMSM Employing Ultra Sparse Matrix Converter”, *International Journal of Power Electronics and Drive System (IJPEDS)*, 9(1), pp. 64-72, 2018.

[11] Nikkhajoei H., Tabesh A., Iravani R., “Dynamic model of a matrix converter for controller design and system studies”, *IEEE Transaction on Power Delivery*, vol. 21, pp. 744–754, 2006.

[12] Klumpner C. , Blaabjerg F., Boldea I., Nielsen P., "New Modulation Method for Matrix Converters”, *IEEE Trans. Industry Applications*,42, pp.797-806, 2006.

[13] Saadoun A., Yousfi A. , Amirat Y., “Modeling and Simulation of DSP Controlled SV PWM Three Phase VSIA”., *Journal of Applied Sciences*, 7(7), pp. 989-994, 2007.

[14] Xu L., Cartwright P, Direct active and reactive power control of DFIG for wind energy generation”, *IEEE Trans. Energy Conversion*, 21(3), pp. 750-758, 2006.

[15] Datta R., Ranganathan V.T, “Direct Power Control of grid-connected Wound Rotor Induction Machine without rotor position sensors”, *In: IEEE Trans. Power Electron*. 16(3), pp. 390-399, 2001.

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