Materials and Devices
An International Scientific Journal
Managed by scientists for Science - http://co-ac.com
OPEN ACCESS Freely Accessible Scientific Papers.
CA-IP

Article type: T-Technical paper

Dynamic Modeling of Double Star Synchronous Generator with permanent magnets

Gning N S (1) (2), Nadia AIT A. (1), Seck A. (2), Mourad AIT A. (1), Thiaw L. (2), Benkhoris M.F. (1)

(1) IREENA, University of Nantes, Saint Nazaire, France
(2) L.E.R, University Cheikh Anta Diop of Dakar, Dakar, Senegal

Corresponding author : nabou439@gmail.com

RECEIVED: 11 june 2019 / RECEIVED IN FINAL FORM: 05 august 2019/ ACCEPTED: 07 august 2019

Abstract: In this paper, the dynamic modeling of the double-star generator is presented, then its adaptation in an electromechanical conversion. We reported all torque production to the first equivalent submachine to minimize losses. The model implementation is done under the Matlab/Simulink environment. The DC bus current and voltage control loops have been realized by synthesizing a PI controller. The results obtained are consistent with a good followup of the imposed references..

Keywords: Double Star Generator; electromechanical conversion; controller PI; dynamic modeling.

Cite this article: N.S. Gning , Nadia. Ait.A, Mourad. Ait. A, Seck. A, Thiaw.L, Benkhoris. M.Fl, *OAJ Materials and Devices, Vol* ***4 (2)****, 0208 (2019) – DOI : 10.23647/ca.md20190208*

Introduction

Faced with the global demand for nature conservation and the maintenance of natural biodiversity, the world is moving to wards renewable energies to generate electricity.

In this context the demand for electromechanical converters is increasing. Often the architecture of an electromechanical energy conversion consists in adding a three-phase alternating machine to a three-phase PWM (Pulse Width Modulation) converter. With this classic architecture, a defect in one element of the energy conversion chain alone can cause the actuator to loose total or partial control. Therefore, to increase the reliability of the energy conversion chain, the use of two machines for the redundancy problem often creates difficulties related to comanagement. Recently [1][2] the use of double stator machines was proposed, allowing to integrate two machines in one, with two independent windings connected in stars.

Studies carried out on double star machines show that in addition to reducing the pulsation amplitudes of the torque by using a large number of phases, a good choice of the phase shift angle between the two stator stars, in this case an electrical angle of 30 degrees, further reduces these pulsations, making them even more attractive [3][4].

This configuration has been applied to asynchronous machines [5][6][7][8] and to permanent magnet synchronous machines in motor operation[9]. We propose to replace conventional machines (three-phase) by synchronous double-star permanent magnet machines in generator operation connected to a continuous bus.

In this paper, first we present the modeling of the permanent magnet FEM double star generator. The PI controller and the description of the machine control are the second part.

Third, we present the simulation results performed under the Matlab/Simulink environment.

Dynamic modeling of the generator

The topology DS-PMSG -Converter-Bus Continuous can be done using several structures of converters. We are interested in this study to the structure with three-phase con verters because it is the most used in the industry. In this case the converters can be:

-Independent: each of the stars is connected to its own source of DC voltage via a three-phase converters.

-In parallel: all the stars are connected to the same DC voltage source via the three-phase converters. From these two topologies, we will choose the topology to a single continuous capacitor bus C which is less cumbersome and reduces the cost of installation. The load is represented by a resistive load R.

Assumptions

The modeling of a DS-PMSG is based on the following main assumptions:

•Magneto-motive forces have a sinusoidal distribution.

•Mutual inductance are characterized only by their fundamental.

•Magnetic saturation is neglected.

•The two stars are strictly identical and shifted up by an angle π/6.

DS-SPMG modeling in abc frame

As shown in figure 1, the DS-SPMG is represented the stator structure is described as follows

Two three-phase windings (a1,b1,c1; a2,b2,c2) offset by an angle of 30 degrees. Θ gives the rotor position.

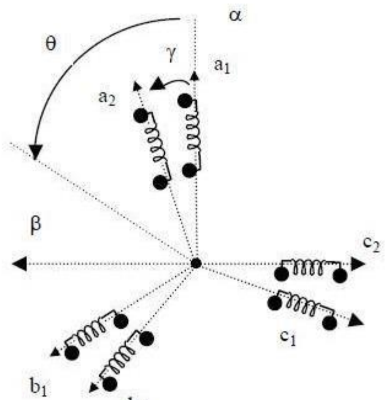

Figure 1: DS-SPMG in abc frame

This allowed to consider and to modeling the DS-SPMG as a six-phase generator. The stator voltage equation for the six phases is given by equation (1) as follow:

$$[V_s] = -[R_S][I_S] - \frac{d}{dt}[L][I_s] + [e_s] \quad \textbf{(1)}$$

DS-SPMG model in (α; β, z1; z2; o1; o2) frame

in the **(α; β**) frame, all axes are projected to pass from a three-phase to a two-phase frame.

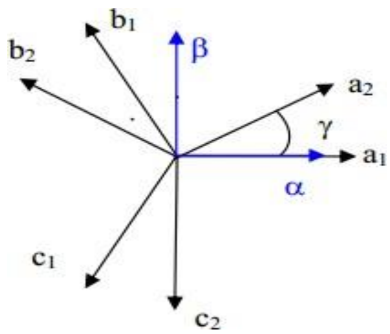

Figure 2: Projection in α, β frame

In order to minimize the coupling between the state variables, we can rewrite the model of the machine in the orthonormal Frame α, β, z1; z2; o1; o2, applying the transformation matrix T6 [11].

[iα; iβ; iz1; iz2; ic1; ic2]= [T6] [is]

After calculation, the model given by equation (1) becomes:

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_{z1} \\ V_{z2} \\ V_{o1} \\ V_{o2} \end{bmatrix} - [R_S] \begin{bmatrix} i_\alpha \\ i_\beta \\ i_{z1} \\ i_{z2} \\ i_{o1} \\ i_{o2} \end{bmatrix} + \begin{bmatrix} e_\alpha \\ e_\beta \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} -$$

$$\frac{d}{dt}\begin{bmatrix} l_{fs}+3M_{ss} & 0 & 0 & 0 & 0 & 0 \\ 0 & l_{fs}+3M_{ss} & 0 & 0 & 0 & 0 \\ 0 & 0 & l_{fs} & 0 & 0 & 0 \\ 0 & 0 & 0 & l_{fs} & 0 & 0 \\ 0 & 0 & 0 & 0 & l_{fs} & 0 \\ 0 & 0 & 0 & 0 & 0 & l_{fs} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_{z1} \\ i_{z2} \\ i_{o1} \\ i_{o2} \end{bmatrix} \quad (2)$$

M_{ss} : maximum value of mutual inductance

l_{fs} : leakage inductance

$$e_\alpha = \sqrt{3} * \varphi_i * \frac{d}{dt}\cos(\omega t)$$

$$e_\beta = \sqrt{3} * \varphi_i * \frac{d}{dt}\sin(\omega t)$$

ω : pulsation

φ_i : magnetic flow

Applying this basis change, the obtained model is composed of two fully decoupled submachines:

•The primary submachine, expressed in the reference α; β, contributes to the generation of electromechanical torque.

•The secondary submachine expressed in the reference z1; z2; o1; o2 not participate in the generation of the electromagnetic torque.

DS-PMSG Modeling in Park frame

Only the primary submachine contributes to the electromagnetic conversion of the torque. The second submachine is only a seat of losses.The Park transform is applied only primary submachine. The model is given by equation (3):

$$\begin{bmatrix} \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} & [0]_{2\times4} \\ [0]_{4\times2} & [I]_{4\times4} \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \\ i_{z1} \\ i_{z2} \\ i_{o1} \\ i_{o2} \end{bmatrix} = -[R_S] \begin{bmatrix} i_d \\ i_q \\ i_{z1} \\ i_{z2} \\ i_{o1} \\ i_{o2} \end{bmatrix} -$$

$$\begin{bmatrix} V_d \\ V_q \\ V_{z1} \\ V_{z2} \\ V_{o1} \\ V_{o2} \end{bmatrix} + \begin{bmatrix} e_d \\ e_q \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} \begin{bmatrix} 0 & -\omega L_d \\ \omega L_q & 0 \end{bmatrix} & [0]_{2\times4} \\ [0]_{4\times2} & [I]_{4\times4} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_{z1} \\ i_{z2} \\ i_{o1} \\ i_{o2} \end{bmatrix} \quad (3)$$

$$e_d = 0$$

$$e_q = \sqrt{3} * \varphi_i * \omega$$

$$L_q = L_q = L_{fs} + 3M_{ss}$$

Controller design principe

To prevent the second submachine to generate losses without producing torque, its currents are imposed null. Always with the aim of minimising losses, the id current of the primary submachine is imposed at zero. This allows the torque to be linearized at the same time

Simulation results

The control block shema is represented by figure 3. We have two control loops: an external loop that controls the DC bus voltage; an internal loop (in red color in figure 3) to regulate the currents in the dq mark. In the simulator, the converters are replaced by a gain G. We synthesized PI regulators for currents and voltage using. the pole compensation method. In the following, we have substituted the indices d, q, z1, z2 respectively to dp, qp, ds, qs so that the indices refer to the primary and secondary submachine.

Reg: regulation block containing four PI for regulation of four current.

Dec: decoupling block

DS-PMSG: this block represents the machine and contains its dynamic model

Calcul.power: power calculation block based on the voltages in the dq frame

Calcul.Uc2: block for calculating the DC bus voltage Uc from the power.

Calcul.iqref: block for calculating the iqref current, which is the only non-zero current of the machine.

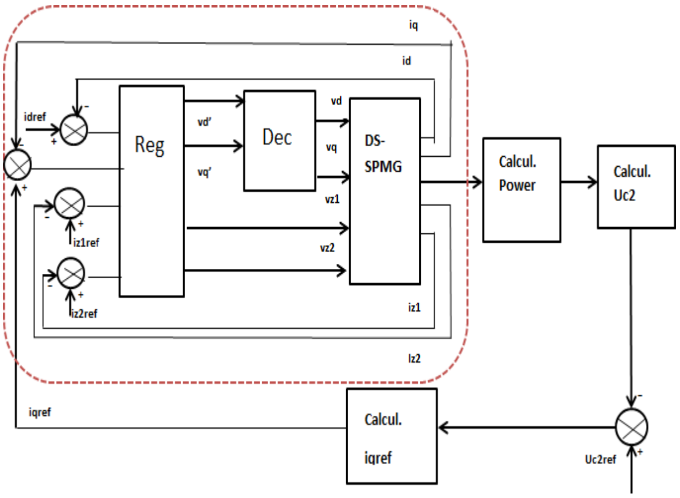

Figure 3: Synoptic of regulation

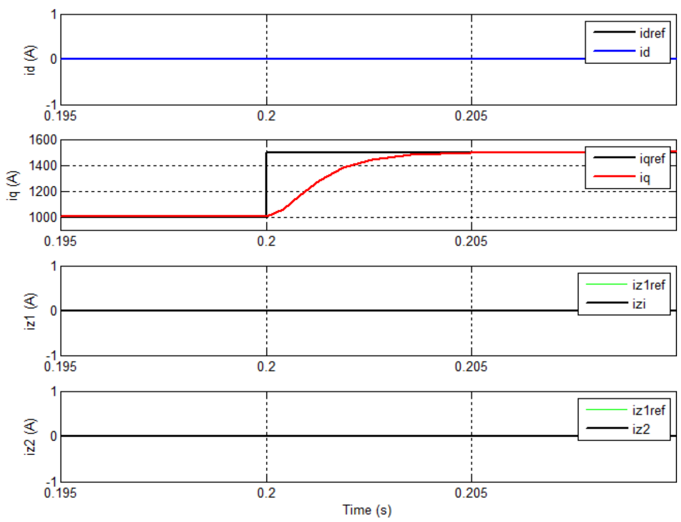

Figure .4. Simulation results

In Figure 4, we have the four currents (id, iq, iz1, iz2) that exactly follow the imposed references.

The simulation results show that only the first submachine participates to the production of torque as seen in the mo-delling.

Therefore, it is the only one to produce the full power of the dual generator. This result not only validates the modeling of the generator but also minimizes losses. These results also allow industries to increase the reliability of operation while remaining in the classic electronic power point of view,

Conclusion

In this paper, a dynamic modeling approach to the double star generator was developed. Then we implemented the model on a simulator developed in Matlab / Simulink envi- ronment. We used the PI regulator. The simulation results

show a good follow-up of the imposed references and allows to validate the model.

In the following we think about regulate the dynamic model of the generator in degraded mode.

Complementary informations on authors

Ndeye Seynabou GNING ndeye-seynabou.gning@etu.univ-nantes.fr, https://www.researchgate.net/profile/Ndeye_Gning2

Lamine Thiaw: lamine.thiaw@ucad.edu.sn, https://www.researchgate.net/profile/Lamine_Thiaw

Mouhamed Fouad Benkhoris mohamed-fouad.benkhoris@univ-nantes.fr, https://www.researchgate.net/profile/Mohamed_Fouad_Benkhoris

REFERENCES

[1]Zhang, A Houari, A Seck, L Moreau, “Fault tolerant of a double stator permanent magnet generator in tidal curent energy system,” IEEE, vol. 978, pp. 4678–8075, 2016.

[2]Gregor, R., Barrero, F., Toral, SL, Duran, MJ, Arahal, MR, Prieto, J. et Mora, JL (2010). Méthode de contrôle du courant PWM vectoriel à espace prédictif pour entraînements de moteurs à induction triphasés doubles asymétriques. IET Electric Power Applications , 4 (1), 26-34.E.

[3]B. Sedrine, “Machines à commutation de fux à grand nombre de phases : Modèles comportementaux en mode dégradé et élaboration d’une stratégie de commande en vue de l’amélioration de la tolérance aux pannes,” Ph.D. dissertation, Ecole Normale Superieure de Cachan, 2014.

[4]Fall, O., Charpentier, J. F., Nguyen, N. K., & Letellier, P. (2016, June). Comparaison de Performances de Différentes Structures de Machines Synchrones à Aimants Permanents (MSAP) Polyphasées en Mode Normal et en Modes Dégradés en Vitesse Variable avec Défluxage pour des Applications Hydroliennes.

[5]D. Hadiouche, “Contribution à l’étude de la machine asynchrone double étoile: modélisation, alimentation et structure,” Ph.D. dissertation, Université Henri Poincaré, Nancy-I, 2001.

[6]A. YAHDOU, “Commande et observation par mode glissant d’une machine asynchrone double étoile sans capteur mécanique,” Master’s thesis, Université Henri Poicare Nancy-I, 2001.

[7]M. Yacine, “Contribution à l’étude de la machine asynchrone doubleétoile. application à la sureté de fonctionnement.” Ph.D. dissertation, Université Freres MentouriI-Constantine, 2015.

[8]LI, Kang, DOKI, Shinji, et FUJITSUNA, Masami. The position sensorless control for the wound-field synchronous motor with double three-phase wound stator in stop/low-speed driving. In : IECON 2015-41st Annual Conference of the IEEE Industrial Electronics Society. IEEE, 2015. p. 003218-003223..

[9]B. Naas, “Direct torque control based three level inverter-fed double star permanent magnet synchronous machine,” Science Direct, vol. 18, pp. 521–530, 2012.

[10]F. Terrien and M. Benkhoris, “Analysis of double star motor drives for electrical propulsion,” in Electrical Machines and Drives Ninth International Conference on IET, vol. 468, pp. 90–94, 1999.

[11] M.MERABTENE, “Modelling of a double star synchronous motor fed by pwm inverter under fault conditions,” International Conference on Electrical Machines ICEM’2002, Bruges, Belgique, 25-28 August 2002, CD-ROM.

[12]L. Parsa, “On advantages of multi-phase machines,” in 31st Annual Conference of IEEE Industrial Electronics Society, 2005.IECON 2005.IEEE,p. 6, 2005.

[13]E. Levi, “Multiphase electric machines for variable-speed applications,” IEEE Transactions on industrial electronics, vol. 55, no. 5, pp. 1893–1909, 2008.

[14]SHAMSI-NEJAD, Mohammad-Ali, NAHID-MOBARAKEH, Babak, PIERFEDERICI, Serge, et al. Fault tolerant permanent magnet drives: Operating under open-circuit and short-circuit switch faults. King Mongkut’s University of Technology North Bangkok International Journal of Applied Science and Technology, 2014, vol. 7, no 1, p. 57-64.B. N. Badreddine Naas, Nezlie, “Direct torque control based three level inverter fed double star permanent magnet synchro- nous machine,” Science Direct, vol. 18, pp. 521–530, 2012.

[15]A. Rockhill and T. Lipo, “A generalized transformation methodology for polyphase electric machines and networks,” in Electric Machines & Drives Conference (IEMDC), 2015 IEEE International. IEEE, pp. 27–34, 2015.

[16]A. Dieng and al, “Fault-tolerant control of 5-phase pmsg for marine current turbine applications based on fractional controller,” IFAC Proceedings Volumes, vol. 47, no. 3, pp. 11 950–11 955, 2014.

[17]Iffouzar, K., Benkhoris, M. F., Ghedamsi, K., & Aouzellag, D. (2016). Behavior analysis of a dual stars induction motor supplied by pwm multilevel inverters. REVUE ROUMAINE DES SCIENCES TECHNIQUES-SERIE ELECTROTECHNIQUE ET ENERGETIQUE, 61(2), 137-141.

[18]L. Parsa and H. A. Toliyat, "Fault-tolerant five-phase permanent magnet motor drives," in Industry Applications Conference, 2004. 39th IAS Annual Meeting. Conference Record of the 2004 IEEE, vol. 2. IEEE, pp. 1048–1054, 2004.