DEVELOPMENT OF IRONLESS CORELESS AXIAL FLUX PERMANENT MAGNET GENERATOR

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LIST OF SYMBOLS

η	Efficiency
P_{out}	Power output
P_{in}	Power input
P_{loss}	Power losses
W_h	Hysteresis loss
K_h	Hysteresis constant
f	Frequency
B_m	Magnetic flux density
W_e	Eddy current loss
K_e	Eddy current constant
v	Velocity of the wire
ω	Rotating speed of rotor in rad/s
R	Turning radius
e	Generated voltage/Counter electromotive force
B	Magnetic flux
u	Velocity of moving charge
f	Force magnitude
ϕ	Magnetic flux
τ	Pole pitch
r	Radius
g	Thickness of magnet
μ_0	Air permeability
B_r	Remanence
H_c	Coercivitiy of magnet

δ	Air gap length
H_c	External magnetic field strength
m	Magnetic moment
t_1	Desired end time
t_0	Start time
I	Current
V	Voltage
R	Resistance
P	Power
V_L	Line voltage
V_ϕ	Phase voltage
I_L	Line current
I_ϕ	Phase current
p	Number of poles
N	Rotational speed of rotors in RPM
τ	Torque

LIST OF ABBREVIATIONS

AC	Alternating Current
AFPM	Axial-flux permanent-magnet
CAD	Computer Aided Design
CEMF	Counter Electromotive Force
CNC	Computer Numerical Control
DC	Direct Current
DDPMG	Direct-drive permanent magnet generator
DDSG	Direct-drive synchronous generator with electrical excitation
DFIG	Double fed induction generator
DFIG3G	Double-fed induction generator with three-stage gearbox
EESG	Electrically Excited Synchronous Generator
emf	Electromotive Force
ESTRN	Equivalent strain
FE	Finite Element
FEM	Finite Element Method
IG	Induction generator
NdFeB	Neodymium Iron Boron
RFPM	Radial-flux permanent-magnet
RMS	Root Mean Square
URES	Displacement resultant
VFD	Variable frequency drive

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ABSTRACT

Axial flux permanent magnet generator is well known on application of wind turbine electricity generation. The elimination of some iron core usage in the axial flux permanent magnet generator had significantly improve the generator's efficiency compare to the conventional generator. However, the presence of cog cause by the ferrite material within the generator is seen somehow restricting the application of the generator where low rotational torque is required. Cogging creates an attraction force between magnets and ferrite material in a generator. More power is required to overcome cogging before the generator can be spun continuously. With the increase of power output, the problem of cogging is also increased. Therefore, more power is required to overcome the increased torque. The research sought to fundamentally study the possibility of removing ferrite material in an electric generator. The generator was designed, fabricated and experimentally validated to qualify its no-load and loaded characteristics. The research began with fundamental studies on electric generator and eventually followed by the design concept. The concept was later analyzed in simulation mode by using finite element software to study its characteristics in order to determine its optimum arrangements. Based on the optimum design obtained in the finite element simulations, the generator was then developed and tested in experimental mode to qualify and quantify its qualitative and quantitative characteristics. Since the generator was made coreless and ironless, the cogging torque was therefore reduce to minimum. Results in both simulation and experimental modes showed good agreement between the two. The generator managed to generate a few hundred watts of power and the efficiency was rated to be approximately 78%. Based on the quantitative experiments, pure sinusoidal 3-phase voltage wave was captured on a scope. Cog-free motion was found to have demonstrated low starting torque spin. Hence, it can be concluded that it would be suitable for use in low torque application. Many applications can benefit from this generator such as in electric generation itself, wind turbine as well as applications in the automotive industry.

ABSTRAK

Penjana elektrik fluks paksi magnet kekal adalah terkenal dalam applikasi penjanaan elektrik turbin angin. Oleh kerana penghapusan penggunaan teras besi dalam penjana elektrik flukspaksi magnet kekal, kecekapan penjana elektrik telah meningkat berbanding dengan penjana elektrik konvensional. Kewujudan gigi roda atau tugal disebabkan oleh bahan ferit kelihatan mengehadkan applikasi penjana elektrik dalam keadaan yang memerlukan putaran kilas atau tork yang rendah. Penugalan menghasilkan satu daya tarikan di antara magnet-magnet dengan teras besi berlamina di dalam penjana elektrik. Kuasa yang lebih diperlukan untuk mengatasi masalah gigi roda sebelum penjana elektrik boleh diputar secara berterusan. Dengan meningkatnya output kuasa, masalah penugalan juga meningkat. Oleh itu, lebih kuasa diperlukan untuk mengatasi peningkatan kilasan. Penyelidikan ini bertujuan mengkaji asas-asas kemungkinan penggunaan penjana elektrik tanpa bahan ferit. Penjana elektrik direka, dibina dan diuji untuk disahkan ciri-ciri penjana elektrik tanpa beban dan dengan beban secara uji kaji. Penyelidikan ini bermula dengan kajian asas terhadap penjana elektrik dan seterusnya konsep reka bentuk. Konsep ini kemudiannya dianalisis secara simulasi dengan menggunakan perisian “finite element” untuk mengkaji ciri-cirinya dan menentukan perkiraan optimumnya. Berdasarkan reka bentuk optimum yang diperolehi secara simulasi menggunakan finit elemen, penjana elektrik ini kemudian dibina dan diuji secara ujikaji untuk mengukur ciri-ciri kualitatif dan kuantitatif. Oleh kerana penjana ini dibuat dengan tanpa teras dan juga tanpa menggunakan besi, penugalan kilas dapat mengurangkan ke tahap minima. Keputusan dalam kedua-dua simulasi dan eksperimen telah menunjukkan keserasian antara kedua-duanya. Penjana elektrik ini berjaya menjana beberapa ratus watt kuasa dan dengan anggaran keberkesanan 78%. Berdasarkan eksperimen kuantitatif, gelombang bentuk sinus tulen bervoltan 3 fasa telah dikesan pada skop. Gerakan tanpa gigi roda didapati menghasilkan putaran kilas permulaan yang rendah. Oleh itu, dapatlah disimpulkan bahawa ia sesuai untuk kegunaan dalam applikasi yang memerlukan kilas yang rendah. Banyak aplikasi dapat memanfaatkan penjana ini seperti dalam penjana elektrik sendiri, turbin angin dan juga dalam aplikasi lain dalam industri automotif.

REFERENCES

Abdullah, M. A., Yatim, A. H. M., Tan, C. W. and Saidur, R. (2012). A review of maximum power point tracking algorithms for wind energy systems. *Renewable and sustainable energy reviews*, *16*(5), 3220-3227.

Ahmed D. and Ahmad A. (2013). *An optimal design of coreless direct-drive axial flux permanent magnet generator for wind turbine*. Journal of Physics: Conference Series 439 (2013) 012039

Bianchi, N. and Bolognani, S. (2002). Design techniques for reducing the cogging torque in surface-mounted PM motors. *Industry Applications, IEEE Transactions on*, *38*(5), 1259-1265.

Breton, C., Bartolome, J., Benito, J. A., Tassinario, G., Flotats, I., Lu, C. W. and Chalmers, B. J. (2000). Influence of machine symmetry on reduction of cogging torque in permanent-magnet brushless motors. *Magnetics, IEEE Transactions on*, *36*(5), 3819-3823.

Bumby, J. R. and Martin, R. (2005). Axial-flux permanent-magnet air-cored generator for small-scale wind turbines. *IEE Proceedings-Electric Power Applications*, *152*(5), 1065-1075.

Caricchi, F., Crescimbini, F. and Santini, E. (1995). Basic principle and design criteria of axial-flux PM machines having counterrotating rotors. *Industry Applications, IEEE Transactions on*, *31*(5), 1062-1068.

Chalmers, B. J. and Spooner, E. (1999). An axial-flux permanent-magnet generator for a gearless wind energy system. *Energy Conversion, IEEE Transactions on*, *14*(2), 251-257.

Chan, T. F. and Lai, L. L. (2007). *An axial-flux permanent-magnet synchronous generator for a direct-coupled wind-turbine system*. Energy Conversion, IEEE Transactions on, *22*(1), 86-94.

Chen, J. L. and Liu, T. H. (2012). Implementation of a predictive controller for a sensorless interior permanent-magnet synchronous motor drive system. *Electric Power Applications, IET*, *6*(8), 513-525.

Chen, Y., Pillay, P. and Khan, A. (2005). *PM Wind Generator Topologies*. IEEE Transactions on Industry Application, Vol. 41, No. 6, November/December 2005

Chung, D. W. and You, Y. M. (2014). Design and Performance Analysis of Coreless Axial-Flux Permanent-Magnet Generator for Small Wind Turbines. *Journal of Magnetics*, *19*(3), 273-281.

Del Ferraro, L., Giulii Capponi, F., Terrigi, R., Caricchi, F. and Honorati, O. (2006, October). Ironless axial flux PM machine with active mechanical flux weakening for automotive applications. *Industry Applications Conference, 2006. 41st IAS Annual Meeting. Conference Record of the 2006 IEEE* (Vol. 1, pp. 1-7). IEEE.

Di Napoli, A., Caricchi, F., Crescimbini, F. and Noia, G. (1991, August). Design criteria of a low-speed axial-flux PM synchronous machine. *International Conference on the Evolution and Modern Aspects of Synchronous Machines* (pp. 1119-1123).

Drazikowski, L. and Koczara, W. (2011). Permanent magnet disk generator with coreless windings. *COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, 31*(1), 108-118.

Eastham, J. F., Profumo, F., Tenconi, A., Hill-Cottingham, R., Coles, P. and Gianolio, G. (2002). Novel axial flux machine for aircraft drive: Design and modeling. *Magnetics, IEEE Transactions on, 38*(5), 3003-3005.

Electrical Engineering, Online Electrical Engineering Study Site. *Principle of DC Generator*. Retrieved from http://www.electrical4u.com/principle-of-dc-generator/

Fei, W., Luk, P. C. K. and Jinupun, K. (2010). *Design and analysis of high-speed coreless axial flux permanent magnet generator with circular magnets and coils.* IET electric power applications, 4(9), 739-747.

Fitzgerald, A. E. and Kingsley, C. (1961). *Electric machinery: the dynamics and statics of electromechanical energy conversion*. McGraw-Hill.

Gieras, J. F., Wang, R. J. and Kamper, M. J. (2008*). Axial flux permanent magnet brushless machines (Vol. 1)*. New York, NY: Springer.

Gör, H. and Kurt, E. (2016). Preliminary studies of a new permanent magnet generator (PMG) with the axial and radial flux morphology. *International Journal of Hydrogen Energy*

Gor, H. and Kurt, E. (2016). Waveform characteristics and losses of a new double sided axial and radial flux generator. *International Journal of Hydrogen Energy.*

GreenGear. (2015). Choosing Between A Conventional, Silenced or An Inverter Generator. Retrieved from http://www.greengearglobal.com/choosing-conventional-silenced-inverter-generator/

Hosseini, S. M., Agha-Mirsalim, M. and Mirzaei, M. (2008). *Design, Prototyping, and Analysis of a Low Cost Axial-Flux Coreless Permanent-Magnet Generator*. IEEE Transaction on Magnetics, Vol. 44, No. 1, January 2008

Huang, S., Luo, J., Leonardi, F. and Lipo, T. A. (1999). A comparison of power density for axial flux machines based on general purpose sizing equations. *Energy Conversion, IEEE Transactions on, 14*(2), 185-192.

Hwang, C. C., Li, P. L., Chuang, F. C., Liu, C. T. and Huang, K. H. (2009). Optimization for reduction of torque ripple in an axial flux permanent magnet machine. *Magnetics, IEEE Transactions on, 45*(3), 1760-1763.

Javadi, S. and Mirsalim, M. (2010). Design and analysis of 42-V coreless axial-flux permanent-magnet generators for automotive applications. *Magnetics, IEEE Transactions on*, *46*(4), 1015-1023.

Jenal, M., Sulaiman, E., Ahmad, M. Z., Zakaria, S. N. U., Utomo, W. M., Zulkifli, S. A. and Bakar, A. A. (2013, November). Design study of single and three-phase synchronous generator using J-MAG designer. *Clean Energy and Technology (CEAT), 2013 IEEE Conference on* (pp. 226-231). IEEE.

JMAG, Simulation Technologies for Electromechanical Design. Retrieved from https://jmag-international.com/

K&J Magnetics, Inc. *Temperature and Neodymium Magnet*. Retrieved from http://www.kjmagnetics.com/blog.asp?p=temperature-and-neodymium-magnets

Kobayashi, H., Doi, Y., Miyata, K. and Minowa, T. *Design of axial-flux permanent magnet coreless generator for the multi-megawatts wind turbines. EWEC2009*.

Krishnan, R. (2009). Permanent magnet synchronous and brushless DC motor drives. *CRC press.*

Kurt, E., Gör, H. and Demirtaş, M. (2014). Theoretical and experimental analyses of a single phase permanent magnet generator (PMG) with multiple cores having axial and radial directed fluxes. *Energy Conversion and Management*, *77*, 163-172

Li, H. and Chen, Z. (2008). *Overview of different wind generator systems and their comparisons.* IET Renewable Power Generation, *2*(2), 123-138.

Li, S., Haskew, T. A. and Xu, L. (2010). Conventional and novel control designs for direct driven PMSG wind turbines. *Electric Power Systems Research*, *80*(3), 328-338.

Liang, T. J., Yang, L. S. and Chen, J. F. (2007). Analysis and design of a single-phase AC/DC step-down converter for universal input voltage. *Electric Power Applications, IET*, *1*(5), 778-784.

Liu, H., Locment, F., & Sechilariu, M. (2015, July). Maximum power point tracking method for small scale wind generator experimental validation. In *Society of Instrument and Control Engineers of Japan (SICE), 2015 54th Annual Conference of the* (pp. 864-869). IEEE.

Lombard, N. F. and Kamper, M. J. (1999). Analysis and performance of an ironless stator axial flux PM machine. *Energy Conversion, IEEE Transactions on*, *14*(4), 1051-1056.

Lopez, H. E. M. (2007). *Maximum Power Tracking Control Scheme for Wind Generator Systems*. Doctoral dissertation, Texas A&M University.

Madawala, U. K. and Boys, J. T. (2005). Magnetic field analysis of an ironless brushless dc machine. *Magnetics, IEEE Transactions on*, *41*(8), 2384-2390.

Mahmoudi, A., Kahourzade, S., Rahim, N. A., Ping, H. W. and Uddin, M. N. (2013). Design and prototyping of an optimised axial-flux permanent-magnet synchronous machine. *Electric Power Applications, IET*, *7*(5), 338-349.

Mahmoudi, A., Rahim, N. A. and Hew, W. P. (2011). Axial-flux permanent-magnet machine modeling, design, simulation, and analysis. *Scientific Research and Essays*, *6*(12), 2525-2549.

Mirzaei, M., Mirsalim, M. and Abdollahi, S. E. (2007). Analytical modeling of axial air gap solid rotor induction machines using a quasi-three-dimensional method. *Magnetics, IEEE Transactions on*, *43*(7), 3237-3242.

Mo, W., Zhang, L., Shan, A., Cao, L., Wu, J. and Komuro, M. (2008). Improvement of magnetic properties and corrosion resistance of NdFeB magnets by intergranular addition of MgO. *Journal of Alloys and Compounds 461*(1), 351-354.

Molina, M. G., dos Santos, E. C. and Pacas, M. (2010, September). Advanced power conditioning system for grid integration of direct-driven PMSG wind turbines. *Energy Conversion Congress and Exposition (ECCE), 2010 IEEE* (pp. 3366-3373). IEEE.

Mosincat, I., Lu, K. and Pedersen, K. (2011). Hysteresis losses influence on the cogging torque of high-efficiency Surface Mounted PM Machines.

Muljadi, E., Butterfield, C. P. and Wan, Y. H. (1999). Axial-flux modular permanent-magnet generator with a toroidal winding for wind-turbine applications. *Industry Applications, IEEE Transactions on*, *35*(4), 831-836.

Muyeen, S. M., Takahashi, R., Murata, T. and Tamura, J. (2010). A variable speed wind turbine control strategy to meet wind farm grid code requirements. *Power Systems, IEEE Transactions on*, *25*(1), 331-340.

Nave, C. R. (2006). Magnets and Electromagnets. Retrieved from http://ef.engr.utk.edu/hyperphysics/hbase/magnetic/elemag.html

NDT Resource Center. (2014). T*he Hysteresis Loop and Magnetic Properties*. Retrieved from https://www.nde-ed.org/EducationResources/CommunityCollege/MagParticle/Physics/HysteresisLoop.htm

NEETS Module 1, Chapter 5. (2013). *Direct Current Generators*. Retrieved from http://www.navymars.org/national/training/nmo_courses/NMO2/module5/14177_ch1.pdf

NEETS Module 5. (2013). *Introduction to Generator and Motors.* Retrieved from http://electriciantraining.tpub.com/14177/css/14177_24.htm

Nidec Corporation. (2014). *2-1-3 Rotating Speed Of DC Motor And Counter-electromotive Force*. Retrieved from http://www.nidec.com/en-Global/technology/motor/basic/00013/

Nishimura, K., Hirachi, K., Komiyama, S. and Nakaoka, M. (2008, February). Two buck choppers built-in single phase one stage pfc converter with reduced DC voltage ripple and its specific control scheme. *Applied Power Electronics Conference and Exposition, 2008. APEC 2008. Twenty-Third Annual IEEE* (pp. 1378-1383). IEEE.

Oh, S. C. and Emadi, A. (2004). Test and simulation of axial flux-motor characteristics for hybrid electric vehicles. *Vehicular Technology, IEEE Transactions on*, *53*(3), 912-919.

Omron. Omron MX5 Datasheet. Retrieved from mikrokontrol.rs/proizvodi/pdf/I113E-EN-02+MX2+Datasheet.pdf

Parviainen, A., Niemelä, M. and Pyrhönen, J. (2004). Modeling of axial flux permanent-magnet machines. *Industry Applications, IEEE Transactions on*,*40*(5), 1333-1340.

Polinder, H., Van der Pijl, F. F., Vilder, D., & Tavner, P. J. (2006). Comparison of direct-drive and geared generator concepts for wind turbines. *Energy conversion, IEEE transactions on*, *21*(3), 725-733.

Pop, A. A., Jurca, F., Oprea, C., Chirca, M., Breban, S. and Radulescu, M. M. (2013, September). Axial-flux vs. radial-flux permanent-magnet synchronous generators for micro-wind turbine application. *Power Electronics and Applications (EPE), 2013 15th European Conference on* (pp. 1-10). IEEE.

Hosseini, S. M., Agha-Mirsalim, M., & Mirzaei, M. (2008). Design, prototyping and analysis of a low-cost disk permanent magnet generator with rectangular flat-shaped magnets. *Iranian Journal of Science and Technology*,*32*(B3), 191.

Heller, M. E. (2014). *Conventional Generator Review*. Retrieved from http://www.topportablegeneratorsreview.com/conventional_generators_review.html

Portela, P., Sepúlveda, J. and Esteves, J. S. (2008). *Alternating Current and Direct Current Generator*. International Journal on Hands-on Science, Vol.1, No.1, September 2008

Qiu, Z., Zhou, K. and Li, Y. (2011, July). Modeling and control of diode rectifier fed PMSG based wind turbine. *Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), 2011 4th International Conference on* (pp. 1384-1388). IEEE.

Rizzoni, G. (2007). *Principle and Applications of Electrical Engineering 5th edition*. McGraw-Hill Higher Education.

Saidur, R., Islam, M. R., Rahim, N. A. and Solangi, K. H. (2010). A review on global wind energy policy. *Renewable and Sustainable Energy Reviews*,*14*(7), 1744-1762.

Samarins.com. *Alternator, How It Works, Symptoms, Testing, Problems, Replacement*. Retrieved from http://www.samarins.com/glossary/alternator.html

Spooner, E. and Chalmers, B. J. (1992). TORUS': a slotless, toroidal-stator, permanent-magnet generator. *Electric Power Applications, IEE Proceedings B, 139*(6), 497-506.

Stampfi, H. (2003). Linear motor applications: Ironcore versus Ironless Solution. Retrieved from http://www.controldesign.com/assets/Media/MediaManager/wp_035_etel_thompson.pdf

Storr W. (2013). *Transformer Construction.* Electronics-Tutorials.ws. Retrieved from http://www.electronics-tutorials.ws/transformer/transformer-construction.html

Tamura, J. (2012). Calculation method of losses and efficiency of wind generators. *Wind Energy Conversion Systems* (pp. 25-51). Springer London.

Teco Electric & Machiner (Pte) Ltd. AEEB. AEVB Low Voltage Series. Retrieved from www.teco.com.sg/admin2/images/e-catalog/Catalogue%20AEEB.pdf

Ting, C. C. and Yeh, L. Y. (2014). Developing the full-field wind electric generator. *International Journal of Electrical Power & Energy Systems, 55*, 420-428.

Vijayaraghavan, G., Brown, M. and Barnes, M. (2008). Electrical noise and mitigation-Part 1: Noise definition, categories and measurement.

Virtic, P. and Avsec, J. (2011). Analysis of coreless stator axial flux permanent magnet synchronous generator characteristics by using equivalent circuit. *Przeglad Elektrotechniczny, 87*(3), 208-211.

Virtic, P., Pisek, P., Marcic, T., Hadziselimovic, M. and Stumberger, B. (2008). Analytical analysis of magnetic field and back electromotive force calculation of an axial-flux permanent magnet synchronous generator with coreless stator. *Magnetics, IEEE Transactions on*, *44*(11), 4333-4336.

Vodovozov, V. and Jansikene, R. (2006). *Power Electronic Converters*. Tallinn University of Technology Department of Electrical Drives and Power Electronics.

Wang, R. J., Kamper, M. J., Van der Westhuizen, K. and Gieras, J. F. (2005). Optimal design of a coreless stator axial flux permanent-magnet generator. *Magnetics, IEEE Transactions on, 41*(1), 55-64.

Z. Zhang, A. Chen, A. Matveev, R. Nilssen, and A. Nysveen, 'High-power generators for offshore wind turbines', *Energy Procedia 35* (2013) 52 – 61.

Zhang, S., Tseng, K. J., Vilathgamuwa, D. M., Nguyen, T. D. and Wang, X. Y. (2011). Design of a robust grid interface system for PMSG-based wind turbine generators. *Industrial Electronics, IEEE Transactions on*, *58*(1), 316-328.