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Optimization of Flux Switching Generator Using Sequential Technique

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Abstract

This study describes the optimization of flux switching generator (FSG) using a technique called sequential technique. Several FSG designs have been observed and studied before fixing for one specific design of the generator. However, all the designs encountered a common drawback of having high voltage drop and low output voltage. Thus, this study had outlined to serve the purpose of designing FSG with the maximum output voltage. The basic design of FSG used in this project was done using the JMAG software. This generator was designed based on specific parameters fixed which are the stator with 42.5mm of diameter, rotor with 25.5mm diameter, permanent magnet with 6mm width, and stack length of 30mm was used. Upon successful optimization, the design becomes the initial design for the project. The initial design was analyzed as a no-load test to obtain the results of coil-flux linkage, maximum back EMF, maximum output fundamental voltage and maximum apparent power delivered by the generator. All the results were then analyzed and explained in this paper. In addition, a study of six different sequences in designing the FSG were conducted in this study which plays around the three basic components of FSG which are stator, rotor and permanent magnet. The parameters of all the components were modified to the sequences decided, which will come up with different values of fundamental output voltage before deciding the best sequence by observing the output voltage of each of the sequences.

1. Introduction

In 1955, Rauch and Johnson has introduced a single-phase permanent magnet flux switching machine (PMFSM) while in 1997, E.Hoang et al. built three-phase system [1], [2]. Electric motors and generators are the most important elements of the motor drive systems [3]. The demand for applications of high torque motors and high voltage generators can be seen worldwide especially in the rapid technological development and innovation in electrical drives. Due to the overwhelming advantages and more configurations that have been introduced by previous researchers [4], the rising research and design towards PMFSM has shown to be attractive [5]. This research was later expanded towards hybrid excitation flux switching systems which is a technology that combines the advantages of field windings and permanent magnets for introducing magnetic flux.

The proposed flux switching generator is observed under no load condition to analyze the initial voltage of the basic generator design. According to the observations, the proposed design is ideal for any kind of generator application. However, the sequence of design for the generator plays a major role in the flux switching generator system where it determines the output voltage of the generator [6]. In fact, the flux switching generator system has three main components which take the major parts in the system which are rotor, armature and magnet.

Thus, the sequential technique will play around the sequences within these three components and comes out with six different sequences. Each of the sequences will produce different values of fundamental output voltage readings for the generator system as overall. All the sequential techniques to alter the designs of the stated components will be done to the basic structure of the flux switching generator. Thus, obtaining the highest voltage for the generator by using sequential technique is proposed.

At this current moment, the usage of permanent magnet (PM) flux switching machines (PMFSMs) is widely applied in many industries [7]. These applications are researched and investigated with unique flux nature such as axial flux [8] and transverse flux. Moreover, PMFSM with segmented permanent magnets consequent pole configuration is also being investigated by industries to achieve maximum power density of their machines. PMFSM is generally divided into two types, which are permanent magnet flux switching motor and permanent magnet flux switching generator. The major benefits of using permanent magnet (PM) material in electric synchronous machines are it can produce higher efficiency and power density [9]. Oppositely, permanent magnets have the drawback of having fixed permanent magnet generated flux. This fact is considered as a biggest obstacle when it comes to the usage of permanent magnet flux switching generator applications where the flux adjustment cannot be done.

Thus, this problem could be overcome by the optimization of flux switching technology [10] that combines the advantages of field windings and permanent magnets for inducing magnetic flux. By implementing this technique, the flux can be varied even when the permanent magnet is used. In this study, the optimization of flux switching generator (FSG) using sequential technique is highlighted. This project is focused on designing different sequences of designing the parts of FSG where it will function at its highest induced voltage with greater output apparent power. Moreover, the flux switching generator is to be worked with fixed frequency and different number of turns according to the area of armature coil [11].

This project seeks to achieve the following objectives. Firstly, the objective is to optimize the design of a flux switching generator with specific parameters using JMAG designer software. The second aim of this project is to determine the best sequential technique to ensure the maximum fundamental voltage on a flux switching generator. This project focuses on several key scopes. Firstly, the proposed design of flux switching generator is based on the parameter and specifications as described in Table 1.

Table 1 *Parameters of FSG*

Parameter	Value
Diameter of stator	42.5mm
Diameter of rotor	51mm
Rotor pole height	10.5mm
Rotor pole width	6mm
PM width	5mm
PM length	15.5mm
Armature coil outer width	10.5mm
Armature coil teeth width	15mm
Air gap	0.5mm
Stator back length	30mm
Number of phases	1
Number of rotor	1
Number of stator	1
Number of slot	4
Number of pole	8
Number of armature coil	8
Number of turns of armature coil	454
Armature slot area (mm^2)	178
Permanent magnet density	7.5269×10^{-3}Wb/mm^2

2. Methodology

Fig. 1 shows the overall flow chart of the project.

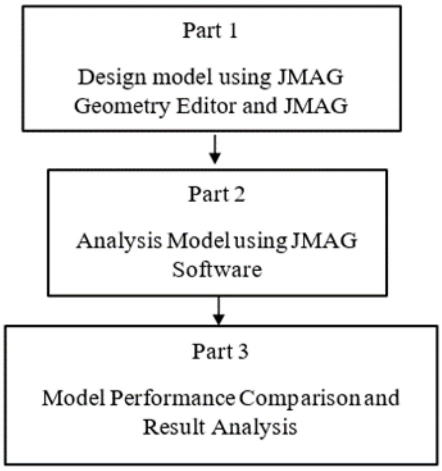


Fig. 1 *General flow chart of the project*

2.1 Design Methodology of the Proposed FSG

The project implementation is being divided into two parts, which are geometry editor and JMAG-Designer. Geometry editor is considered as the first part of the project implementation whereas JMAG designer is the second. For the first part, each component of the generator will be designed separately such as rotor, stator, armature coil and permanent magnet. Meanwhile, the condition settings and simulation will be done in the second part of the project implementation. For this project, the component designs will be done in sequential techniques to determine the best sequence that could provide a maximum amount of current comparatively. Fig. 2 illustrates the workflow of the project methodology in the form of flowchart form, while Fig. 3 shows the design of separated parts of FSG proposed.

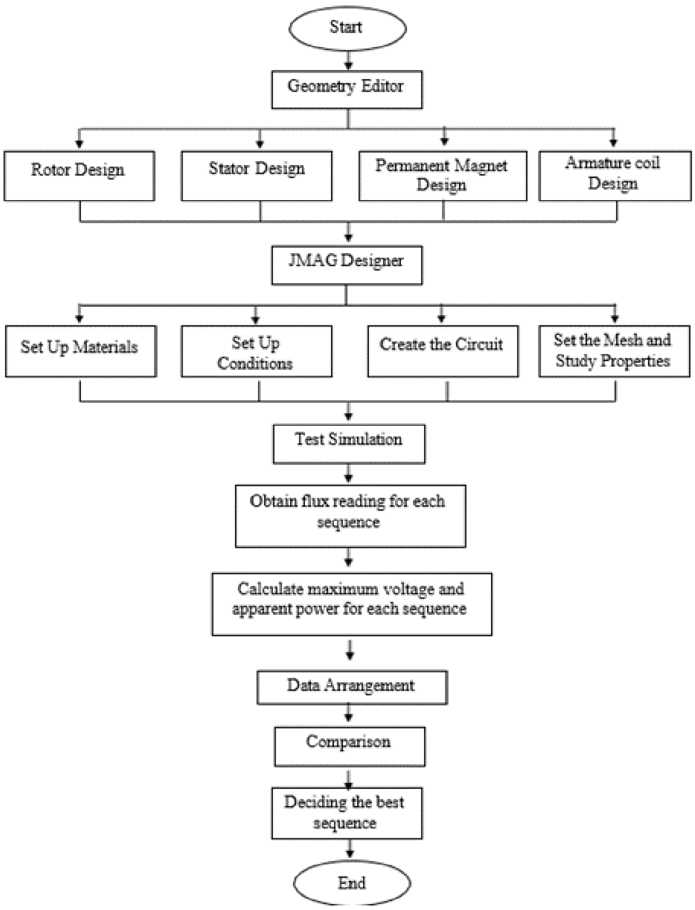


Fig. 2 *Flow chart of the project implementation*

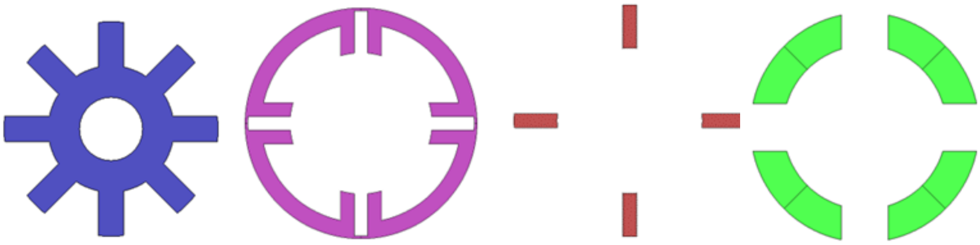


Fig. 3 *FSG parts design (a) Rotor (b) Stator (c) Permanent magnet (d) Armature coil*

2.2 Material and Condition Setting

Table 2 shows the material and condition settings for the design of flux switching generator (FSG) according to different parts of it.

Table 2 *Material and condition settings for FSG*

Part	Material	Condition
Rotor	Nippon Steel 35H210	Motion: Rotation Torque: Nodal force
Stator	Nippon Steel 35H210	-
Armature Coil	Conductor Copper	FEM coil
Permanent Magnet	Neomax-P8H (irreversible) Magnetization Pattern: Circumferential Anisotropic pattern	-

2.3 Circuit Designing and Setting

According to the number of poles of the FSG, eight separated armature coils (AC) are grouped to form a circuit as shown in Fig. 4.

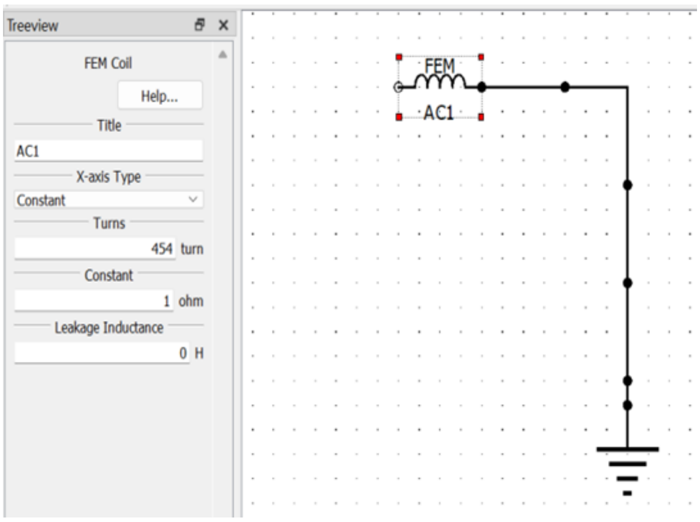
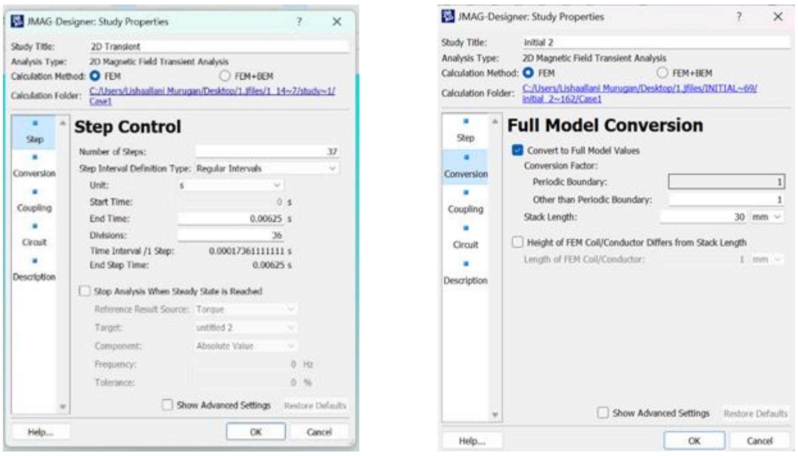


Fig. 4 *Armature coil circuit configuration with initial number of turns*

2.4 Mesh and Properties Setting

All the generator components were added to the mesh setting and set to sliding mesh. Fig. 5 shows the study of properties of the flux switching generator (FSG) using two different settings: (a) Step control setting and (b) Full model conversion setting. The step control setting is done for the study properties of the generator using step-by-step approach, while the full model conversion setting allows for the study of the generator's properties using a more comprehensive and detailed model.



(a) (b)

Fig. 5 *Study properties (a) Step control setting (b) Full model conversion setting*

3. Result and Analysis

3.1 Analysis of the Sequence

The initial FSG was optimized according to the sequential technique for all those six sequences. The chosen parameter for each part of the generator is based on the maximum back-emf value that could be obtained from the design. Table 3, Table 4, Table 5, Table 6, Table 7 And Table 8 shows the chosen parameters for each part of the FSG with the output fundamental voltage obtained from sequence one, two, three, four, five and six respectively.

Table 3 *Chosen parameter and back-emf for sequence one*

Parameter	Value (mm)	Back-emf (V)
Rotor radius	28.5	488.92
Rotor pole height	10.5	488.92
Rotor width	10	529.87
AC outer width	11.5	580.74
AC teeth width	17	616.40
PM length and Width	13.5 and 5.74	616.40

Table 4 *Chosen parameter and back-emf for sequence two*

Parameter	Value (mm)	Back-emf (V)
Rotor radius	28.5	488.92
Rotor pole height	10.5	488.92
Rotor width	10	529.87
PM length and width	13.5 and 5.74	529.87
AC outer width	11.5	580.74
AC teeth width	17	616.40

Table 5 *Chosen parameter and back-emf for sequence three*

Parameter	Value (mm)	Back-emf (V)
AC outer width	14.5	567.51
AC teeth width	13	582.81
PM length and Width	16.5 and 4.7	653.47
Rotor radius	25.5	653.47
Rotor pole height	9.5	654.91
Rotor width	8	701.84

Table 6 *Chosen parameter and back-emf for sequence four*

Parameter	Value (mm)	Back-emf (V)
AC outer width	14.5	567.51
AC teeth width	13	582.81
Rotor radius	25.5	582.81
Rotor pole height	10.5	582.81
Rotor width	6	582.81
PM length and Width	16.5 and 4.7	653.48

Table 7 *Chosen parameter and back-emf for sequence five*

Parameter	Value (mm)	Back-emf (V)
PM length and Width	16.5 and 4.7	470.95
AC outer width	14.5	700.38
AC teeth width	17	705.64
Rotor radius	25.5	705.64
Rotor pole height	9.5	706.55
Rotor width	8	752.17

Table 8 *Chosen parameter and back-emf for sequence six*

Parameter	Value (mm)	Back-emf (V)
PM length and Width	16.5 and 4.7	470.95
Rotor radius	25.5	470.95
Rotor pole height	9.5	471.75
Rotor width	8	514.75
AC outer width	14.5	757.62
AC teeth width	15	757.62

3.2 Overall Discussion

Fig. 6 shows the increment in the value of output fundamental voltage obtained from sequence one, two, three, four, five and six respectively as per the flow of optimization determined earlier. At certain points, a constant value of back-emf can be seen which means the design from previous analysis cannot be improved anymore in terms of its' fundamental voltage. The abbreviations R_r, R_{ph}, R_w, AC_{ow}, AC_{tw} and PM_{lw} stands for rotor radius, rotor pole height, rotor width, AC outer width, AC teeth width and PM length and width respectively.

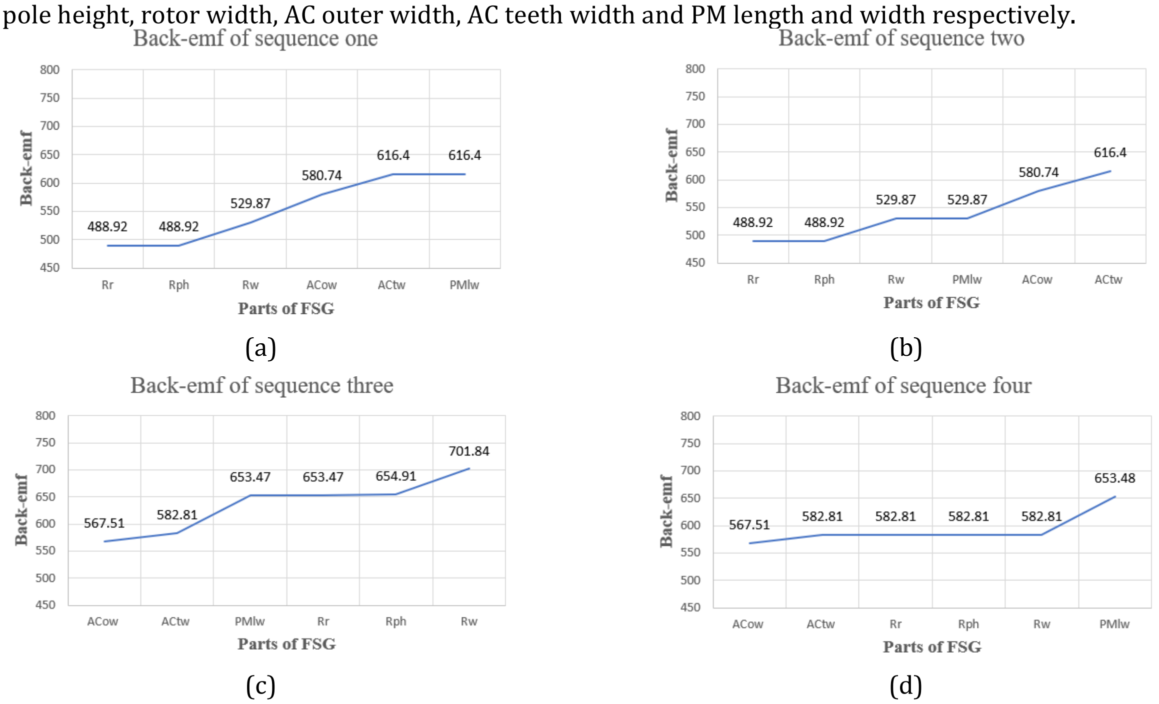
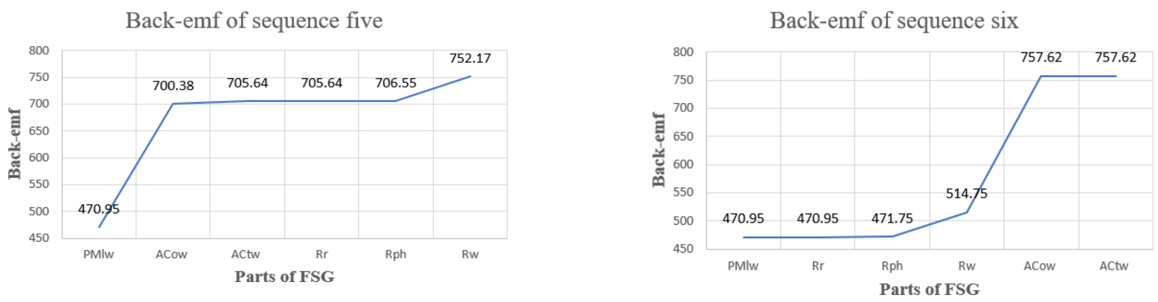


Fig. 6 *Increment of back-emf (a) Sequence one (b) Sequence two (c) Sequence three (d) Sequence four (e) Sequence five (f) Sequence six*



(e) (f)

Fig, 6 *continued*

Fig. 7 shows the waveform of back-emf obtained from the initial FSG design and for the final FSG design chosen based on sequential technique which is from sequence six. From the graph, the obvious improvisation in terms of back-emf can be seen where the fundamental back-emf of the FSG increased about 381.81V.

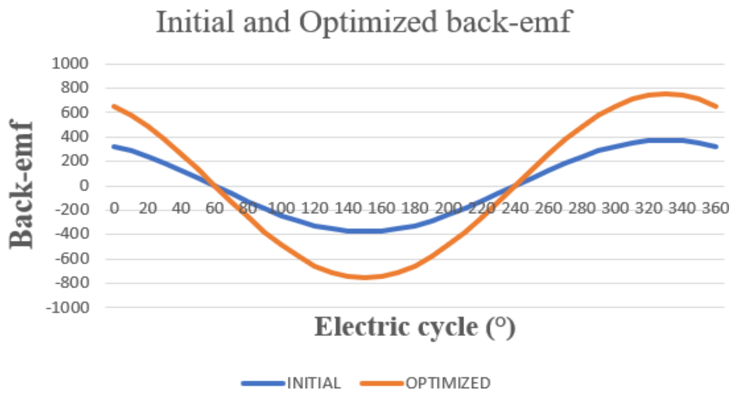


Fig 7 *Comparison of back-emf between initial and optimized FSG design*

4. Conclusion

The present discussion has demonstrated the comparison performance of initial and optimize the design of single-phase 4slot-8pole flux switching generator (FSG) design using sequential technique. The comparison was made under the fundamental voltage obtained from each of the sequences' design and its' corresponding apparent power delivered. Successively, the optimized generator from sequence six has greater performance compared to initial design and the designs from other sequences which brings the highest induced fundamental voltage. The optimized FSG design has increased the performance of induced fundamental voltage more than twice the voltage of initial design. In the final analysis, it can be summarized that the induced voltage increment is based on the design parameters as well as the number of turns of the armature coil where, the initial FSG design consists of 454 turns while the optimized FSG design is having 685 turns of copper coil in armature coil. With all the analytical surveys, it is obvious that the optimized design of FSG with respect to the design parameters is one of the influential designs for certain applications such as transportation, renewable energy and aerospace applications. It is foreseeable that more interesting research would be devoted to the FSGs by considering the recent trend and growth in usage of flux switching generators in industries.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author attests to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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References

[1] Chen, J. T., and Z.Q Zhu, "Winding Configuration And Optimal Stator And Rotor Pole Combination Of Flux-Switching PM Brushless AC Machines," IEEE Trans. Energy Conversion, Vol. 2, p.p. 293–302, 2010.

[2] M. Jenal, E. Sulaiman, M. F. Omar, G. M. Romalan, and H. A. Soomro, “Development of a novel permanent magnet flux switching machine prototype for light weight electric vehicles,” 2015 IEEE Student Conf. Res. Dev. SCOReD 2015, pp. 739–744, 2015.

[3] Ion Boldea, “Electric generators and motors: An overview,” CES transactions on electrical machines and systems, vol. 1, no. 1, pp. 3–14, Mar. 2017.

[4] A. Al-Timimy, P. Giangrande, M. Degano, M. Galea, and C. Gerada, “Comparative study of permanent magnet-synchronous and permanent magnet-flux switching machines for high torque to inertia applications,” Nottingham ePrints (University of Nottingham), Apr. 2017.

[5] Automotive Applications,” pp. 242–249, 2003. [8] Hemamalini B, “Design and Analysis Of Flux Switching Motor,” Faculty of Electrical Engineering Anna University, 2016.

[6] D. Lumbreras, E. L. Barrios, J. Balda, M. I. Navarrete, R. Reina Gonzalez, and P. Sanchis, “Medium-Voltage Cascaded Sequential Topology for Large-Scale PV Plants,” *IEEE Access*, vol. 9, pp. 130601–130614, Jan. 2021, doi: https://doi.org/10.1109/access.2021.3113618.

[7] W. Ullah, F. Khan, and S. Hussain, “A Comparative Study of Dual Stator With Novel Dual Rotor Permanent Magnet Flux Switching Generator for Counter Rotating Wind Turbine Applications,” IEEE Access, vol. 10, pp. 8243–8261, Jan. 2022.

[8] W. Zhao, T.A. Lipo, and B. Kwon, “A Novel Dual-Rotor, Axial Field, FaultTolerant Flux-Switching Permanent Magnet Machine With High-Torque Performance,” IEEE Transactions on Magnetics, vol. 51, no. 11, pp. 1–4, Nov. 2015.

[9] “Advantages and Applications of Permanent Magnet Synchronous Motor,” Stanford Magnets, Jan. 19, 2021.

[10] H. Wang, G. Zhang, and M. Cheng, “Flux-Regulation Theories and Principles of Hybrid-Excited Flux-Switching Machines,” IEEE Transactions on Industrial Electronics, vol. 62, no. 9, pp. 5359–5369, Sep. 2015.

[11] Dillan Ockhuis, M. J. Kamper, and A. T. Loubser, “Hybrid Excitation Method for Higher Pole Number Grid-Tie Synchronous Generators,” ResearchGate, Oct. 11, 2020.