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Design and Implementation of Asymmetric Converters with DSC Control in SRG Operations

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***Abstract**: The switched reluctance machine (SRM) stands out as a preferred choice for electric vehicles due to its numerous benefits, such as its uncomplicated design that doesn't necessitate winding installation on the rotor and operates without the need for permanent magnets. SRM has the ability to run at high RPM. SRM with 3-phase asymmetric converter can be used as a generator, called Switched Reluctance Generator. The generation process of SRM involves employing negative torque. SRM performance tends to be highly inefficient under low-speed conditions, primarily because the negative torque magnitude becomes minimal. Two operational methods for SRM, stemming from the DSPIC30F4012, are single-pulse control and PWM control. A rotary encoder is required in addition to the converter to detect the rotor position and obtain a serial pulse. This paper will propose a generating approach employing a magnetizing-demagnetizing control strategy, which serves as an illustrative instance of PWM control techniques.*

Keywords— SRG, Asymmetric Converter, DSPIC, PWM, Rotary Encoder

1. INTRODUCTION

In an era characterized by an insatiable demand for clean and renewable energy sources, the quest for efficient and sustainable power generation methods has gained paramount importance. Among the emerging technologies that hold great promise in this endeavor is the utilization of Switched Reluctance Generators (SRGs). These generators, known for their simplicity, robustness, and suitability for renewable energy applications, have garnered significant attention in recent years. Additionally, its benefits encompass a straightforward design that doesn't require winding installation on the rotor and doesn't rely on permanent magnets [1]. The SRM exhibits strong torque, minimal maintenance expenses [2], [3], dependable fault tolerance, and the ability to operate at different rotational speeds [4]–[6]. However, to fully harness the potential of SRGs, the development of precise and adaptive control systems is imperative.

This paper delves into the realm of SRG operations, specifically focusing on the Design and Implementation of Asymmetric Converters with DSPIC30F4012 Control. The intricate interplay between power electronics and digital signal processing in this context is pivotal in achieving efficient energy conversion and seamless integration with the grid.

Our study embarks on a multifaceted journey, encompassing the intricate design and real-world implementation of asymmetric converters as an integral component of SRG systems. The asymmetric converters, characterized by their ability to handle unbalanced loads and fluctuating power inputs, present a unique opportunity to enhance the overall efficiency and performance of SRGs. Furthermore, the incorporation of the DSPIC30F4012 microcontroller offers a robust platform for real-time control and monitoring. Leveraging digital signal processing capabilities, this control system enables precise adjustments and adaptive responses to varying operational conditions, thereby optimizing energy extraction from SRGs. This paper is structured to provide a comprehensive insight into the theoretical underpinnings of SRGs and asymmetric converters. We delve into the principles of operation, control strategies, and the intricacies of the DSPIC30F4012 microcontroller. Subsequently, we present the practical implementation of our proposed system, along with experimental results, to validate the efficacy of our approach.

This research endeavors to bridge the gap between theory and practical application in the realm of SRG technology. By elucidating the design and implementation of asymmetric converters with DSPIC30F4012 control, we aim to contribute significantly to the development of efficient and adaptable SRG systems, thereby advancing the cause of renewable energy generation and sustainable power solutions.

2. RESEARCH METHOD

2.1 Switched Reluctance Generator

Switched reluctance generator based on Switched reluctance machines (SRMs). Switched reluctance machines are a type of electric machinery that utilizes reluctance torque, making them a subset of reluctance motors. In contrast to typical brushed DC motors, they receive electrical power through the stator windings (enclosure) rather than the rotor. This simplifies the mechanical aspect of the design significantly because it eliminates the necessity for energizing the moving component, thus eliminating the requirement for a commutator. However, it introduces complexity to the electrical design, as some form of switching system must be employed to supply power to the various windings. Switching system to energize the different coils. The electronics can precisely time the current switching, making SRM configuration easier. Its primary drawback is torque ripple [7]. A control technology that mitigates torque oscillations at low speeds has been showcased.

Similar controller configurations can be applied to generators. The load is systematically shifted to the coils to align the current with the rotation. Such generators can operate at much higher speeds [8] than traditional models, as the armature can be made from a single piece of magnetizable material, typically in the shape of a grooved cylinder. In such instances, the abbreviation SRM extends to represent "Switched Reluctance Machine" or "SRG" denoting "Switched Reluctance Generator." Both the engine and generator designs prove beneficial for initiating the primary engine, leading to savings on a separate starter mechanism.

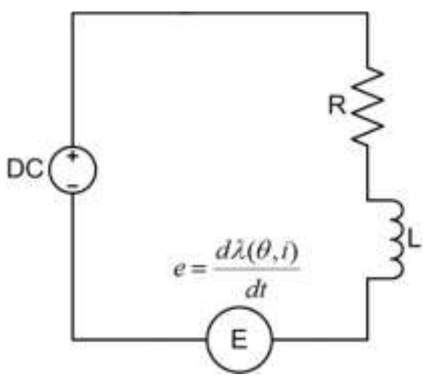

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Figure 1 Equivalent circuit of Switched Reluctance Machine

The corresponding schematic, depicted in Figure 1, comprises elements like resistance (R), inductance (L), and Electromotive force (EMF). When the motor is in motion, the stator winding of the SRM generates a back-EMF, which exhibits a polarity voltage inversely linked to the power source. The equation value for each phase in the SRM circuit can be written as follows:

$$V = R.i + L\frac{di}{dt} + e(\theta.i) \qquad (1)$$

where V is voltage, i phase current, R resistance, L inductance, θ rotor position, and ω motor speed.

The highest inductance level in the Switched Reluctance Motor (SRM) is attained when the rotor is in alignment with the stator [9], [10]. During the generation phase, the inductance decreases, and the switched reluctance machine (SRM) operates as a switched reluctance generator (SRG). This happens as the rotor, initially aligned with the stator (parallel), transitions to a position that is no longer parallel to the stator (unaligned) [11].

During this period, SRM will produce a reverse torque, capable of decelerating the SRM's speed and replenishing the battery to enhance the electric vehicle's driving range. You can determine the SRM's inductance by applying a pulse injection at various positions along the stator winding.

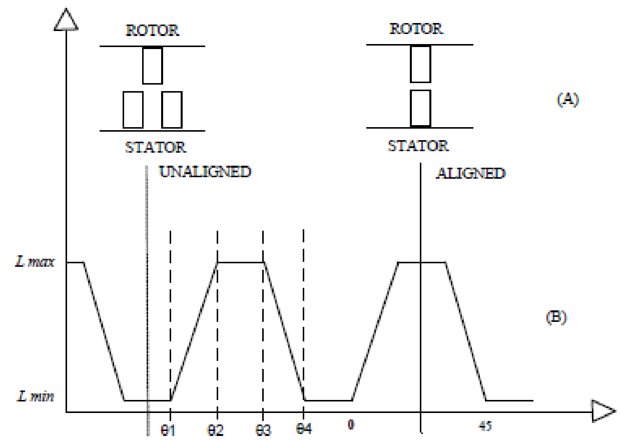

Fig. 2 Inductance profile compared to rotor position

Switched Reluctance Machine (SRM) operates as a generator when an excitation is applied after the rotor and stator have moved apart or when the inductance of the SRM decreases, as depicted in Fig. 2. During this generation phase, the SRM inductance decreases, producing a negative torque [12], effectively decelerating the SRM's speed and simultaneously recharging the battery.

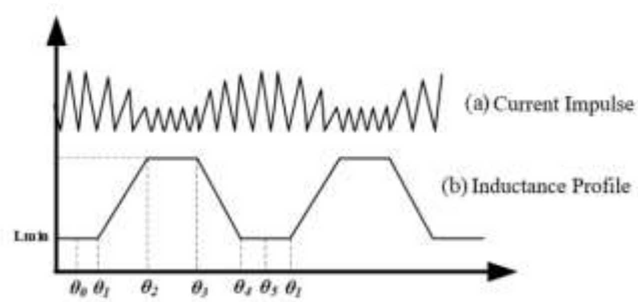

Fig. 3 Phase current and inductance profile

The SRM's inductance profile can be established by delivering pulse injections at every location along the stator winding [13].

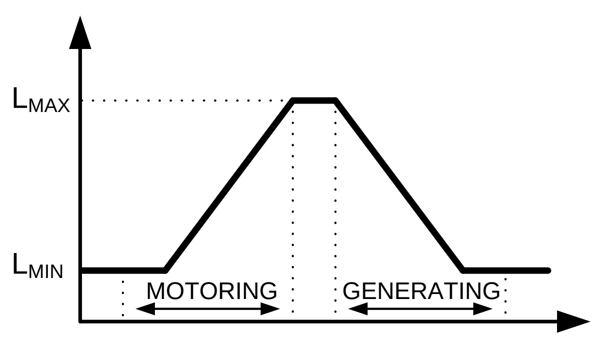

Fig. 4 Inductance profile of SRM

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2.2 Asymmetric Converter

Asymmetric converter has 6 static switches and 6 diodes. The Asymmetric converter on the Switched Reluctance motor works as an on-off switch during certain configurations. In the schematic of asymmetric converter, there are the DC source (Vdc), capacitor (Cs), switch (S), phase stator winding, and diode (D). In Fig. 5 you can see the schematic of asymmetric converter.

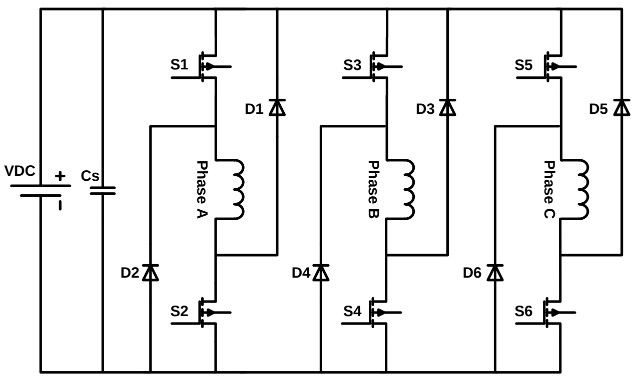

Fig. 1 Asymmetric converter schematic

Asymmetric converter is used in SRM operation to supply excitation current to the stator of the SRM. SRM operation with the asymmetric converter can utilize both magnetizing and demagnetizing modes of operation. Magnetizing mode is an excitation process given to the phase winding by turning on switches (S1) and (S2) simultaneously. In this condition, the voltage in the phase winding is the same as the Vdc input which produces a positive torque when the phase inductance increases. The magnetizing operating mode is shown in Fig. 6.

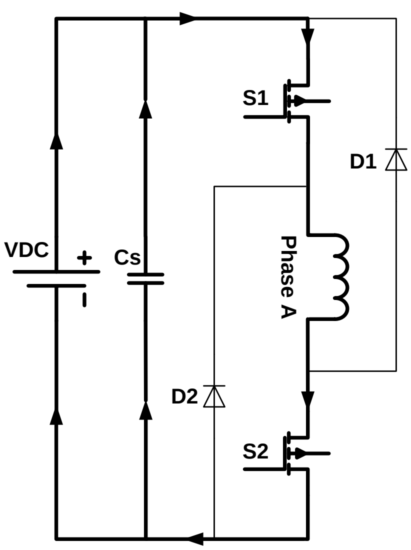

Fig. 2 Asymmetric converter on magnetizing mode

The next mode of operation is demagnetizing. The demagnetizing operating mode occurs after the magnetizing process in the stator winding. This mode works when switch one (S1) and switch two (S2) are turned off simultaneously, energy will go to the load (L1) and flow through the diodes (D1 & D2) from the windings on the stator. The demagnetizing operation mode can be seen in Fig. 7.

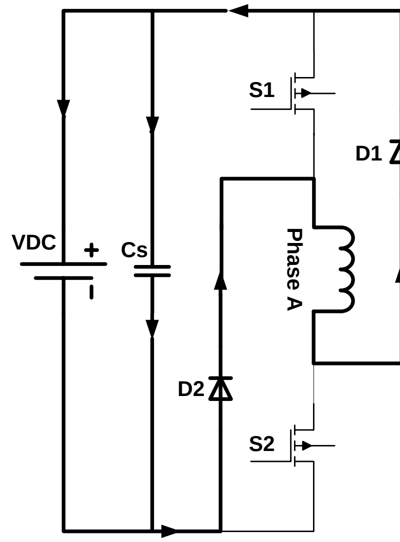

Fig. 3 Asymmetric converter on demagnetizing mode

2.3 Rotary Encoder

A rotary encoder is an electromechanical apparatus that converts the angular position or movement of a shaft or axis into an analog or digital signal output. Two primary categories of rotary encoders exist: absolute and incremental. The absolute encoder's output reflects the present axis position, essentially serving as an angle converter. On the other hand, the output from the incremental encoder conveys details regarding the shaft's movement, typically undergoing further processing to derive information like position, speed [14], and distance.

The rotary encoder used in E50S8-2500-3-V-5, which use a 5VDC power supply to work. This rotary encoder is an optical incremental encoder type. Among rotary encoders, incremental ones are the most extensively utilized because they offer real-time position data. The two internal incremental motion sensors do not impose any limitations on the measurement resolution of an incremental encoder.

Fig. 4 Rotary Encoder coupled to SRM's shaft

The depicted rotary encoder produces three output signals. Signals A and B generate a periodic digital waveform in quadrature as the encoder shaft rotates. Signal Z, on the other hand, emits a pulse when the shaft traverses a specific angle. These three output signals will serve as data to be processed and transmitted by DSC [15].

3. Results and Discussion

To bolster this research, laboratory experiments were undertaken to validate its findings. Based on the research method already established in the generating of SRM, testing was carried out on the SRM hardware in the laboratory. Tests have been carried out using a prototype depicted in Fig. 9.

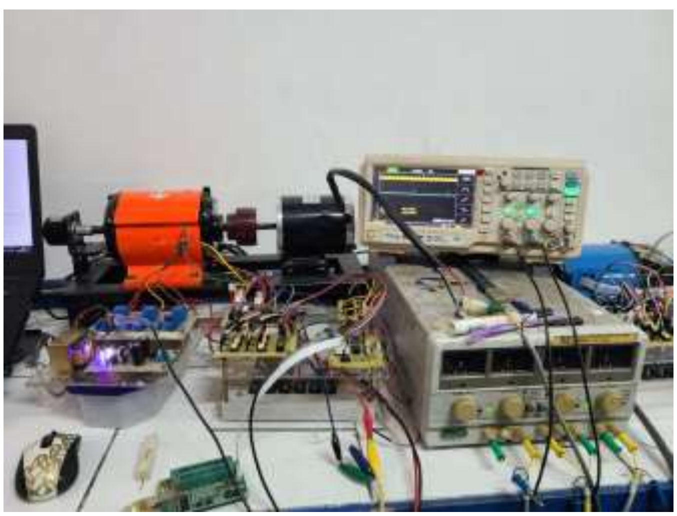

Fig. 5 Prototype for experimental works

It can be explained that the prototype uses an SRM, DC Motor as a prime mover, Rotary Encoder E50S8-2500-3-V-5 as a rotor position sensor [16], asymmetric converter consisting of 10 MOSFET IRFP250N, and TLP250 driver as an asymmetric converter driver circuit, dsPIC30F4012 as a microcontroller, HX10P current sensor, and battery for converter supply. The parameters of tools used in this experiment are shown in Table 1.

Table 1: Parameters of SRG Prototype

Parameter	Value	Unit
Rotary Encoder E50S8-2500-3-V-5		
Output Pins	3	-
Pin A	2500	PPR
Pin Z	1	Impluse
Input Voltage	5	Volt
DSPIC30F4012		
Memory	16	Mbit
Clock	50	MHz
Voltage	5	Volt
3-Phase Asymmetric Converter		
MOSFET IRFP250N	10	-
DC Link	12	Volt

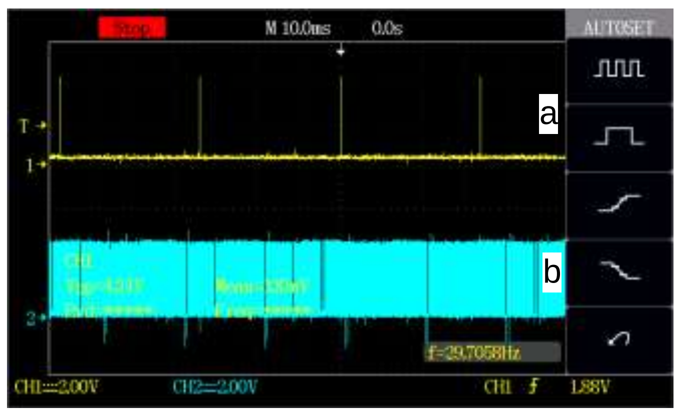

Fig. 6 Experimental result of (a) pulse Z of rotary encoder, (b) pulse A of rotary encoder

In Fig. 10, pulses A and Z are obtained from a rotary encoder that is coupled to the SRG shaft. Pulses A and Z are used to provide pulse signals to determine the PWM switching pattern so that the SRM operates in generating mode.

A

Fig. 7 Experimental result of (a) injected current on phase A, (b) pulse Z of rotary encoder

Fig. 11 shows the current pulse signal compared to the Z pulse in Phase A. One Z pulse indicates one full rotation of the SRG shaft. In one rotation, there are 8 current pulses because this SRG in the research has 8 rotor blades. The switching of the switch to make the SRG function as a generator is adjusted according to the rotor's position. By obtaining the switching of the switch in one phase, the switching of the switch in the other 2 phases is also obtained.

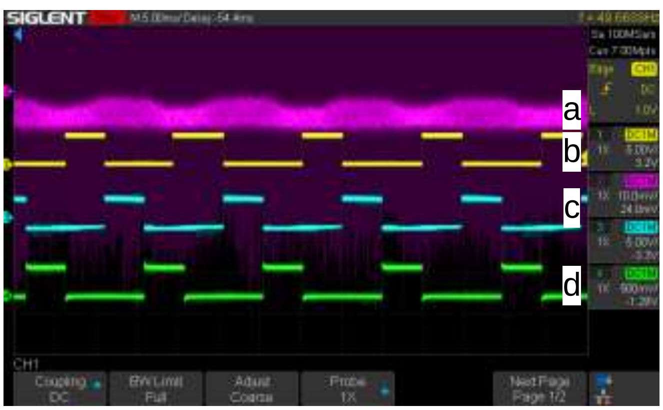

Fig. 8 Experimental result of (a) injected current on Phase A, (b) PWM on DSC for phase A, (c) PWM on DSC for phase B, (d) PWM on DSC for phase C

The switching pattern depicted in Fig. 12 shows that within one revolution, there are eight sequential switching events in each phase. During the switching process, there is a phase shift of 15° starting from Phase A, then Phase B, Phase C, and so on. Each phase is intentionally shifted from the others to ensure that each leg operates alternately, avoiding collisions between them. This arrangement allows the current in the magnetization process to flow through one leg first.

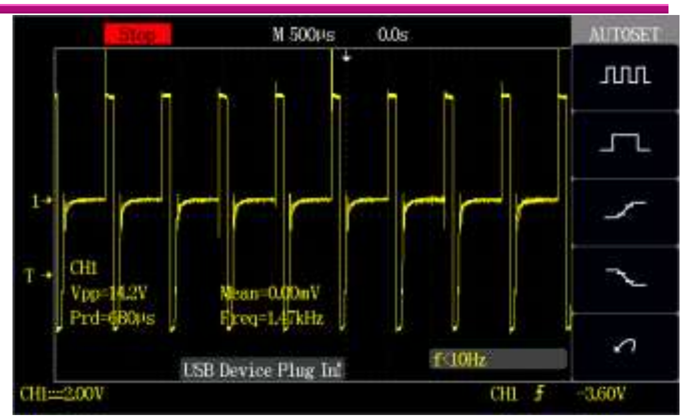

Fig. 9 Experimental result of voltage waveform on phase A

The picture above, Fig. 13, shows the voltage in phase A. If we look at the waveform, the voltage from the neutral point rises to a certain value and then goes towards the negative side. This indicates that after the voltage from the battery is used, there is voltage flowing back towards the battery. Thus, the SRG not only functions as a motor but also operates as a generator where it can send electricity back to the battery.

Looking at the current, as seen in Fig. 14 below, A, B, and C are the currents in each phase A, phase B, and phase C, while D is the battery current. If we examine the signal D, there is a side where its value is positive, followed by a ripple on the negative side. The ripple on the negative side indicates that there is current flowing in the opposite direction, not from the battery to the converter, but from the converter back to the battery. Therefore, the SRM here acts as a generator, sending the generated current back to the battery.

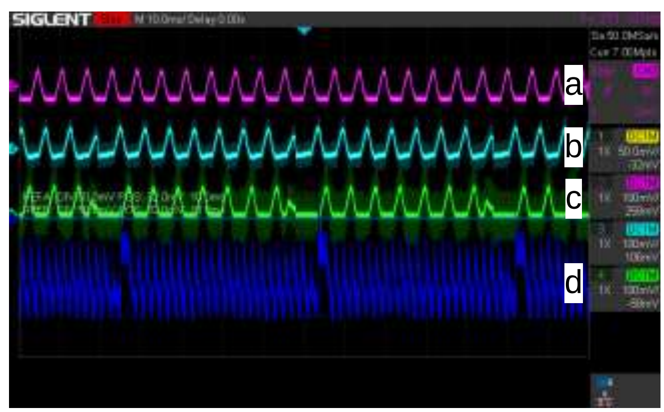

Fig. 10 Experimental result of (a) current waveform on phase A, (b) current waveform on phase B, (d) current waveform on phase C, (d) battery current waveform

4. Conclusion

The research utilized a prototype of an SRG, DC Motor, Rotary Encoder E50S8-2500-3-V-5, asymmetric converter, dsPIC30F4012 microcontroller, current sensor HX10P, and battery for converter supply. Pulses A and Z were used to determine the PWM switching pattern by the DSC, allowing the SRG to function as a generator using asymmetric converter. Asymmetric converter allows the SRM to function as a motor and a generator. The voltage in each phase indicates that after using the battery voltage, the generated current flows back to the battery, demonstrating the SRG's dual functions.

5. Acknowledgment

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6. References

[1] D. A. Torrey, "Switched reluctance generators and their control," *IEEE Trans. Ind. Electron.*, vol. 49, no. 1, pp. 3–14, 2002, doi: 10.1109/41.982243.

[2] K. A. C. Chirapo, J. A. Torrico, A. J. S. Filho, J. Azcue, and I. Delgado-Huayta, "Speed vector control strategy with torque ripple reduction for 12/8 switched reluctance motor," *Proc. 2017 IEEE 24th Int. Congr. Electron. Electr. Eng. Comput. INTERCON 2017*, 2017, doi: 10.1109/INTERCON.2017.8079669.

[3] S. Mir, I. Husain, and M. E. Elbuluk, "Energy-efficient C-dump converters for switched reluctance motors," *IEEE Trans. Power Electron.*, vol. 12, no. 5, pp. 912–921, 1997, doi: 10.1109/63.623010.

[4] C. Gan, J. Wu, Q. Sun, W. Kong, H. Li, and Y. Hu, "A Review on Machine Topologies and Control Techniques for Low-Noise Switched Reluctance Motors in Electric Vehicle Applications," *IEEE Access*, vol. 6, no. c, pp. 31430–31443, 2018, doi: 10.1109/ACCESS.2018.2837111.

[5] N. Kawata and A. Chiba, "Design of Switched Reluctance Generator for Competitive Energy Efficiency in the Latest Hybrid Electric Vehicle," *2018 IEEE Energy Convers. Congr. Expo. ECCE 2018*, no. c, pp. 6461–6467, 2018, doi: 10.1109/ECCE.2018.8557755.

[6] X. Zan, Z. Jiang, K. Ni, W. Zhang, Y. Gong, and N. Wu, "Modular battery management for SRM drives in hybrid vehicles based on a novel modular converter," *IEEE Access*, vol. 8, pp. 136296–136306, 2020, doi: 10.1109/ACCESS.2020.3011451.

[7] C. Pu and L. Hui-Min, "The improvement of switched reluctance motor control system in the field of electric vehicles," *Proc. - 2011 4th Int. Symp. Knowl. Acquis. Model. KAM 2011*, no. 1, pp. 312–314, 2011, doi: 10.1109/KAM.2011.89.

[8] D. W. Choi, S. I. Byun, and Y. H. Cho, "A Study on the maximum power control method of switched reluctance generator for wind turbine," *IEEE Trans. Magn.*, vol. 50, no. 1, 2014, doi: 10.1109/TMAG.2013.2274174.

[9] W. Wang, Y. Huo, S. Yan, and Y. Dou, "The impact of excitation voltage fluctuation on phase current of switched reluctance generator," *Proc. - 2017 IEEE South. Power Electron. Conf. SPEC 2017*, vol. 2018-Janua, pp. 1–6, 2018, doi: 10.1109/SPEC.2017.8333558.

[10] E. Rahmanian, H. Akbari, and G. H. Sheisi, "Maximum Power Point Tracking in Grid Connected Wind Plant by Using Intelligent Controller and Switched Reluctance Generator," *IEEE Trans. Sustain. Energy*, vol. 8, no. 3, pp. 1313–1320, 2017, doi: 10.1109/TSTE.2017.2678679.

[11] S. Riyadi, "A simple method to control the excitation angle for switched reluctance motor," *Indones. J. Electr. Eng. Informatics*, vol. 9, no. 2, pp. 384–393, 2021, doi: 10.52549/ijeei.v9i2.2814.

[12] T. A. D. S. Barros, P. J. D. S. Neto, P. S. N. Filho, A. B. Moreira, and E. R. Filho, "An Approach for Switched Reluctance Generator in a Wind Generation System with a Wide Range of Operation Speed," *IEEE Trans. Power Electron.*, vol. 32, no. 11, pp. 8277–8292, 2017, doi: 10.1109/TPEL.2017.2697822.

[13] W. Wang *et al.*, "Control system of switched reluctance generator," *Proc. 2017 IEEE Russ. Sect. Young Res. Electr. Electron. Eng. Conf. ElConRus 2017*, pp. 1064–1069, 2017, doi: 10.1109/EIConRus.2017.7910740.

[14] F. Briz, J. A. Cancelas, and A. Diez, "Speed Measurement Using Rotary Encoders," *Ieee*, pp. 538–542, 1994.

[15] J. Cai, L. Lu, Z. Liu, H. Jia, X. Zhao, and F. Xu, "An inductive position sensor with switched reluctance motor structure," *2017 20th Int. Conf. Electr. Mach. Syst. ICEMS 2017*, pp. 12–15, 2017, doi: 10.1109/ICEMS.2017.8056495.

[16] H. E. Akhter, V. K. Sharma, A. Chandra, and K. Al Haddad, "Determination of optimum switching angles for speed control of switched reluctance motor drive system," *Indian J. Eng. Mater. Sci.*, vol. 11, no. 3, pp. 151–168, 2004.