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Performance Study of Single-Phase Self-Excited Induction Generator in Stand-Alone System

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Abstract

The performance of Self-Excited Induction Generators is significantly influenced by excitation conditions and load variations. One of the critical factors in maintaining voltage and frequency stability is the selection of an appropriate shunt capacitor to supply the required reactive power. This study investigates the impact of shunt capacitance variation on Self-Excited Induction Generators performance under different operating conditions. Experimental analysis is conducted to examine the relationship between shunt capacitance, terminal voltage, excitation current, and frequency stability at various load levels. The results demonstrate that increasing shunt capacitance enhances terminal voltage and excitation current. Furthermore, this study presents best practices for determining the excitation capacitance to ensure stable SEIG voltage generation in standalone power generation applications.

***Keywords**: SEIG, E xcitation Current, Shunt Capacitance, Terminal Voltage, frequency stability.*

Abstrak

Kinerja Generator Induksi *Self-Excited* (SEIG) sangat dipengaruhi oleh kondisi eksitasi dan variasi beban. Salah satu faktor penting dalam menjaga stabilitas tegangan dan frekuensi adalah pemilihan kapasitor shunt yang tepat untuk memasok daya reaktif yang dibutuhkan. Studi ini menyelidiki dampak variasi kapasitansi shunt terhadap kinerja Generator Induksi *Self-Excited* (SEIG) dalam berbagai kondisi operasi. Analisis eksperimental dilakukan untuk mengkaji hubungan antara kapasitansi shunt, tegangan terminal, arus eksitasi, dan stabilitas frekuensi pada berbagai tingkat beban. Hasil penelitian menunjukkan bahwa peningkatan kapasitansi shunt meningkatkan tegangan terminal dan arus eksitasi. Lebih lanjut, studi ini menyajikan praktik terbaik untuk menentukan kapasitansi eksitasi guna memastikan pembangkitan tegangan SEIG yang stabil dalam aplikasi pembangkit listrik mandiri.

Kata kunci: SEIG, Arus Eksitasi, Kapasitansi Shunt, Tegangan Terminal, Stabilitas Frekuensi.

Introduction

Induction machines have gained widespread adoption as generators in distributed power systems due to their robust construction, low maintenance requirements, and cost-effectiveness compared to synchronous generators [1], [2]. The increasing integration of renewable energy sources, particularly in wind [3] and small-scale hydropower [4] applications, has further highlighted the need for reliable and economical generation technologies [5]. In this context, the Self-Excited Induction Generator (SEIG) has demonstrated significant potential as an autonomous power source, with its inherent capability for self-excitation eliminating the need for external excitation systems [6], [7], [8], [9]. This characteristic, combined with the generator's operational flexibility under variable loading conditions, makes SEIG particularly suitable for off-grid renewable energy systems where conventional synchronous generators may prove impractical or uneconomical [10].

However, SEIG performance is highly dependent on excitation conditions and connected loads [11], [12], [13]. One key factor in maintaining voltage and frequency stability is the use of a shunt capacitor to supply the reactive power necessary for sustained operation [14], [15], [16]. Variations in shunt capacitance can significantly impact terminal voltage, excitation current, and overall system frequency stability [17]. Thus, careful selection and optimization of shunt capacitance are essential for ensuring the efficient operation of SEIG-based renewable energy systems [18], particularly in isolated grids.

Method

This study employs an experimental method to analyze the performance of a stand-alone single-phase induction generator in an isolated network. The experiment was conducted by observing the electrical parameters of the generator when subjected to a resistive load with varying power levels. The equipment used in this study includes a single-phase induction generator as the primary power source in the isolated network system, a fixed-capacitance capacitor to assist in generator excitation, parallel capacitors at the generator terminals, and a resistive load consisting of incandescent lamps with a power variation ranging from 100 W to 500 W.

Figure 1 shows the experimental configuration, consisting of a test bench with a coupled induction generator and motor, instrumentation panel, and VSD unit. The testing system involves a 1.5 HP single-phase induction generator driven by a 1.5 HP three-phase induction motor. The three-phase induction motor is directly shaft-coupled to the generator and controlled by the VSD to maintain constant rotational speed during testing.

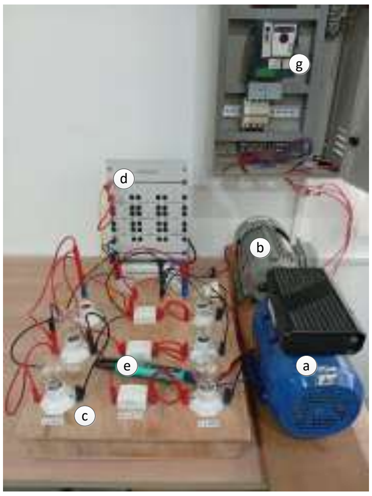

Figure 1. Experimental Equipment (a) Single-phase SEIG (b) Three-phase induction machine (c) Resistive load (d) Shunt capacitor (e) voltage and frequency measurement device (f) Variable Speed Drive

The experiment was conducted in several stages. The first stage involved system preparation, where the single-phase induction generator was configured with a fixed excitation capacitor, as shown in Figure 2. Measurement instruments were connected to record terminal voltage, excitation current, and frequency. In the subsequent testing phase, the generator was operated at a constant speed of 50.3 Hz, regulated using a Variable Speed Drive (VSD), while the resistive load was incrementally varied from 100 W to 500 W. At least five tests were performed, including the analysis of terminal voltage and frequency characteristics.

Tests were conducted on excitation current and voltage characteristics, as well as the relationship between terminal voltage characteristics and parallel capacitors. The measurement results were compiled into graphs and tables to facilitate analysis. This method is expected to provide insights into the performance of the single-phase induction generator under varying operational conditions. However, this study has certain limitations, including maintaining a constant generator speed throughout the experiment and using only resistive loads to eliminating reactive power components and associated voltage-current phase shifts.

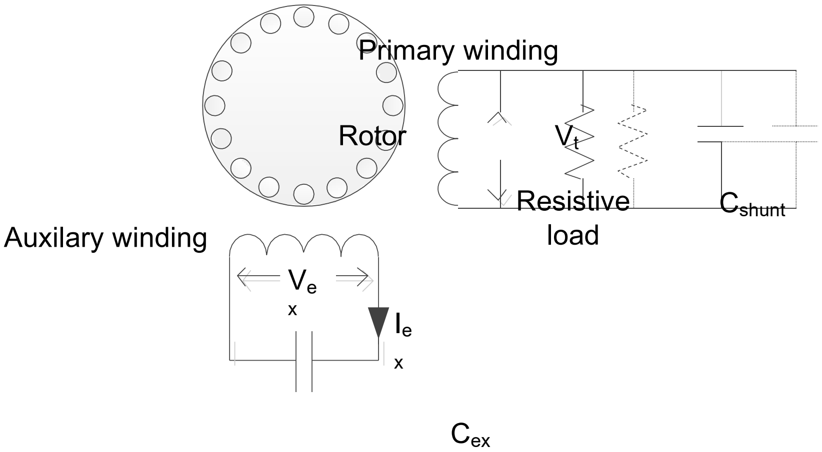

Figure 2. SEIG Configuration

Result and Discussion

Several experiments were conducted in this study to examine the characteristics of terminal voltage in relation to the shunt capacitor and load variations, the characteristics of excitation current and voltage concerning changes in the shunt capacitor, and the variations in terminal frequency due to changes in the shunt capacitor.

a. Excitation Capacitor Selection for Single-Phase SEIG

An effective method for selecting an optimal excitation capacitor involves using a capacitor with the same rating as the original run capacitor from a single-phase induction motor. As illustrated in Figure 3, this capacitor is reconfigured by connecting it to the auxiliary winding Z_1-Z_2, while the terminal voltage is measured across the main winding U_1-U_2. In cases where the main winding fails to generate power, a low-level DC voltage is briefly applied to the auxiliary terminal to initiate excitation. This approach ensures proper matching of the excitation capacitor to the motor's characteristics, thereby enhancing the stability and efficiency of the SEIG system.

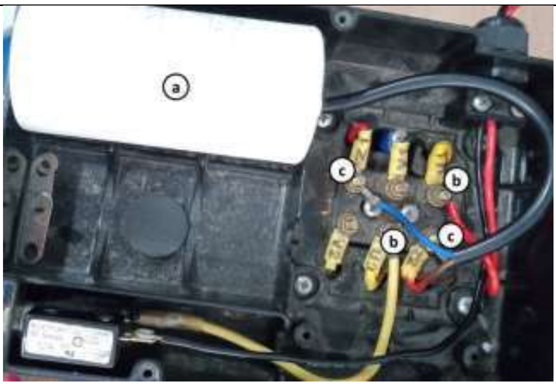

Figure. 3 Excitation Capacitor Installation (a) 40 uF Capacitor (b) Primary Winding Terminal (c) Auxiliary Winding Terminal

b. Effect of Shunt Capacitance on Terminal Voltage Stability

Based on Figure 4, the terminal voltage characteristics of the Self-Excited Induction Generator (SEIG) can be observed as the load varies from 0 to 500 watts with different shunt capacitor values. The horizontal axis represents the load rating in watts, while the vertical axis indicates the terminal voltage in volts. In this experiment, the VSD was set to ensure that the SEIG produced a terminal frequency of 50 Hz. Under these conditions, the SEIG generated a terminal voltage of 117 volts.

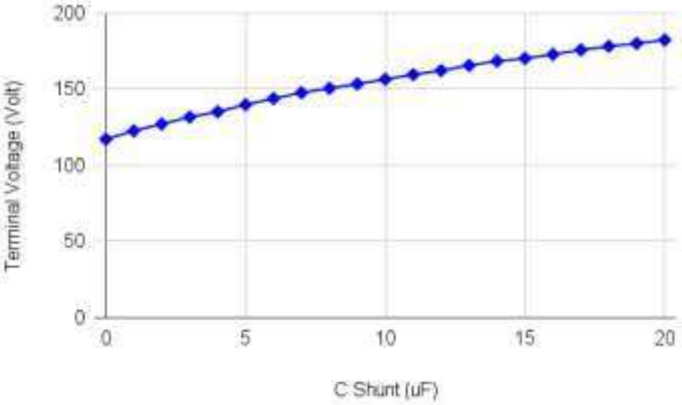

Figure 4. Variation of Terminal Voltage with Changes in Shunt Capacitor

The curve in Figure 4 depicts the variation in the SEIG terminal voltage with increasing load, where each line corresponds to a different shunt capacitance value: no capacitor, 1 μF, 2 μF, 3 μF, 4 μF, and 5 μF. The results demonstrate that increasing the shunt capacitance elevates the terminal voltage, highlighting the critical role of capacitor selection in regulating SEIG voltage performance under varying load conditions.

c. Impact of Load on Terminal Voltage

This experiment aims to examine the relationship between load rating and terminal voltage for various capacitance values. The graph illustrates how capacitance variations influence terminal voltage across different load levels. The horizontal axis represents the load power (watts), while the vertical axis indicates the terminal voltage (volts). From Figure 5, it can be observed that an increase in load power results in a decrease in terminal voltage for all capacitance values.

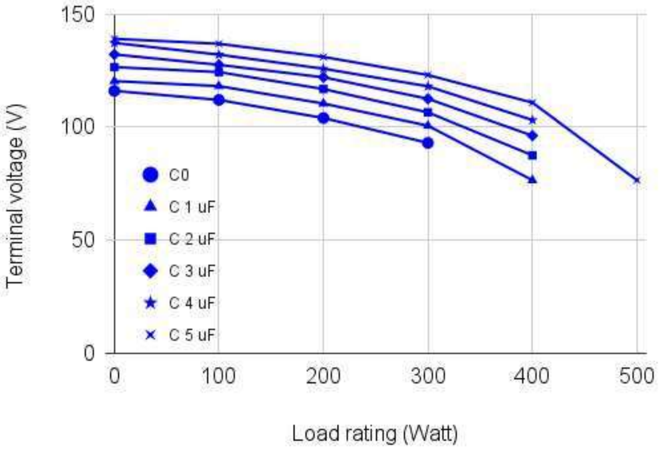

Figure 5. Variation of Terminal Voltage with Load Changes

Additionally, higher capacitance values (C) tend to maintain a higher terminal voltage compared to smaller capacitance values, highlighting the role of capacitors in stabilizing the system voltage. The different lines in the graph represent conditions without a capacitor (C0) and five different capacitance values (1 µF, 2 µF, 3 µF, 4 µF, and 5 µF). The experimental results indicate that the terminal voltage gradually decreases as the load increases. In the curve without a capacitor, the voltage drops more rapidly and can only sustain up to a load of 300 watts before drastically declining, leading to generator demagnetization. In contrast, the curve marked with a cross symbol (C = 5 µF) remains stable up to a load of 500 watts without experiencing demagnetization.

This finding demonstrates that increasing capacitance helps maintain terminal voltage for a longer duration by improving the power factor and supporting the rotor's magnetic field. If the load increases beyond the rated capacity without adequate compensation, the voltage will continue to decline until the generator loses its magnetization, potentially leading to operational instability or even complete system shutdown.

d. Effect of Shunt Capacitance on Terminal and Excitation Voltage

Figure 6 illustrates the relationship between shunt capacitance, terminal voltage, and excitation voltage (V_x, as seen in Figure 2). The shunt capacitance is varied from 0 to 5 µF, while the vertical axis represents terminal voltage in volts (V). It can be observed that both terminal voltage and excitation voltage increase as the shunt capacitance increases. The terminal voltage curve shows a gradual rise, while the excitation voltage curve follows a similar trend but at a higher voltage level than the terminal voltage.

This trend indicates that increasing the shunt capacitance enhances the system voltage by strengthening the magnetic field excitation. This can be attributed to the increased reactive power generated by the capacitor, which helps sustain the magnetic field within the generator. Therefore, increasing the shunt capacitance can be an effective method [18] for improving voltage stability in self-excited generator systems, which is crucial for isolated stand-alone power system applications.

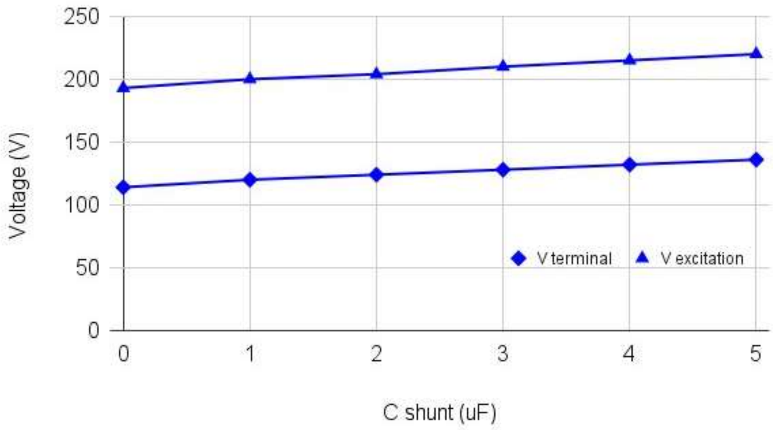

Figure 6. Relationship Between Excitation Voltage and Terminal Voltage with Shunt Capacitance

e. Impact of Shunt Capacitance on Frequency Stability Under Varying Loads

Figure 7 presents the relationship between frequency variation and load changes for different shunt capacitance values. The graph shows that frequency decreases with increasing load power. The curves demonstrate the influence of shunt capacitance variations (1 µF to 5 µF) on frequency stability. An increase in generator current is observed, leading to reduced rotor speed caused by higher electromagnetic torque. Consequently, the operational frequency declines. The results indicate that capacitors do not significantly improve frequency stability.

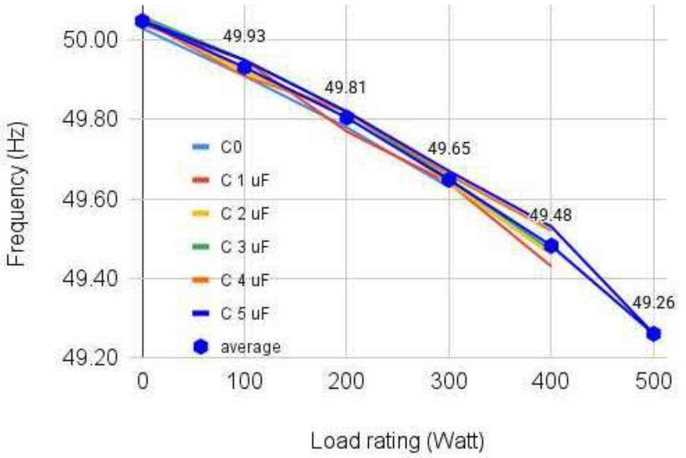

Figure 7. Variation of Terminal Frequency with Load Changes

f. Effect of Shunt Capacitance on Excitation Current

Figure 8 presents a graph illustrating the relationship between shunt capacitance and excitation current during no load condition. The graph shows that excitation current gradually increases as the shunt capacitance increases. Without a shunt capacitor, the excitation current is relatively low, whereas with increasing capacitance up to 5 µF, the excitation current exhibits a consistent rise. This trend indicates that the addition of a shunt capacitor not only contributes to an increase in terminal voltage but also enhances the excitation current in the generator’s auxiliary winding.

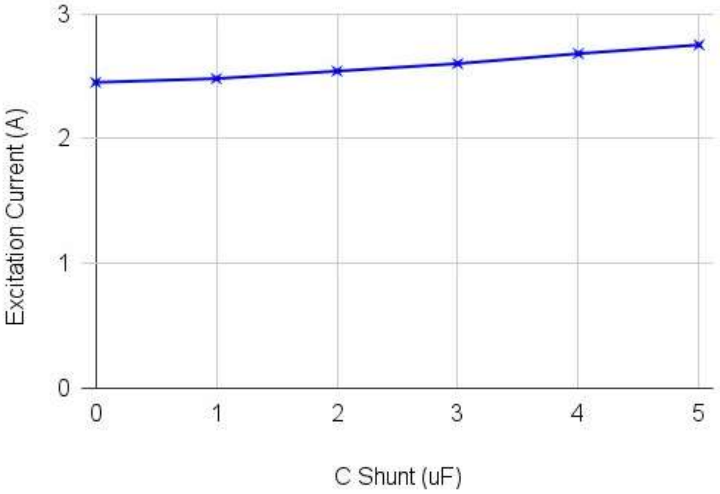

Figure 8. Variation of Excitation Current with Shunt Capacitance

The increase in excitation current can be attributed to the rise in reactive power supplied by the capacitor, which helps sustain excitation voltage and strengthen the rotor’s magnetic field. With a stronger magnetic field, the generator can maintain more stable operation, especially under varying load conditions.

The results suggest that shunt capacitance can effectively enhance field excitation and maintain generator performance in SEIG-based power generation systems. This approach is particularly beneficial for stand-alone systems disconnected from the main grid. However, optimizing the capacitance value remains crucial to prevent excessive increases in excitation current and voltage, which could negatively impact efficiency and reduce the generator's operational lifespan.

Experimental results highlight the role of shunt capacitance in improving voltage, excitation, and frequency stability in SEIG systems. The graphical analysis confirms that increasing shunt capacitance aids in maintaining terminal voltage and excitation. However, shunt capacitors do not significantly enhance terminal frequency. The relationship between shunt capacitance and excitation current demonstrates a trend of increasing excitation current with higher capacitance values. While this helps sustain terminal voltage and the magnetic field, excessive excitation current can lead to higher power losses, increased temperatures in the auxiliary winding, and potential long-term reductions in generator efficiency. Therefore, further analysis is necessary to determine the safe excitation current limits and develop control strategies to prevent excessive auxiliary winding stress.

All presented results represent steady-state conditions, without considering the dynamic effects of sudden load changes. In real-world applications, power systems often experience instantaneous load variations, which can cause voltage and frequency oscillations before reaching a stable state. Thus, it is essential to investigate how a system with shunt capacitance responds to load transients and whether this method is effective in damping short-term fluctuations.

Conclusion

This study investigates the performance of a stand-alone self-excited induction generator (SEIG) system operating in an isolated grid configuration. The results demonstrate that while shunt capacitance effectively maintains voltage stability, its contribution to terminal frequency improvement is limited. Furthermore, excessive excitation current was found to adversely affect system efficiency.

The research focuses on a small-scale generator system where shunt capacitance significantly influences the generated voltage stability. However, in large-scale power applications, additional factors including grid interactions and transmission line impedance may substantially impact SEIG performance. These findings suggest the need for further research to examine SEIG behavior in more complex grid environments.

References

[1] R. C. Bansal, “Three-Phase Self-Excited Induction Generators: An Overview,” IEEE Transactions on Energy Conversion, vol. 20, no. 2, pp. 292–299, May 2005, doi: 10.1109/tec.2004.842395.

[2] G. K. Singh, “Self-excited induction generator research—a survey,” Electric

Power Systems Research, vol. 69, no. 2–3, pp.107–114, Nov. 2003, doi: 10.1016/j.epsr.2003.08.004.

[3] L. Varshney, A. S. S. Vardhan, A. S. S. Vardhan, S. Kumar, R. K. Saket, and P. Sanjeevikumar, "Performance characteristics and reliability assessment of self excited induction generator for wind power generation," IET Renewable Power Generation, vol. 15, no. 9, pp. 1927–1942, Feb. 2021, doi: 10.1049/rpg2.12116.

[4] S. Chakraborty and R. Pudur, "Performance enhancement of Three-Phase SEIG to feed Single-Phase load in micro-hydro systems using a novel capacitor excitation topology," in Energy, environment, and sustainability, 2024, pp. 427–444. doi: 10.1007/978-981-97-1406-3_15.

[5] A. Syuhada, T. Tarmizi, and A. Akhyar, "Effect of rotation on achieving constant voltage in three-phase self-excited induction generator for small scale wind turbines application," Jurnal POLIMESIN, vol. 22, no. 3, p.338, Jul. 2024, doi: 10.30811/jpl.v22i3.5279.

[6] Y. Liu, M. A. Masadeh, and P. Pillay, "Power-Hardware-In-The-Loop-Based emulation of a Self-Excited induction generator under unbalanced conditions," IEEE Transactions on Industry Applications, vol. 58, no. 1, pp. 588–598, Oct. 2021, doi: 10.1109/tia.2021.3118985.

[7] A. Bhansali, N. Narasimhulu, R. P. De Prado, P. B. Divakarachari, and D. L. Narayan, "A review on sustainable energy sources using machine learning and deep learning models," Energies, vol. 16, no. 17, p. 6236, Aug. 2023, doi: 10.3390/en16176236.

[8] G. Singh and V. R. Singh, "Transient and Steady State Analysis of SEIG using an Elephant Herding Optimization Approach," Journal of Circuits Systems and Computers, Feb. 2023, doi: 10.1142/s0218126623502286.

[9] S. Chakraborty, J. Samanta, and R. Pudur, "Experimental analysis of a modified scheme for supplying single-phase remote loads from micro-hydro based three- phase self-excited induction generator,"Measurement Sensors, vol. 33, p.101166, Apr. 2024, doi: 10.1016/j.measen.2024.101166.

[10] N. Krismadinata, D. Fiandri, N. Asnil, I. Husnaini, M. N. Abdullah, and M. Singh, "Voltage and frequency regulation induction generator employing AC-AC converter," IOP Conference Series Earth and Environmental Science, vol. 1281, no. 1, p. 012039, Dec. 2023, doi: 10.1088/1755-1315/1281/1/012039.

[11] A. J. Ali, M. Y. Suliman, L. A. Khalaf, and N. S. Sultan, "Performance investigation of stand-alone induction generator based on STATCOM for wind power application," International Journal of Power Electronics and Drive Systems/International Journal of Electrical and Computer Engineering, vol. 10, no. 6, p. 5570, Sep. 2020, doi: 10.11591/ijece.v10i6.pp5570-5578.

12] M. F. Khan and M. R. Khan, "Modeling and analysis of a Six-Phase Self excited Induction Generator feeding induction motors," IEEE Transactions on Energy Conversion, vol. 36, no. 2, pp. 746–754, Aug. 2020, doi: 10.1109/tec.2020.3013784.

[13] M. M. Khalaf and A. M. Ali, "Voltage Build-Up behavior of Self-Excited induction generator under different loading conditions,"International Conference on Advanced Science and Engineering (ICOASE), 190-194., Dec. 2020, doi: 10.1109/icoase51841.2020.9436546.

[14] M. Devkota and S. Adhikari, "Enhancement of Voltage Stability by Optimal Placement of Shunt Compensation using Bus Voltage Stability Indices and Reactive Power Margin," Himalayan Journal of Applied Science and Engineering, vol. 3, no. 2, pp. 1–9, Nov. 2022, doi: 10.3126/hijase.v3i2.52291.

[15] L. Varshney, A. S. S. Vardhan, A. S. S. Vardhan, S. Kumar, R. K. Saket, and P. Sanjeevikumar, "Performance characteristics and reliability assessment of self- excited induction generator for wind power generation," IET Renewable Power Generation, vol. 15, no. 9, pp. 1927–1942, Feb. 2021, doi: 10.1049/rpg2.12116.

[16] G. Singh and V. R. Singh, “SEIG-based transient- and steady-state analysis using dragon fly approach,” Soft Computing, vol. 27, no. 6, pp. 2993–3005, Sep. 2022, doi: 10.1007/s00500-022-07458-1.

[17] Y. Anagreh and A. Al-Quraan, “The Behavior of Terminal Voltage and Frequency of Wind-Driven Single-Phase Induction Generators under Variations in Excitation Capacitances for Different Operating Conditions,” Energies, vol. 17, no. 15, p. 3604, Jul. 2024, doi: 10.3390/en17153604.

[18] V. B. M. Krishna and V. Sandeep, “Experimental investigations on loading capacity and reactive power compensation of Star configured three phase self - excited induction generator for distribution power generation,” Distributed Generation & Alternative Energy Journal, Feb. 2022, doi: 10.13052/dgaej2156-3306.37316