Model Order Reduction of a Single Machine Infinite Bus Power System Using the Hankel-Norm Model Reduction Algorithm

Nguyen Manh Quan
Hanoi University of Industry, Hanoi, Vietnam
quannm@haui.edu.vn

Ha Trung Kien
Hanoi University of Industry, Hanoi, Vietnam
hatrungkien@haui.edu.vn

Dang Danh Hoang
Thai Nguyen University of Technology, Thai Nguyen, Vietnam
hoangktd1977@tnut.edu.vn (corresponding author)

Received: 24 April 2025 | Revised: 14 May 2025 and 7 June 2025 | Accepted: 9 June 2025

 DOI: https://doi.org/10.48084/etasr.11684

ABSTRACT

This study focuses on reducing the model order of a Single Machine Infinite Bus Power (SMIBP) system in order to simplify the system dynamics while preserving its essential stability characteristics. The primary objective is to assess the effectiveness of the Hankel-Norm Model Reduction (HNMR) algorithm in truncating the state-space representation from the full-order model (order 7) to lower orders (4, 5, and 6). The research methodology involves converting the transfer function of the SMIBP system into its state-space representation, applying the HNMR algorithm to compute the controllability and observability Gramians, constructing the descriptor operator, performing Singular Value Decomposition (SVD), and extracting the stable part via the Schur complement. Experimental results indicate that the reduced-order model of order 4 exhibits an H_∞ error of approximately 7.47 and a Mean Square Error (MSE) of 71.69, whereas the order 5 model shows significant improvement with an H_∞ error reduced to 1.43 and an MSE of only 7.84. The order 6 model, on the other hand, achieves extremely low errors, with H_∞ and MSE values of merely 0.05 and 0.08, respectively. These findings confirm that increasing the reduced order substantially enhances the accuracy of the approximated model relative to the original system. In conclusion, the HNMR algorithm is validated as an effective method for reducing the order of SMIBP systems, with the order 6 reduced model representing the optimal choice for applications requiring high accuracy and preservation of the dynamic characteristics of the original system.

Keywords-single machine infinite bus; model order reduction; Hankel-Norm model reduction; power system stability; dynamic system; control design; reduced-order model

I. INTRODUCTION

The Single Machine Infinite Bus Power (SMIBP) system is a standardized and simplified model that nevertheless provides a highly representative framework for analyzing power system dynamics. This model describes a single synchronous generator connected to an infinite bus system through a transmission line, where the "infinite bus" is assumed to be an ideal voltage source with a constant voltage and frequency, irrespective of any power oscillations from the generator [1, 2]. It is the most fundamental and widely used model in power system stability studies, particularly for small-signal stability analysis, transient response evaluation, and control design [3, 4]. The mathematical structure of the SMIBP system is generally represented by a set of second-order nonlinear differential equations characterizing the rotor swing, combined with either linear or nonlinear electromagnetic expressions, depending on the level of model detail. For control and analysis purposes, the system can be linearized around its steady-state operating point and expressed in a state-space representation [5, 6].

The SMIBP system is extensively employed in both academic research and practical engineering applications to address objectives such as voltage stability, rotor angle stability, damping of mechanical oscillations, and performance evaluation of reactive power compensation devices like SVC, STATCOM, or UPFC [7, 8]. In the control domain, the SMIBP model serves as a basis for the design, simulation, and validation of Power System Stabilizers (PSS), fuzzy controllers, adaptive controllers, and more recently, artificial intelligence-based controllers such as neural networks or deep learning systems [9, 10]. The integration of metaheuristic optimization techniques and machine learning approaches into the SMIBP system has been shown to effectively enhance transient stability, particularly under conditions of severe disturbances or rapid load variations [1, 7, 11, 12]. Moreover, the SMIBP model acts as an intermediate framework for the development and assessment of Model Order Reduction (MOR) techniques, which can then be applied to large-scale power systems while retaining essential dynamic characteristics [13]. In industrial applications, the SMIBP system is also utilized for testing generator control performance, evaluating system responses during localized disturbances, and training power system engineers through realistic simulation scenarios [14, 15]. Although the SMIBP system serves as an efficient foundational model for power system control technology research and development, extending this model to a higher order, by incorporating additional state variables, such as field current, terminal voltage, or control via power electronics devices, poses a series of analytical and control design challenges [16-18]. The high-order SMIBP model substantially increases computational complexity due to the significant rise in the number of state equations. This escalation affects the performance of simulation, optimization, and control design methods, particularly when the model exhibits high stiffness or pronounced nonlinearity [19-21]. Retaining crucial properties of the original system, such as Lyapunov stability, transient response accuracy, and controllability, observability, becomes more difficult as the order increases [22-24]. Moreover, high-order models may exhibit phenomena such as chaotic oscillations, low-frequency oscillations, or internal resonances due to interactions among control devices [25-27]. In complex power systems such as the SMIBP, reducing the model order to simplify the dynamic structure and reduce the computational burden while preserving the system's inherent stability is a significant challenge. Model order reduction not only facilitates more efficient simulation and analysis but also plays a crucial role in the optimal controller design. In this context, the Hankel-Norm Model Reduction (HNMR) algorithm has been extensively investigated due to its capability to accurately approximate the system's dynamic characteristics through the Hankel matrix, thereby selecting an optimal order without compromising system stability [26, 28]. The HNMR algorithm is based on the Hankel-norm approximation theory, which quantitatively assesses the contribution of each state to the system dynamics [28, 29]. Applying HNMR to the SMIBP system offers numerous benefits, especially when dealing with high-order models that include a wide array of electrical and mechanical parameters. The complexity of the SMIBP, when augmented with additional elements such as power electronic control or reactive compensation devices, requires a sophisticated reduction process to ensure that the fundamental dynamic properties, such as transient response and Lyapunov stability, are maintained [26, 30]. Recent research highlights the importance of MOR in load management and enhancing the reliability of power systems, thus reinforcing the theoretical foundation for reduction methods like HNMR [27, 29].

To validate the effectiveness of HNMR in reducing the complexity of the SMIBP system, the authors implemented this reduction algorithm in an infinite bus power system model [31, 32]. The study demonstrates that the application of the HNMR algorithm shortens simulation time and also preserves the essential dynamic characteristics of the system. Consequently, the reduced-order model significantly supports the analysis and design of optimal controllers and lays a solid foundation for advanced research on power system stability.

II. METHOD

A. Hankel-Norm Model Reduction Algorithm

The HNMR algorithm is based on Hankel norm approximation theory. In this theory, the distance between the original system and its reduced-order model is evaluated using the Hankel norm of the operator that maps the past input space to the future output space. This approach not only guarantees the intrinsic stability of the reduced model but also optimizes the approximation error in the mid-frequency range. The implementation process of the HNMR algorithm is outlined as follows [27-30]:

- **Input:** The full-order state-space system $(A, B, C, D) \in \mathbb{R}^{n\times n}, \mathbb{R}^{n\times m}, \mathbb{R}^{p\times n}, \mathbb{R}^{p\times m}$ and the desired reduced order $r < n$.
- **Output**: The reduced-order system $(\hat{A}, \hat{B}, \hat{C}, \hat{D}) \in \mathbb{R}^{r\times r}, \mathbb{R}^{r\times m}, \mathbb{R}^{p\times r}, \mathbb{R}^{p\times m}$.
- Step 1: Compute the controllability and observability Gramians by solving the following Lyapunov equations:

  $$AP + PA^{\mathrm{T}} + BB^T = 0 \quad (1)$$

  $$A^T Q + QA + C^T C = 0 \quad (2)$$

  where $P \succ 0$ and $Q \succ 0$. This step quantifies the controllability and observability levels of each state.
- Step 2: Construct the descriptor operator E using the product of the Gramians:

  $$E = QP - \partial^2 I \quad (3)$$

  where $\hbar_r > \partial \geq \hbar_{r+1}$ and $\hbar_i$denote the singular values of the Hankel operator $H = QP$. The objective here is to isolate the contributions of the r most significant states in terms of the Hankel norm.
- - Step 3: Perform Singular Value Decomposition (SVD) on the operator E as:

  $$E = U_E \Sigma_E V_E^T \quad (4)$$

  and partition the results as follows:

  $$EU_E = [U_{E1}\ U_{E2}];\ \ V_E = [V_{E1}\ V_{E2}];$$

  $$\Sigma_E = \begin{bmatrix} \Sigma_{E1} & 0 \\ 0 & 0 \end{bmatrix} \quad (5)$$

  with $\Sigma_{E1} \in \mathbb{R}^{r\times r}$ containing the r largest singular values.
- Step 4: Using the obtained singular vectors, transform the original system into a new basis to partition it into

subblocks with different priority levels. This is accomplished by (6).

$$A=\begin{bmatrix}A_{11} & A_{12}\\ A_{21} & A_{22}\end{bmatrix}=U_E^T(\partial^2 A^T+QAP)V_E;$$
$$B=\begin{bmatrix}B_1\\ B_2\end{bmatrix}=U_E^T(QB-C^T); \quad (6)$$
$$C=[C_1 \quad C_2]=(CP-\partial B^T)V_E;\ D_1=D$$

- Step 5: Construct the equivalent lower-order state-space model using the Schur complement approximation:

$$\hat{A}=\Sigma_{E1}^{-1}(A_{11}-A_{12}A_{22}^{\dagger}A_{21});$$
$$\hat{B}=\Sigma_{E1}^{-1}(B_1-A_{12}A_{22}^{\dagger}B_2); \quad (7)$$
$$\hat{C}=C_1-C_2A_{22}^{\dagger}A_{21};\ \hat{D}=D_1-C_2A_{22}^{\dagger}B_2$$

where $A_{22}^{\dagger}$ denotes the Moore-Penrose pseudoinverse of A_{22}.

- Step 6: Extract the stable part of the reduced model by employing spectral decomposition techniques to ensure that the final model $(\hat{A}, \hat{B}, \hat{C}, \hat{D})$ of order r preserves the essential dynamic characteristics of the original system.

B. Single Machine Infinite Bus Power System Model

The diagram in Figure 1 illustrates the key components of an SMIBP system. These components include:

- Synchronous generator: The central element that connects to the infinite bus via a tie-line.
- Turbine and governor: Provides mechanical drive to the synchronous generator and assists in primary frequency control.
- Excitation system: Supplies the necessary excitation to the generator's field winding.
- Automatic Voltage Regulator (AVR): Regulates the excitation system to maintain a stable terminal voltage.
- Power System Stabilizer (PSS): Enhances the system stability by supplying additional damping control.
- Infinite bus: Represents the Thevenin equivalent of a large, interconnected power system.

This SMIBP model is predominantly used for the study of power system stability. The block diagram delineates the interactions among the components as follows:

- The turbine and governor deliver the mechanical input to the generator.
- The excitation system regulates the generator's field current.
- The AVR adjusts the terminal voltage by controlling the excitation system.
- The PSS receives speed deviation as its input and supplies supplementary control signals to the AVR.
- The generator is connected to the infinite bus through a tie-line.

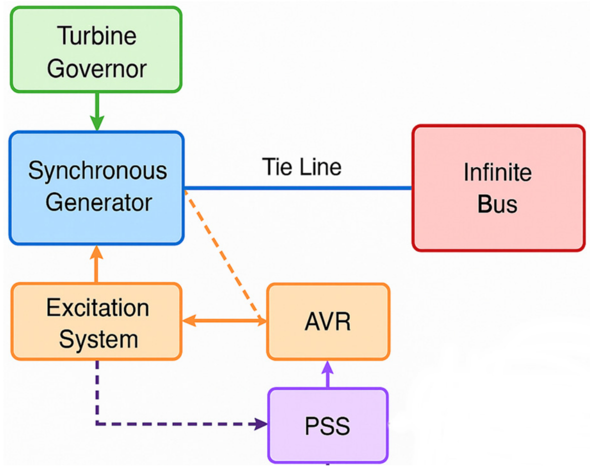

Fig. 1. Block diagram of the SMIBP system.

III. APPLICATION OF HANKEL-NORM MODEL REDUCTION TO A SINGLE MACHINE INFINITE BUS POWER SYSTEM

Consider the dynamic model of the SMIBP system [31, 32], which has a transfer function given by:

$$F(s)=\frac{2000s^6+121700s^5+1211000s^4+7454000s^3+58270000s^2+3156000s+2075000}{s^7+65.85s^6+984.2s^5+12130s^4+97300s^3+429400s^2+2188000s+999500} \quad (8)$$

The HNMR algorithm was implemented in MATLAB to reduce the original seventh-order system to lower-order models of orders 4, 5, and 6. The corresponding obtained transfer functions are given in below, whereas the reduction errors in terms of the H_∞ norm and MSE are summarized in Table I.

$$F_{r=4}(s)=\frac{6.562s^4+1936s^3+1344s^2+1.1\times10^5s-1.459\times10^4}{s^4+4.99s^3+145.1s^2+261.2s+4086} \quad (9)$$

$$F_{r=5}(s)=\frac{-1.361s^5+2038s^4+952.4s^3+1.156\times10^5s^2-6816s+4392}{s^5+5.663s^4+146.9s^3+323.9s^2+4183s+1304} \quad (10)$$

$$F_{r=6}(s)=\frac{0.05098s^6+1993s^5+1.947\times10^4s^4+1.241\times10^5s^3+1.038\times10^6s^2+6.147\times10^4s+3.666\times10^4}{s^6+14.46s^5+199.6s^4+1631s^3+7325s^2+3.88\times10^4s+1.81\times10^4} \quad (11)$$

TABLE I. COMPARISON OF REDUCED-ORDER MODELS FOR DIFFERENT REDUCTION ORDERS

Reduced order (r)	**H_∞ error**	**MSE**
4	7.473195345831305	71.694345318950695
5	1.430003795946640	7.835960542638253
6	0.050977464813167	0.083937719133206

The results in Table I indicate that, as the reduced order increases from 4 to 6, both the H_∞ error and the MSE decrease significantly. Specifically:

- For the order-4 reduced model, the H_∞ error is approximately 7.47 and the MSE is around 71.69, suggesting substantial information loss compared to the full-order model.

- Increasing the reduced order to 5 leads to a marked improvement, with the H_∞ error decreasing to 1.43 and the MSE to 7.84, indicating that the order-5 model provides a better approximation of the full-order system.
- The order-6 reduced model yields H_∞ and MSE values that are almost negligible (0.051 and 0.084, respectively), signifying an excellent match with the full-order model.

Figure 2 shows the Nyquist plots of the full-order system and its reduced-order counterparts. The curves, representing the frequency response in terms of magnitude and phase, indicate that higher reduced orders result in curves that closely align with those of the original system over critical frequency ranges. Notably, the order-6 model exhibits a nearly perfect match with the full-order system, indicating that it preserves the dynamic characteristics and essential amplitude-phase information required to maintain system stability. In contrast, lower-order models, such as the order-4 model, show significant deviations, especially in frequency regions with strong amplitude and phase variations, thereby compromising the accuracy of the reduced model.

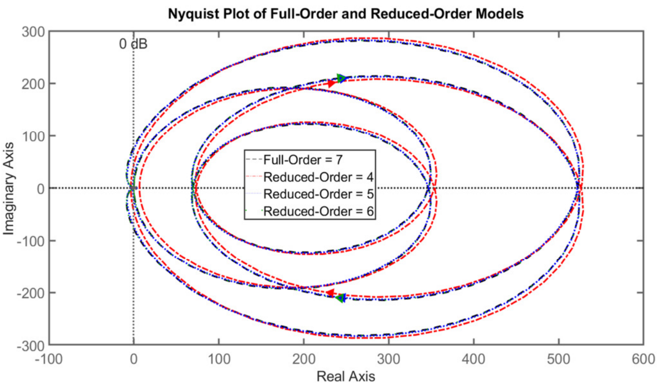

Fig. 2. Nyquist plots of the full-order and reduced-order models.

Figure 3 shows the Nichols plots, which provides an integrated view of the gain and phase relationships for the various models. The order-6 reduced model displays gain and phase responses that closely mirror those of the full-order system, with phase deviations within ±2° and amplitude errors below 0.1 dB at key frequencies. In comparison, the order-4 model exhibits phase discrepancies up to ±15° and amplitude errors around 3 dB in sensitive frequency regions. The order-5 model shows moderate improvements, with phase deviations limited to ±5° and amplitude errors around ±1.5 dB at critical frequencies. These results confirm that higher reduced orders lead to more accurate preservation of the gain-phase characteristics, ensuring that the control performance remains comparable to that of the original system. Analysis of the magnitude plot in Figure 4, over the simulated frequency range from 10^{-2} rad/s to 10^{2} rad/s reveals that, for frequencies below 10 rad/s, the curves for the order-4 and order-5 models deviate from that of the full-order system. The order-4 model exhibits the greatest discrepancy. However, in the frequency range between 10 rad/s and 100 rad/s, both the order-4 and order-5 models align closely with the full-order response. The frequency response of the order-6 model is in complete agreement with the full-order system. Figure 5 shows the phase plots over the frequency range from 10^{-2} rad/s to 10^{2} rad/s. In the interval between 3 rad/s and 20 rad/s, the phase response of the order-5 model closely follows that of the full-order system; however, deviations exist in other frequency regions. Across the entire frequency spectrum, the phase response of the order-4 model deviates the most, whereas the order-6 model exhibits a phase response identical to that of the original system.

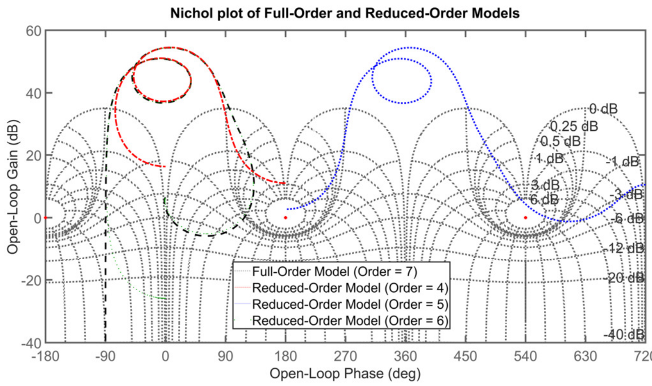

Fig. 3. Nichols plots of the full-order and reduced-order models.

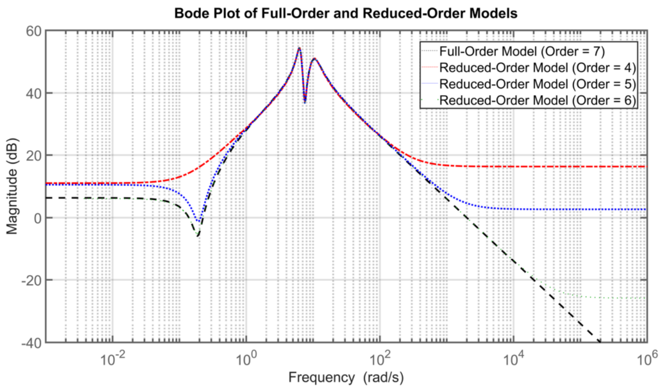

Fig. 4. Magnitude plots of the full-order and reduced-order models.

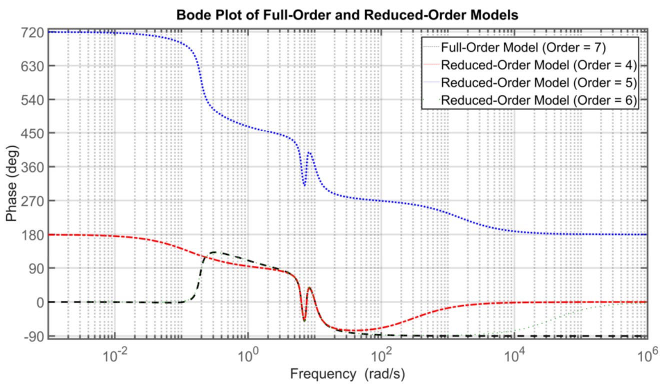

Fig. 5. Phase plots of the full-order and reduced-order models.

The step response comparison in Figure 6 indicates that for time intervals shorter than 1.6 s, the response of the order-4 model closely tracks that of the full-order system. However, beyond 1.6 s, the order-4 model gradually deviates, particularly during the settling phase. Overall, the step responses of the order-4 and order-5 models resemble that of the full-order system, with the order-5 model demonstrating the closest match.

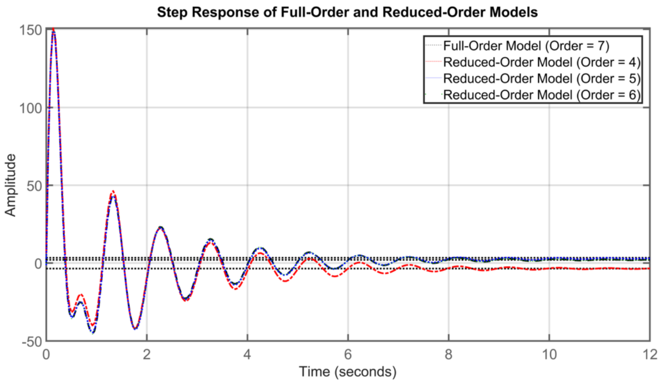

Fig. 6. Step responses of the full-order and reduced-order models.

The dynamic model order reduction of the SMIBP system from order 7 to orders 4, 5, and 6 reveals significant differences in approximation accuracy relative to the full-order model. Error metrics, frequency response analyses, and time-domain evaluations confirm that the order-6 reduced model performs exceptionally well, with negligible H_∞ error and MSE, as well as nearly identical frequency (via Nyquist, Nichols, magnitude, and phase plots) and time-domain step responses compared to the original system. The order-5 model also delivers satisfactory results with significantly reduced errors relative to the order-4 model, though minor discrepancies persist in certain sensitive frequency regions. Conversely, the order-4 model shows pronounced information loss, with substantial errors and notable deviations, especially at low frequencies and during the settling phase.

Based on these analyses, it is recommended to employ the order-6 reduced model in applications that demand high precision, as it can preserve the dynamic characteristics of the full-order system. Should computational efficiency be a priority, the order-5 model might serve as a viable alternative, provided the resulting errors remain within acceptable limits for the specific application. The order-4 model is suitable only for scenarios where stringent accuracy is not critical. The selection of the reduced order must carefully balance accuracy and computational performance depending on the practical application requirements.

IV. DISCUSSION

This work demonstrated the effectiveness of the HNMR algorithm in simplifying the high-order (7th-order) dynamic model of an SMIBP system. The empirical results revealed that the 6th-order reduced model achieves high fidelity, exhibiting an H_∞ error and MSE of merely 0.051 and 0.084, respectively, thereby preserving the essential dynamic characteristics of the original system almost entirely. Although other model order reduction techniques have been applied to power systems, including various methods for SMIBP systems [2], stiffness-oriented approaches [30], or second-order methods such as the Arnoldi method [26], the HNMR approach presented herein offers a systematic procedure grounded in Hankel singular values [28, 29]. This methodology not only inherently guarantees the stability of the reduced-order model, but also facilitates a clear, quantitative assessment of the trade-off between model order and approximation error, as measured by metrics like the H_∞ norm and MSE. The attainment of such low approximation errors for the 6th-order model underscores the suitability of HNMR for SMIBP systems, particularly in applications demanding high accuracy and the preservation of dynamic behaviors, outperforming lower-order models (4th- and 5th-order), which exhibited significantly larger errors. The primary contribution of this study lies in providing a detailed quantitative evaluation of HNMR performance across different reduction orders for a specific SMIBP model, thereby offering practical guidance for selecting an appropriate model order for stability analysis and controller design in similar contexts.

V. CONCLUSION

This study demonstrates that the Hankel-Norm Model Reduction (HNMR) algorithm serves as an effective tool for reducing the order of dynamic models in Single Machine Infinite Bus Power (SMIBP) systems, particularly when dealing with high-order original models. Experimental results indicate that the 6th-order reduced model preserves nearly all the dynamic characteristics of the original system, exhibiting minimal H_∞ error and Mean Square Error (MSE). This underscores the algorithm's high approximation accuracy. The 5th-order model also yields promising results, with significantly lower errors compared to the 4th-order model, though minor deviations persist in frequency-sensitive regions. In contrast, the 4th-order model reveals substantial information loss, characterized by large errors and noticeable deviations in response, especially at low frequencies and during the settling phase in the time domain. These findings highlight the critical need to select an appropriate reduction order to balance accuracy and computational efficiency in practical applications. The reduction order should be chosen based on a careful evaluation of the trade-offs between precision and computational performance, tailored to the objectives of the intended application.

Beyond providing an efficient model reduction approach for SMIBP systems, this study paves the way for further exploration of HNMR applications in more complex power systems. The obtained results lay a foundation for designing optimal controllers, enhancing system stability, and improving operational performance under real-world conditions. Additionally, this work enriches the theoretical framework of model order reduction in power system control, offering valuable insights for future research and practical implementations.

ACKNOWLEDGMENT

The authors gratefully acknowledge Thai Nguyen University of Technology, Vietnam, for supporting this work. This work is independent of any grant-funded research projects.

REFERENCES

[1] M. Fahim-Ul-Haque, Md. R. Islam, M. Shafiullah, and Md. S. Hossen, "Stability Enhancement of Single Machine Infinite Bus System with UPFC using Bat Algorithm," in *2022 31st Conference of Open Innovations Association (FRUCT)*, Helsinki, Finland, 2022, pp. 51–57, https://doi.org/10.23919/FRUCT54823.2022.9770924.

[2] P. S. Deb and L. G, "Model Order Reduction of Single Machine Infinite Bus Power System," in *2023 3rd International Conference on Advance Computing and Innovative Technologies in Engineering*, Greater Noida, India, 2023, pp. 492–496, https://doi.org/10.1109/ICACITE57410.2023.10183059.

[3] Y. K. Kirange and P. Nema, "Innovative Approach to Enhance Stability: Neural Network Control and Aquila Optimization Integration in Single Machine Infinite Bus Systems," *Advances in Technology Innovation*, vol. 9, no. 2, pp. 99–115, Apr. 2024, https://doi.org/10.46604/aiti.2024.13360.

[4] Y. Kirange and P. Nema, "A Survey on Improving Power System Dynamic Stability with a Single Machine Infinite Bus," in *2023 International Conference for Advancement in Technology*, Goa, India, 2023, pp. 1–8, https://doi.org/10.1109/ICONAT57137.2023.10080028.

[5] N. Vieyra Valencia, E. Rodríguez-Monzón, P. Maya-Ortiz, and C. Angeles-Camacho, "An Output-Feedback Controller for a Single Machine Infinite Bus Power System," in *Memorias del Congreso Nacional de Control Automático*, Acapulco, Mexico, 2023, pp. 205–210, https://doi.org/10.58571/CNCA.AMCA.2023.047.

[6] H. D. Laksono and R. S. Putra, "Simulation and Analysis of Single Machine Infinite Bus System against Parameter Changes," *ELECTRON Jurnal Ilmiah Teknik Elektro*, vol. 5, no. 2, pp. 216–224, Nov. 2024, https://doi.org/10.33019/electron.v5i2.162.

[7] S. Zhang and N. Yu, "Learning Power System Dynamics with Nearly-Hamiltonian Neural Network," in *2023 IEEE Power & Energy Society General Meeting*, Orlando, FL, USA, 2023, pp. 1–5, https://doi.org/10.1109/PESGM52003.2023.10252786.

[8] N. K. Sharma and P. P. Jagtap, "Modelling and Application of Unified Power Flow Controller (UPFC)," in *2010 3rd International Conference on Emerging Trends in Engineering and Technology*, Goa, India, Aug. 2010, pp. 350–355, https://doi.org/10.1109/ICETET.2010.169.

[9] S. Singh and S. Saini, "Alleviation and control of chaotic oscillations in SMIB power systems using a modified-Whale optimization-based battery-STATCOM," *Journal of Engineering Research*, vol. 12, no. 2, pp. 135–153, Jun. 2024, https://doi.org/10.1016/j.jer.2023.10.004.

[10] M. M. A. S. Mahmoud, "Stabilization of Terminal Voltage and Damping the Mechanical Angle Oscillations in Single-Machine Infinite-Bus Power System Using MISO Fuzzy Controllers." Preprints, Jan. 24, 2022, https://doi.org/10.20944/preprints202201.0256.v2.

[11] S.-K. Kim, S. Lim, and C. K. Ahn, "Model-Independent Observer-Based Critically Damped Terminal Voltage Stabilization for Single Machine Infinite Bus Systems via High-Order Pole-Zero Cancellation Approach," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 71, no. 10, pp. 4861–4872, Oct. 2024, https://doi.org/10.1109/TCSI.2024.3440632.

[12] N. Patel, B. Brahma, A. K. Bhoi, and J. Sarda, "AVR-PSS Generator with Fuzzy Logic Controller and Conventional Damping of Low-Frequency Oscillations," *Journal of The Institution of Engineers (India): Series B*, vol. 106, no. 2, pp. 671–682, Apr. 2025, https://doi.org/10.1007/s40031-024-01119-7.

[13] M. R. Djalal, M. Saini, and A. M. S. Yunus, "Analisis Pemasangan Power System Stabilizer Pada Single Machine Infinite Bus Untuk Kondisi Variasi Beban," *Jurnal JEETech*, vol. 3, no. 2, pp. 102–106, Nov. 2022.

[14] K. Himaja, T. A. Kumar, and S. T. Kalyani, "Dynamic Stability Enhancement of SMIB Power System with PSS-SVC with LQR Optimal Control," *Technological Innovation in Engineering Research*, vol. 3, no. 1, pp. 61–69, Jun. 2022, https://doi.org/10.9734/bpi/tier/v3/2320A.

[15] P. M. Meshram, S. P. Gawande, S. Deshmukh, and A. Chaudhury, "Some Investigations on Synchronous Generator Connected to Infinite Bus," in *2022 International Conference on Emerging Trends in Engineering and Medical Sciences*, Nagpur, India, 2022, pp. 200–205, https://doi.org/10.1109/ICETEMS56252.2022.10093622.

[16] A. Sabo, N. I. Abdul Wahab, M. L. Othman, M. Z. A. Mohd Jaffar, H. Beiranvand, and H. Acikgoz, "Application of a neuro-fuzzy controller for single machine infinite bus power system to damp low-frequency oscillations," *Transactions of the Institute of Measurement and Control*, vol. 43, no. 16, pp. 3633–3646, Dec. 2021, https://doi.org/10.1177/01423312211042781.

[17] W. Du, W. Dong, Y. Wang, and H. Wang, "A Method to Design Power System Stabilizers in a Multi-Machine Power System Based on Single-Machine Infinite-Bus System Model," *IEEE Transactions on Power Systems*, vol. 36, no. 4, pp. 3475–3486, Jul. 2021, https://doi.org/10.1109/TPWRS.2020.3041037.

[18] T. K. Roy, M. A. Mahmud, W. X. Shen, and A. M. T. Oo, "An Adaptive Partial Feedback Linearizing Control Scheme: An Application to a Single Machine Infinite Bus System," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 67, no. 11, pp. 2557–2561, Nov. 2020, https://doi.org/10.1109/TCSII.2019.2962098.

[19] V. P. Rajderkar and V. K. Chandrakar, "Design Coordination of a Fuzzy-based Unified Power Flow Controller with Hybrid Energy Storage for Enriching Power System Dynamics," *Engineering, Technology & Applied Science Research*, vol. 13, no. 1, pp. 10027–10032, Feb. 2023, https://doi.org/10.48084/etasr.5508.

[20] A. M. Hasan, Md. R. Islam, M. Shafiullah, and M. B. Uddin, "Multi-Verse Optimizer for LFO Damping in Single Machine Infinite Bus Power Networks," in *2022 International Conference on Advancement in Electrical and Electronic Engineering*, Gazipur, Bangladesh, 2022, pp. 1–6, https://doi.org/10.1109/ICAEEE54957.2022.9836356.

[21] B. Dhouib, M. A. Zdiri, Z. Alaas, and H. H. Abdallah, "Analyzing the Effects of MBPSS on the Transit Stability and High-Level Integration of Wind Farms during Fault Conditions," *Engineering, Technology & Applied Science Research*, vol. 13, no. 3, pp. 10652–10658, Jun. 2023, https://doi.org/10.48084/etasr.5838.

[22] L. Ling, X. Wenzheng, and X. Haodong, "Adaptive Backstepping Nonsingular Fast Terminal Sliding Mode Control for Three-dimensional Single Machine Infinite Bus System," in *2021 IEEE 4th International Electrical and Energy Conference*, Wuhan, China, 2021, pp. 1–6, https://doi.org/10.1109/CIEEC50170.2021.9510605.

[23] M. A. H. Pramanik, T. K. Roy, S. K. Ghosh, M. S. Anower, and M. A. Mahmud, "An Advanced Excitation Control Scheme for a Synchronous Generator in a Single Machine Infinite Bus System Based on Detailed Dynamical Models," in *2020 IEEE International Conference on Power Electronics, Drives and Energy Systems*, Jaipur, India, 2020, pp. 1–6, https://doi.org/10.1109/PEDES49360.2020.9379338.

[24] S. Song, X. Hou, and J. He, "Adaptive Forwarding Output Feedback Control for Single Machine Infinite Bus System," in *2021 China Automation Congress*, Beijing, China, 2021, pp. 6702–6707, https://doi.org/10.1109/CAC53003.2021.9728585.

[25] S. Keskes, S. Salleem, L. Chrifi-Alaoui, and M. B. Ali Kammoun, "Nonlinear Coordinated Passivation Control of Single Machine Infinite Bus Power System with Static Var Compensator," *Journal of Modern Power Systems and Clean Energy*, vol. 9, no. 6, pp. 1557–1565, Nov. 2021, https://doi.org/10.35833/MPCE.2019.000173.

[26] S. V. Kumbhar and V. P. Mohale, "Comparative Study of the Effect of Power System Stabilizer on a Single Machine Infinite Bus," in *2020 International Conference on Smart Electronics and Communication*, Trichy, India, 2020, pp. 1288–1292, https://doi.org/10.1109/ICOSEC49089.2020.9215325.

[27] T. S. Joyeeta, T. K. Roy, and Md. R. I. Sheikh, "Design of a Nonlinear Excitation Controller for Single Machine Infinite Bus Power Systems to Improve the Tr9ansient Stability," in *2021 International Conference on Automation, Control and Mechatronics for Industry 4.0*, Rajshahi, Bangladesh, 2021, pp. 1–5, https://doi.org/10.1109/ACMI53878.2021.9528164.

[28] A. Yu and A. Townsend, "Leveraging the Hankel norm approximation and data-driven algorithms in reduced order modeling," *Numerical Linear Algebra with Applications*, vol. 31, no. 4, Aug. 2024, Art. no. e2555, https://doi.org/10.1002/nla.2555.

[29] A. Yu and A. Townsend, "Leveraging the Hankel norm approximation and block-AAA algorithms in reduced order modeling." arXiv, Apr. 07, 2023, https://doi.org/10.48550/arXiv.2304.03813.

[30] S. Muntwiler, O. Stanojev, A. Zanelli, G. Hug, and M. N. Zeilinger, "A stiffness-oriented model order reduction method for low-inertia power systems," *Electric Power Systems Research*, vol. 235, Oct. 2024, Art. no. 110630, https://doi.org/10.1016/j.epsr.2024.110630.

[31] D. K. Sambariya and R. Prasad, "Stable reduced model of a single machine infinite bus power system with power system stabilizer," in *2013 International Conference on Advances in Technology and Engineering*, Mumbai, India, 2013, pp. 1–10, https://doi.org/10.1109/ICAdTE.2013.6524763.

[32] V. P. Singh, V. P. Meena, U. K. Yadav, A. Mathur, and N. Barwar, "Order Reduction of Single-Machine-Infinite-Bus System by Utilizing Markov Parameters, Time Moments and Routh Array," *Journal of Control, Automation and Electrical Systems*, vol. 35, no. 1, pp. 105–115, Feb. 2024, https://doi.org/10.1007/s40313-023-01049-7.