DOI: 10.35382/TVUJS.14.8.2024.97

ANALYSIS OF POWER SYSTEM STABILITY AT DUYEN HAI THERMAL POWER PLANT, VIETNAM

Nguyen Ngoc Tien[1], Phan The Hieu[2*], Le Thanh Tung[3]

Abstract – *When the power system operates, instability will cause political, technical, and economic damage. Therefore, analyzing the dynamic stability of the system is extremely important. The power system can recover to its original state and achieve static stability if appropriate operating methods are applied for each situation when an incident occurs, such as isolating the fault point, shedding loads, and adjusting the generator excitation. The paper uses MATLAB Simulink to simulate the process before and after the incident to restore the power system to its stable state. The results evaluate the fluctuations in the generator speed, the generator's electromagnetic moment, and the power deviation angle. At that time, the parameters of the power system, including voltage, current, power, and frequency, may fluctuate. The oscillation level depends on several parameters, such as location and time. Therefore, the above parameters can affect the power quality, causing damage to the equipment. In this article, MATLAB Simulink is used to simulate the states to propose measures to stabilize the power system when the Duyen Hai Thermal Power Plant operates and combines the use of SCADA system to control, monitor, and collect operational data to increase the reliability of power supply.*

Keywords: Duyen Hai Thermal Power Plant, stability of power system, static stability, the transient states.

I. INTRODUCTION

As the power transmission grid expands to meet growing electricity demand, its complexity increases, making stability analysis a top priority. Ensuring power plants' safe, efficient, and reliable operation, mainly Duyen Hai Thermal Power Plant, requires continuous monitoring and assessment. In power system studies, the rotational equations of multiple generators are often simplified into an equivalent single-generator system connected to various bus bars to facilitate stability analysis. Power system stability refers to the ability of the system to maintain equilibrium under normal conditions and return to a stable state after disturbances. Instabilities, such as fluctuations in generator output and load variations, can significantly impact system performance. Severe incidents, including short circuits on transmission lines, may lead to generator disconnection and system fragmentation, further emphasizing the need for stability assessment.

This study focuses on rotor angle stability, which determines the ability of synchronous machines to remain in synchronization. The nonlinear power-angle characteristic is a key factor in stability analysis, as excessive rotor angle deviations can cause instability and power transmission disruptions. Given the critical role of generators in national energy security and economic stability, their protection is essential. This research utilizes MATLAB Simulink to simulate disturbances and assess generator stability, aiming to develop effective protection measures. The study's scope includes analyzing key factors affecting stability, such as excitation control, oscillations, and voltage fluctuations, to enhance power system resilience. The results provide valuable insights for improving operational efficiency, reducing risks, and ensuring uninterrupted power supply.

[1,2,3]Tra Vinh University, Vietnam
*Corresponding author: thehieu@tvu.edu.vn
Received date: 06th July 2024; Revised date: 09th December 2024; Accepted date: 13th December 2024

II. LITERATURE REVIEW

A. *The power system of electricity*

The normal working mode of the generator is stable synchronous mode. The rotor speed and the stationary part rotating magnetic field are equal and equal to the synchronous speed thanks to the balance between mechanical and electric torque. Therefore, the magnetic field rotating the stationary part does not sweep through the rotor; only a one-way excitation current (no induced current) is in the rotor [1].

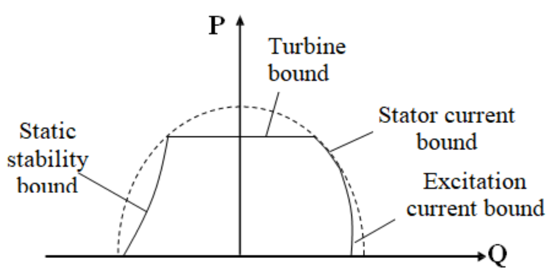

Fig. 1: Generator P – Q characteristic power [1]

The external characteristic of the generator usually refers to the curve of the voltage change when the load current changes under the voltage condition U = const. The internal reactance of the generator is an essential quantity of the synchronous generator under load, and the field coil and controller are used in the generator. Therefore, the synchronous reactance has a transient value much smaller than the steady-state value.

The external characteristics of the generator are designed to be able to change and adjust the excitation voltage within ±5%. In normal working mode, generator parameters such as active power, reactive power coefficients, stationery and armature currents, axial electromotive force, and generator terminal voltage change do not exceed the limits for standard work permits.

When the electrical system has small oscillations, such as a change in load, the balance between the turbine mechanical torque and electromagnetic torque of the generator is lost, and the generator changes speed. The speed control system of the generator works and changes the primary energy power, pulling the generator to the rated frequency. The ability to adjust depends on each unit and the primary reserve. The power system has a reactive power imbalance or a voltage fluctuation. The electrical generator can generate or consume the reactive power by changing the value of the excitation current generator. Limits on the ability to transmit and consume reactive power are presented in Figure 2 [2].

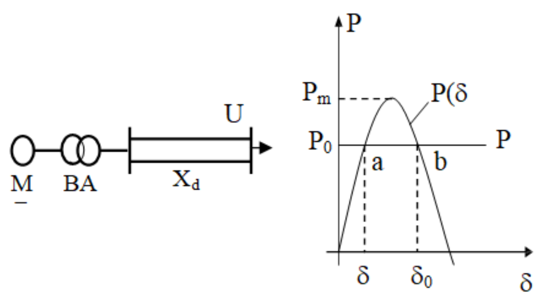

Fig. 2: The power system has an equilibrium [2]

The ability of a power system to recover depends on the static stability of the generator connected to the power system. The transient modes in the power system are intermediate modes that move from one steady state to another.

B. *Stability calculation method in power system*

The first stage is the analysis of the instantaneous dynamic stability, the load current, and the determination of the initial value of the voltage at the busbar, the phase angle. The machine's data (voltage, current, power, frequency, ...) before the fault is calculated from Formula (1).

$$I_i = \frac{\dot{S}_i}{\dot{V}_i} = \frac{P_i - jQ_i}{\dot{V}_i}\text{; i= 1, 2, 3, ..., m} \quad (1)$$

Where:

m is the number of generators.

V_i is the terminal voltage of the it generator.

P_i and Q_i are the generators of real and reactive powers.

The original power distribution solution provides a wealth of data. As the generator armature resistance has a negligible impact on the results, it is often ignored. Consequently, the electromotive force is calculated using Formula (2) [3].

$$\dot{E}_i = V_i - jX'_d I_i \quad (2)$$

All electrical loads are converted to the equivalent value by Formula (3).

$$y_{i0} = \frac{\dot{S}_i}{|\dot{V}_i|^2} = \frac{P_i - jQ_i}{|V_i|^2} \quad (3)$$

The instantaneous armature electromotive forces are added to the power system network into the m*n bus total voltage matrix. The equivalent circuit of all loads converted to a total conductance matrix is shown in Figure 3 [4].

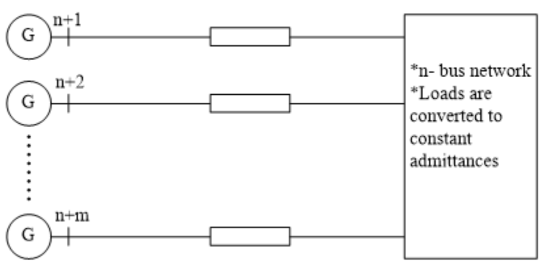

Fig. 3: Power and load of equivalent system [3]

Figure 3 illustrates the voltage matrix at the nodes n+1, n+2, . . ., n+m. For the convenience of analysis, all non-nodes at the main diagonal of the generator voltage matrix are eliminated by Kron expression [5]. To facilitate the calculation of the load buses, the matrix at the bus in Formula (4) is analyzed such that the n buses need to be simply eliminated at the auxiliary diagonals. According to Kirchhoff's 1^{st} law, 'Total current at a node is zero', Im is the generator current represented by the vector, and the generator electromotive force and the load are defined by the vectors E'm and Vn, respectively.

$$[I_1\, I_2\, \vdots\, I_n] = \begin{bmatrix} Y_{11}\, Y_{1n}\, Y_{21}\, Y_{2n} & Y_{1(n+1)}\, Y_{1(n+m)} \\ \cdots\ \cdots Y_{2(n+m)}\ \cdots\ \cdots & Y_{n1}\ \cdots \\ \cdots\ \cdots\ \cdots\ \cdots & Y_{n(n+m)} \end{bmatrix} [V_1\, V_2\, \vdots\, V_n] \quad (4)$$

From the branch currents and total inductance in Formula (4), the currents at the Buses can be found in Formula (5):

$$I_{bus} = Y_{bus} V_{bus} \quad (5)$$

Where:

I_{bus} is the vector of the current fed into the busbar;

V_{bus} is a bus voltage vector measured from a reference node.

The principal diagonal quantities of the voltage matrix at the bus are the sum of the voltages connected to the bus. Off-diagonal quantities are calculated by the negative value of the voltage at the nodes. Values of additional nodes are added to calculate the voltage behind the instantaneous impedances. In addition, the elements at the main diagonal are replaced for ease of calculation.

Then, in Formula (4), the voltage matrix becomes:

The network linearization Formula (5) can be represented using the total admittance matrix obtained from the energy balance equation as Formula (6).

$$[0 \quad I_m] = [Y_{nn}\, Y_{nm}\, Y_{nm}^t\, Y_{mm}][V_n\, E_m] \quad (6)$$

The following formulae can replace the voltage vector V_n.

The nonlinear system of node voltage equations, written as Formula (7), assumes that the currents at the nodes are constant and are determined by the initial value of the node voltage.

$$0 = Y_{nn} V_n + Y_{nm} E'_m \quad (7)$$

By solving Formula (7), the first approximate voltage values V1(1), V2(1), and V3(1) are obtained; according to the approximate node voltage values just found, we can calculate and get Formula (8).

$$I_m = Y_{nm}^t V_n + Y_{mm} E'_m \quad (8)$$

From Formula (8), at each iteration of the iterative process, the summation matrix of node voltages is determined according to Formula (9).

$$V_n = -Y_{nn}^{-1} Y_{nm} E'_m \quad (9)$$

Now, substituting into Formula (9) inferred: When calculating the mode for the power system, the current Im is equal to the algebraic sum of the currents marked at node m. Those currents have different signs depending on the source or load result Formula (10).

$$I_m = [Y_{mm} - Y_{nm}^t Y_{nn}^{-1} Y_{nm}]E'_m = E_{bus}^{red} E'_m \quad (10)$$

The reduced admittance matrix from Formulae (4) and (10) is:

The individual and mutual conduction matrix between nodes (called the node conduction matrix Formula (10) when connected to a node with m branches, Formula (11) is formed.

$$Y_{bus}^{red} = Y_{mm} - Y_{nm}^t Y_{nn}^{-1} Y_{nm} \quad (11)$$

The matrix at the nodes is a square matrix of size (m x m), where m is the number of generators.

The internal voltage of each generator is represented by the electrical output power of each generator: active power, reactive power, and apparent power [3]. The evident power of the generator at the generating nodes is calculated from Formula (6) to Formula (10).

$$\dot{S_{ei}} = \dot{E_i}\dot{I_i} \quad (12)$$

From Formula (12) and the power deviation angle, the active power is found in Formula (13).

$$\dot{P_{ei}} = Re\dot{E_i}\dot{I_i} \quad (13)$$

Where Formulae (12) and (13) the current of the generating branches Formula (14) is calculated from the total conductance matrix and the electromotive force of the generator shows the voltage across the generator terminals.

$$I_i = \sum_{i=1}^{m} Re\, E_j Y_{ij} \quad (14)$$

By substituting Ii into Formula (12), the generator's electromotive force, its value depends on Ed; Eq and the power angle as in Formula (15):

$$E'_i = |E'_i|\angle\delta_i \text{ and } Y_{ij} = |Y_{ij}|\angle\theta_{ij} \quad (15)$$

From Formula (15) and the characteristics of the generator load at each node and the power angle of the load, the active power is calculated as in Formula (16).

$$P_{ei} = \sum_{j=1}^{m} |E'_i||E'_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (16)$$

The system of equations above indicates that the current is fluctuating. The dynamic stabilization of the system is achieved by adjusting the mechanical input power from the turbine and the output power. According to Formula (16), the generator's oscillation depends on various factors, including load and battery capacity. This relationship is further illustrated in Formula (17).

$$P_{mi} = \sum_{j=1}^{m} |E'_i||E'_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (17)$$

The team studies transient stability following the traditional method based on the application when a three-phase short circuit occurs. When a three-phase short circuit occurs at bus k in the transmission power system, resulting in $V_k = 0$. Then, this fault state is simulated by removing the extra diagonals from the voltage matrix. When creating a new matrix, only the elements on the matrix's main diagonal for calculation (discarding all the sub-diagonals) are kept. To facilitate the calculation, the elements on the minor diagonals were removed. The excitation voltage of the generator in the pre-fault and post-fault modes is constant. The capacity of the i^{th} generator according to the total conduction matrix oscillates at the bus decreases (shown in Formulae (14) and (17)). Ignoring the oscillation equation with reduced oscillation, for the generator i inferred:

For generators, the moment of inertia significantly determines the rotational speed, acceleration ability, and power angle. Depending on the distribution of nodes, it contributes considerably to the system's stability as Formula (18).

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} = P_{mi} - \sum_{j=1}^{m} |E'_i||E'_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (18)$$

In there: Y_{ij} are the elements of the summation matrix at the fault bus. Hi is the generator inertia constant i expressed over the generator's apparent power (MVA).

If the mutual inductance of the i generator (H_{Gi}) is its constant of inertia expressed on the H_{Gi} generator (MVA), then H_i is formulated as Formula (19).

The inertia constant is an important parameter when designing and operating a generator. By understanding the factors that affect the inertia constant, we can optimize the generator's performance and reliability, as shown in Formula (19).

$$H_i = \frac{S_{Gi}}{S_{cb}} H_{Gi} \qquad (19)$$

When the active power of generator i is replaced by input P_{ei}^f in Formula (16), the mechanical characteristics of the driving generator affect the speed control (slip) of the generator, the mechanical power of the turbine, and the electrical power of the generator, as shown in Formula (20).

$$\frac{d\delta_i}{dt} = \Delta\omega_i$$
$$\frac{d\Delta\omega_i}{dt} = \frac{\pi f_0}{H_i}(P_{mi} - P_{ei}^f) \qquad (20)$$

When analyzing the problem of instantaneous stability of the generator system, each generator has two formulae of the state that are applied to calculate the oscillation of the power system with many units. When the problem is fixed, it is solved by isolating the faulty line. Then, the voltage matrix at the buses is reanalyzed to accommodate the disturbance of the power system. Furthermore, the voltage matrix at the buses will reduce the voltage fluctuations and adjust the system parameters after the failure of the ith generator is calculated P_{ei}^f by Formula (14).

By using the active power of the system after the P_{ei}^f fault, the simulation results calculate the stable stability of the power system from the unstable state until the steady state is reached. Usually, the delay generator is chosen as the reference machine plotted on the graph. The simulation algorithm is commonly applied to the two unstable states and the steady state to demonstrate that when the system is in a constant state, the value is less than the unstable state of the system under consideration. If the rotor speed does not change, the system is steady. Conversely, when the rotor speed changes, the system becomes unstable.

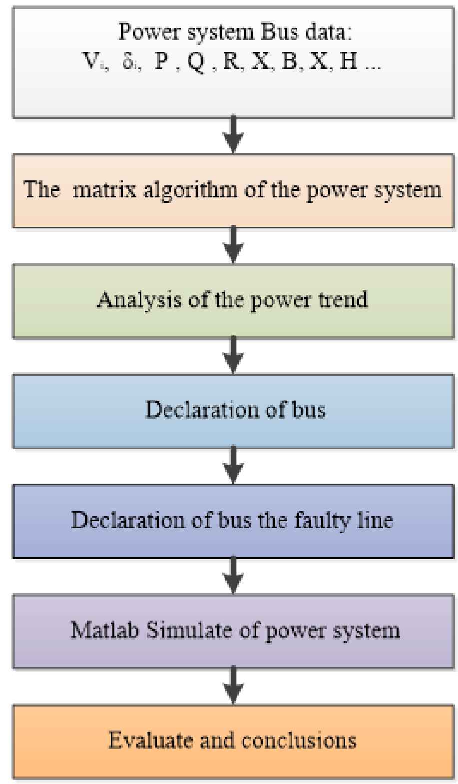

Fig. 4: Flowchart to calculate the stability of multi-generator power system [5]

III. RESEARCH METHODS

A. Using MATLAB Simulink power system stability

The following factors are implemented to simplify the process of investigating the stability of the power system. First, the synchronous machine is replaced by a constant DC voltage source behind the axial transient reactance. Besides, the input power is steady, and the governor operation is ignored during the simulation. Furthermore, the voltage at the bus is fixed, and the electrical loads are regulated to the equivalent and constant inductance. Moreover, noise and variable asynchronous loads are not considered. In addition, the rotor rotation speed of each machine is in phase with the voltage applied on the axial and transverse reactance of the generator. In the same unit, the rotors will move together and are said to be synchronous. A group of machines linked together is converted into one machine.

MATLAB is a large set of software programs in numerical mathematics. The name of the main program is an abbreviation for MATrix LABoratory, showing that the primary orientation of the program is to calculate vectors and matrices. The program's core includes several math functions, input/output functions, and cycle control capabilities by which scripts can be built.

Simulink is a Toolbox with a key role as a powerful tool for modeling and simulating Engineering - Physics systems based on block structure diagrams. The Stateflow Blockset tool is available in MATLAB Simulink to model and simulate elements in a finite state system.

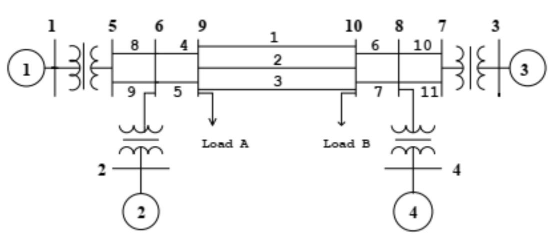

Fig. 5: Model of four generators

Based on the flowchart in Figure 5, MATLAB software simulates the system's operation. Simulation allows us to analyze the instantaneous stability of the power system with many faulty machines, leading to phase differences (3-phase faults). Simulation software requires the user to enter the correct bus values and fault lines must be calculated. The rotor deflection angles of each phase must be considered and plotted when simulating each quantity to be investigated by the generator. Simulation results are repeated many times to determine the critical steady state with the survey time from unstable to steady state.

B. The Southern Vietnam power system

The objective of the survey is to analyze the transient problem applied to the actual system of 500 kV, 220 kV, and 110 kV at Duyen Hai 1 Thermal Power Plant [4].

Table 1: Analysis results summary for Southern Vietnam power system

Content	Number of branches	Specifications	Length (km)
Duyen Hai–Tra Vinh	4	(2×AC500 + 2×AC400) mm^2	50
Vinh Long–Cai Lay	2	2 × AC400 mm^2	35
Tra Vinh–Mo Cay	2	2 × AC500 mm^2	40
Mo Cay–Ben Tre	2	2 × AC400 mm^2	15
My Tho 1–Ben Tre	2	2 × AC330 mm^2	16
Duyen Hai–Mo Cay	2	4 × AC400 mm^2	80

Source: Author's summary [4, 6, 7]

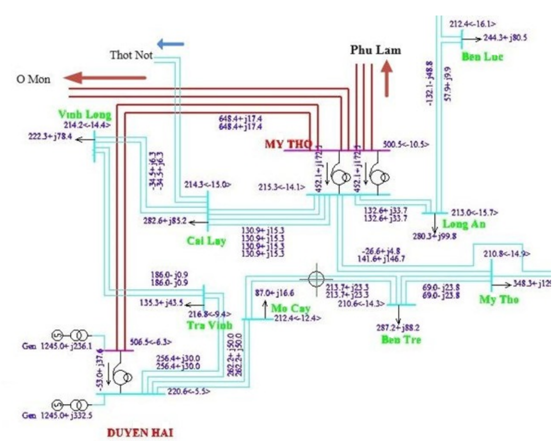

Fig. 6: Electrical system of Duyen Hai Thermal Power Plant, Tra Vinh Province [7]

By using electrical blocks in the Simulink library browser, the simulation model is performed as in Figure 7.

IV. RESULTS AND DISCUSSION

In Figure 7, the system consists of four generators. Bus 4 has the most significant impact on the system under consideration through the power distribution analysis process. When Generator 4 has a problem, the system is affected. Therefore, the following cases must be considered: transverse electromotive force, transverse axial

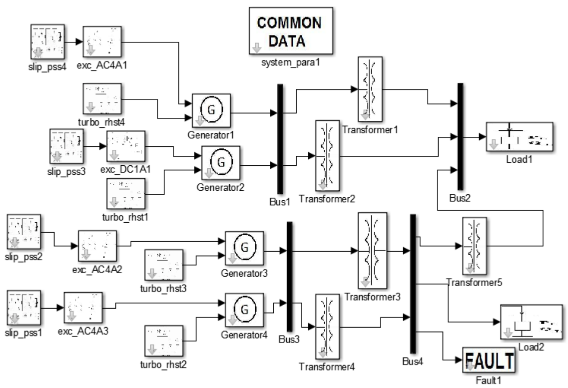

Fig. 7: MATLAB simulation [8]

force, the Generator 4 slip, voltage at Bus 4, and generator rotor deflection angle.

In the case of transverse electromotive force

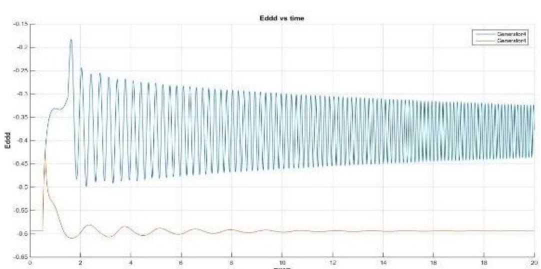

Fig. 8: Transverse electromotive force of Generator 4

Figure 8 shows that at the time of the incident at Bus 4 (Tra Vinh), the rotor angle fluctuation of Generator 4 was affected the most compared to other generators. The transverse electromotive force of Generator 4 is stable at cut-off time t = 0.1 s and unstable at cut-off time t = 1.0 s.

In the case of transverse axial force

Figure 9 shows that at the time of the incident at Bus 4 (Tra Vinh), the rotor angle fluctuation of Generator 4 was affected the most compared to other generators. The axial electromotive force of Generator 4 is stable at cut-off time t = 0.1 s and unstable at cut-off time t = 1.0 s.

In the case of Generator 4 slip

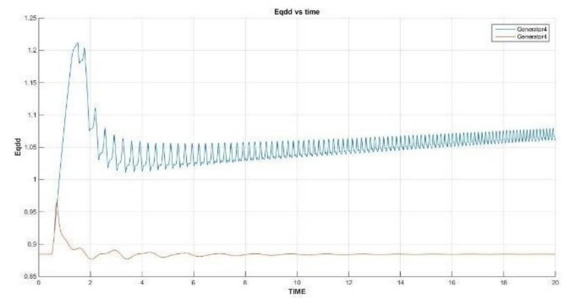

Fig. 9: Axial electromotive force of Generator 4

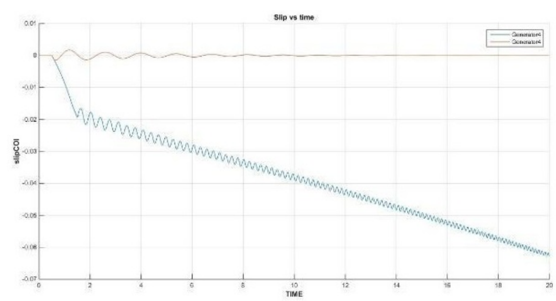

Fig. 10: Generator 4 slip

Figure 10 shows that at the time of the incident at Bus 4 (Tra Vinh), the rotor slip (speed) fluctuation of Generator 4 was affected the most compared to other generators. At that time, the speed of Generator 4 is stable at cut-off time t = 0.1 s and unstable at cut-off time t = 1.0 s.

In the case of voltage at Bus 4

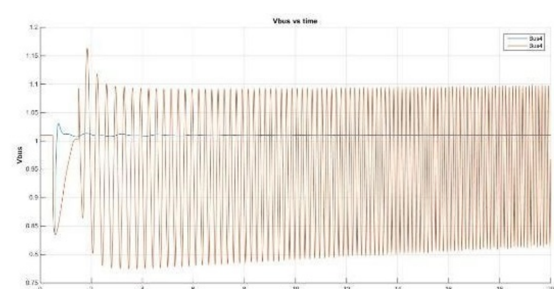

Fig. 11: Voltage at Bus 4

Figure 11 shows the simulation results that at the time of the incident at Bus 4 (Tra Vinh), the voltage at Bus 4 was affected the most compared to other busbars. Then, the voltage at Bus 4 is stable at cutoff time t = 0.1 s and unstable at cutoff time t = 1.0 s.

In case of generator rotor deflection angle

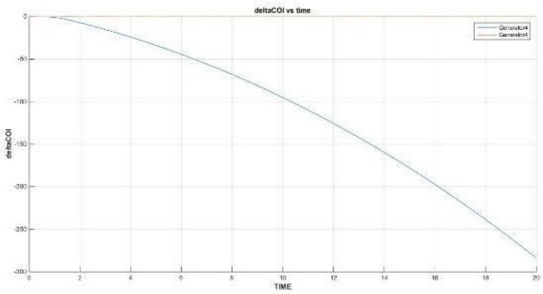

Fig. 12: Generator rotor deflection angle

Figure 12 shows the simulation results at the time of the incident at Bus 4 (Tra Vinh); the rotor deflection angle of Generator 4 is most affected compared to other generators. Then, the rotor deflection angle of Generator 4 is stable at cutting time t = 0.1 s and unstable at cutting time t = 1.0 s.

Through simulation and analysis, several key factors must be considered for the stable operation of the power system. Firstly, generator speed during disturbances is a critical parameter that requires continuous monitoring and control. Previous studies [5, 9] have emphasized the impact of speed fluctuations on system stability, and this research's findings confirm that analyzing factors affecting generator speed helps ensure safe operation. Secondly, adjusting the generator excitation is an effective method for restoring stability. However, as noted in earlier research [10], improper excitation control can lead to further instability. This paper supports this, highlighting the need for precise and careful excitation adjustments to maintain system reliability.

Additionally, generator oscillations can negatively affect power system stability, leading to rotor slip and efficiency losses. Previous studies [11, 12] have shown that identifying and mitigating oscillations can enhance system performance. The simulation results in this study align with these findings, demonstrating that diagnosing oscillation types is essential for implementing effective corrective measures. Furthermore, generator voltage fluctuations are well-documented often leading to instability and deterioration of power quality. The research results reinforce earlier studies' conclusions, confirming that promptly addressing voltage variations is crucial for maintaining system performance.

Finally, power angle is a vital parameter influencing generator performance. Prior research, such as Kundur (1994) [5], has established its role in system stability, and our findings further validate that understanding power angle dynamics is essential for assessing performance and implementing corrective measures. To ensure regular system operation, it is necessary to detect disturbances within t = 0.1 s and resolve them within t = 1.0 s [9]. In summary, MATLAB-based simulations of generator failures provide a valuable tool for evaluating system stability and resilience.

V. CONCLUSION

Considering a direct 3-phase fault between the 220 kV Duyen Hai - Tra Vinh line (Bus 4), the system will be stable at the time of cutting t = 0.1 s. If it is maintained greater than t = 1.0 s, the system will become unstable, as shown in the simulation results above.

When a fault occurs on Bus 4 in the system under consideration, the voltage will decrease. The stability of the load node mainly considers voltage stability, that is, calculating the ability to restore the system to avoid voltage collapse.

The stability of the system at Bus 4 will be determined by evaluating parameters such as the relative phase shift between the electromotive force, the speed of the generator, the excitation current of the generator, the slip of the generator, the grid voltage, and the power angle of the frequency generator of the system. In the scope of this article, only large-capacity generators connected to the Duyen Hai – Tra Vinh line in the power system at voltage levels of 500 kV, 220 kV, and 110 kV will be affected. The unit models for reporting are fully equipped with excitation systems, speed control systems, and power balance systems. The models of future units are referenced from the models of existing units of the same type and capacity of generators; for units without reference, the models are taken from the manufacturer's parameters or the IEEE model.

REFERENCES

[1] La Van Ut. *Analysis and control stability for power system [Phân tích và điều khiển ổn định hệ thống điện]*. Hanoi: Science and Technics Publishing House; 2000.

[2] Ho Van Hien. *Transmission and distribution of power system [Hệ thống truyền tải và phân phối điện]*. Ho Chi Minh City: Viet Nam National University Ho Chi Minh City Press; 2003.

[3] Saadat H. *Power system analysis*. United States of America: McGraw-Hill; 1999.

[4] Duyen Hai Thermal Power Plant 1, 2, 3. *Equipment specifications [Thông số kỹ thuật của thiết bị]*. Tra Vinh, Vietnam: Duyen Hai Thermal Power Plant; 2014.

[5] Kundur P. *Power system stability and control*. United States of America: McGraw-Hill; 1994.

[6] Prime Minister of Vietnam. *The approval of revisions to the national power development plan from 2011 to 2020 with visions extended to 2030 [Phê duyệt điều chỉnh Quy hoạch phát triển điện lực quốc gia giai đoạn 2011–2020 có xét đến 2030]*. Hanoi: Prime Minister. Decision No. 428/QD-TTg, 2016.

[7] Ministry of Industry and Trade of Vietnam. *Electricity planning in the Mekong Delta until 2020, orientation to 2025 [Quy hoạch phát triển điện lực vùng Đồng bằng sông Cửu Long đến năm 2020, tầm nhìn đến năm 2025]*. Hanoi: Ministry of Industry and Trade. Decision No. 8054/QD-BCT, 2012.

[8] Nguyen Thoi Trung. *Finite element method using MATLAB [Phương pháp phần tử hữu hạn sử dụng MATLAB]*. Hanoi: Construction Publishing House; 2015.

[9] Anderson PM, Fouad AA. *Power system dynamics and stability*. Wiley-IEEE Press; 2002.

[10] Sauer PW, Pai MA. *Power system dynamics: stability and control*. Prentice Hall; 1998.

[11] Machowski J, Bialek JW, Bumby JR. *Power system dynamics: stability and control*. John Wiley & Sons; 2008.

[12] IEEE Power & Energy Society. *IEEE guide for synchronous generator modeling practices and parameter verification with applications in power system stability analyses*. IEEE; 2010.