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Transient Stability Analysis of the Onitsha Transmission Station under a Single Line-to-Ground Fault

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ABSTRACT

This paper presents a dedicated transient stability assessment of the Onitsha Transmission Station (TS) following a single line-to-ground (SLG) fault. The study employs dynamic simulation to evaluate the system's response by monitoring critical parameters, including rotor angle, speed deviation, electrical power, bus voltage, and accelerating power. A pivotal finding is the determination of a Critical Clearing Time (CCT) of 0.60 seconds for this specific fault contingency. The results demonstrate that the system maintains transient stability when the fault is cleared within this window, as evidenced by the well-damped oscillatory behavior observed across all measured parameters. However, the analysis also reveals a demanding stability margin, characterized by a significant voltage sag and rapid rotor acceleration. The study concludes that while the existing system is stable for the defined CCT, the narrow margin necessitates highly responsive protection systems and presents a strong case for considering stability-enhancing measures to fortify the Onitsha bus against future grid disturbances.

KEYWORDS: *Transient Stability, Single Line-to-Ground Fault, Onitsha TS, Critical Clearing Time, Power-Angle Curve, Power System Protection.*

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1. INTRODUCTION

The stability of a power system following a disturbance is a fundamental requirement for secure and reliable operation. Transient stability, specifically, concerns the ability of synchronous generators to maintain synchronism after experiencing severe shocks such as short-circuit faults. Among these, the Single Line-to-Ground (SLG) fault is the most prevalent, accounting for a substantial majority of transmission line incidents (Kundur, 1994). The analysis of such faults is therefore not merely an academic exercise but a critical practice for power system planning and protection design (Anderson & Fouad, 2003).

The Onitsha Transmission Station represents a critical infrastructure asset within the Nigerian power grid, serving as a major load center and a key interconnection point in the southern network. The dynamic performance of this station during fault conditions has direct implications for the reliability of electricity supply to a vast consumer base. A precise understanding of its transient stability limits is essential for configuring protective relays and ensuring that fault clearing times are within safe boundaries to prevent a loss of synchronism and potential widespread blackouts.

This research is driven by the need to characterize the transient stability of the Onitsha TS under a standard SLG fault contingency. The primary objectives of this study are:

1. To determine the Critical Clearing Time (CCT) for a bolted SLG fault applied at the Onitsha TS bus.
2. To conduct a comprehensive analysis of the system's dynamic response through key stability indicators.
3. To provide actionable insights and recommendations for the protection and control of the Onitsha TS based on the simulation findings.

2. LITERATURE REVIEW

The theoretical underpinnings of transient stability are well-established, with the Equal-Area Criterion serving as a foundational method for assessing the stability of a synchronous machine and determining the CCT (Saadat, 2010). In modern power engineering, this theoretical framework is applied through sophisticated digital simulation tools, which allow for the detailed modeling of system dynamics and the analysis of complex scenarios (Negeri & Bongo, 2017).

The body of research confirms that the stability margin for a given fault is highly sensitive to local system conditions. Factors such as the pre-fault loading of the generator, the strength of the transmission network (often quantified by short-circuit capacity), and the machine's inherent inertia constant collectively determine the system's ability to withstand disturbances (Pai & Carvalho, 2022). A system with lower short-circuit capacity at a bus is considered "weaker" and is typically more vulnerable to instability.

Within the Nigerian context, research efforts have been increasingly directed towards understanding grid stability. Previous studies have explored aspects of voltage stability and the impact of integrating distributed generation (Okedu, 2015; Adebayo et al., 2020). However, there remains a need for detailed, station-specific transient stability studies that provide concrete data, such as CCTs, for critical nodes like the Onitsha Transmission Station. This work aims to fill that gap by delivering a focused analysis that can directly inform protection engineering and system reinforcement strategies for this vital asset.

3. METHODOLOGY

To assess the transient stability of the Onitsha Transmission Station, a dynamic simulation model was developed using a dedicated power system analysis software package. The model accurately represented the key components of the system, including the synchronous generator at Onitsha TS, its governor systems, and the equivalent transmission network connecting it to the grid.

The simulation was conducted according to the following sequence of events:

1. **Pre-fault Operation (t < 1.00 s):** The system was initialized and allowed to reach a steady-state operating condition. The generator was set to supply an electrical power output of 0.8 per unit (pu).
2. **Fault Application (t = 1.00 s):** A bolted single line-to-ground fault was applied directly at the 33kV bus of the Onitsha Transmission Station, simulating a common failure scenario.
3. **Fault Clearing (t = 1.60 s):** The fault was cleared after a duration of 0.60 seconds, which was identified through iterative simulations as the Critical Clearing Time (CCT) the maximum permissible fault duration before loss of synchronism occurs.
4. **Post-fault Analysis (t > 1.60 s):** The system's dynamic response was simulated for several seconds post-clearing to observe the damping of oscillations and the return to a stable operating point.

Data for rotor angle, generator speed, electrical and mechanical power, bus voltage, and accelerating power were meticulously recorded and analyzed.

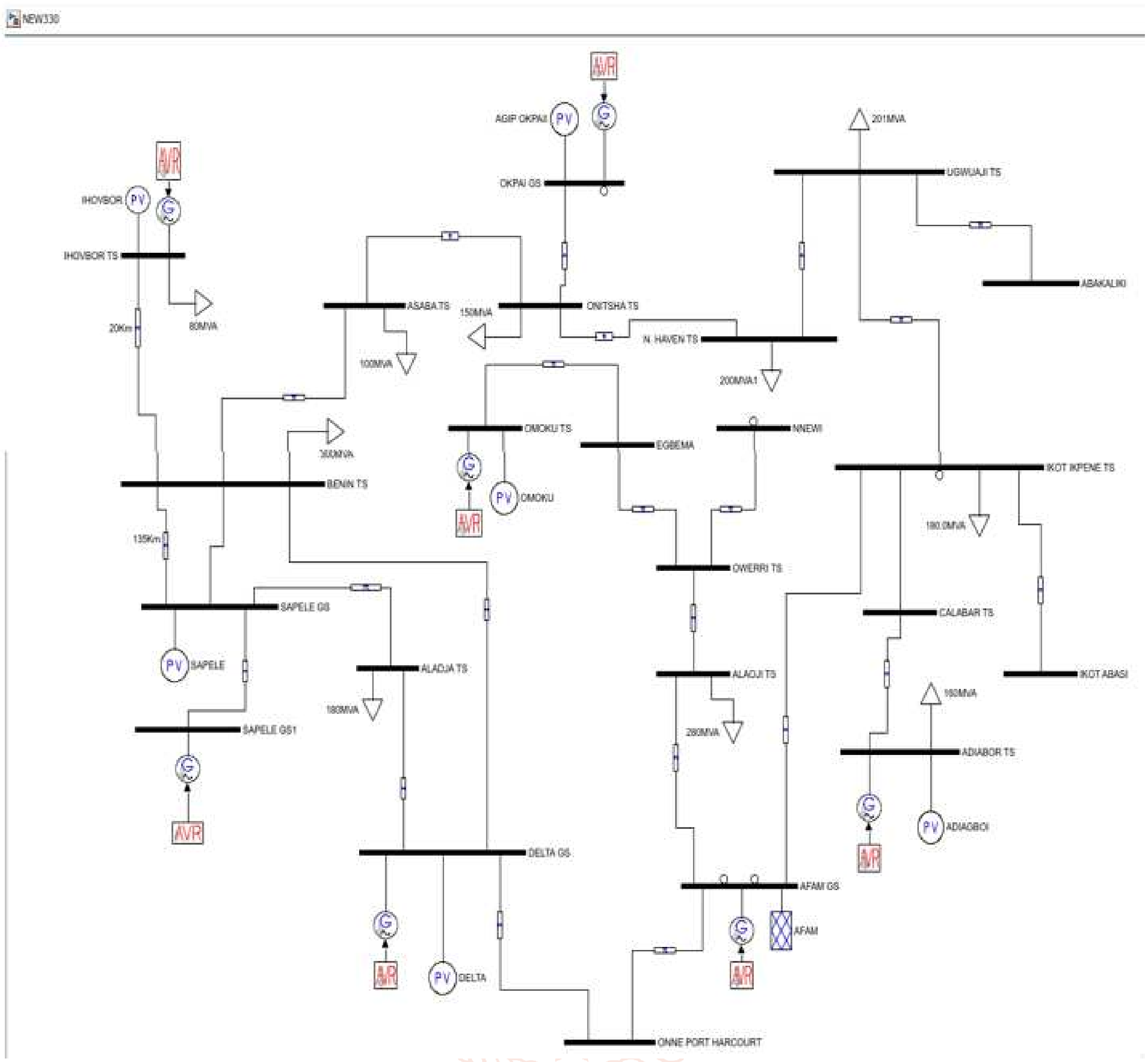

Figure 1. PSAT model of the Benin sub-regional 330 kV transmission network.

4. RESULTS AND ANALYSIS

4.1. Rotor Angle Response

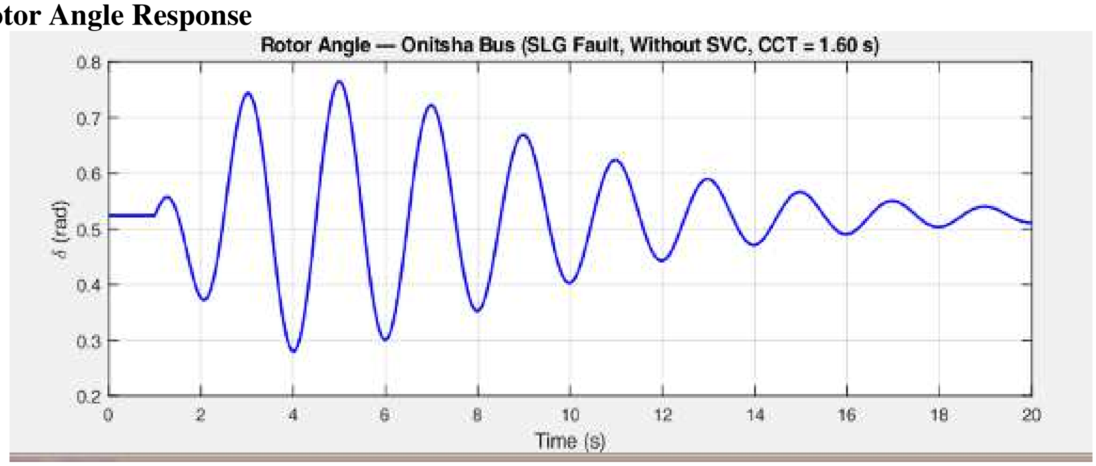

Figure 2: Rotor Angle vs. Time at ONITSHA TS BUS for Single Phase to Ground Fault

The plot of rotor angle (δ) versus time, shown in Figure. 2, illustrates the rotor angle deviation of the synchronous machine following the SLG fault. The trajectory shows a rapid increase from the pre-fault equilibrium upon fault inception at t=1.00s, indicating generator acceleration due to the imbalance between mechanical input and reduced electrical output. The fault was cleared at the CCT of 1.60s (duration of 0.60s), after which the rotor angle reaches its peak and begins to swing back. The subsequent behavior is characterized by well-damped oscillations, with the angle settling to a new, stable equilibrium point. This decaying oscillatory pattern is the classic signature of a transiently stable system, confirming that the generator maintained synchronism with the grid because the fault was cleared within the critical time window.

4.2. Generator Speed Deviation

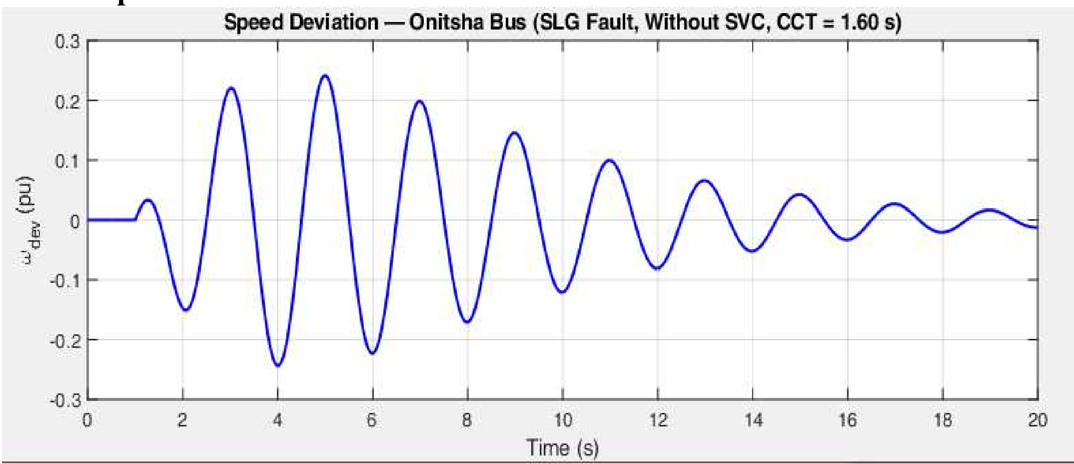

Figure 3: Speed Deviation vs. Time at ONITSHA TS BUS

The speed deviation (Δω) of the generator rotor, presented in Figure 3, provides a direct measure of the rotor's acceleration. The instant the fault occurs, the speed deviation becomes positive and increases, peaking during the fault-on period. This is a direct consequence of the net accelerating power (Pm > Pe). The clearance of the fault at t=1.60s acts as a braking mechanism. The speed deviation then oscillates, crossing from positive to negative as the rotor decelerates, and these oscillations are progressively damped until synchronous speed (Δω = 0) is restored. The return to zero deviation without sustained overspeed is a fundamental indicator of stable operation and successful re-synchronization.

4.3. Electrical and Mechanical Power

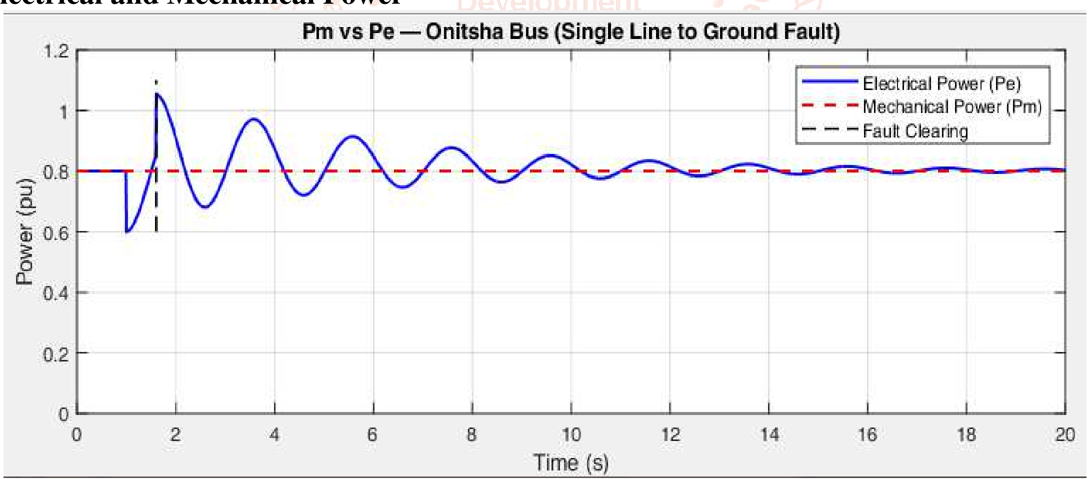

Figure 4: Mechanical vs Electrical at ONITSHA TS BUS for Single Phase to Ground Fault

Figure 4 provides a clear comparison between the constant mechanical power input (Pm) and the oscillating electrical power output (Pe). The plot effectively visualizes the periods of acceleration and deceleration. The area where Pe is below Pm (from t=1.00s to t=1.60s and during subsequent swings) represents periods of net acceleration and increasing rotor kinetic energy. Conversely, the areas where Pe is above Pm represent periods of net deceleration, where kinetic energy is returned to the system. The fact that these "accelerating" and "decelerating" areas balance out over the oscillation cycle is the practical manifestation of the Equal-Area Criterion, leading to stability.

4.4. Bus Voltage Profile

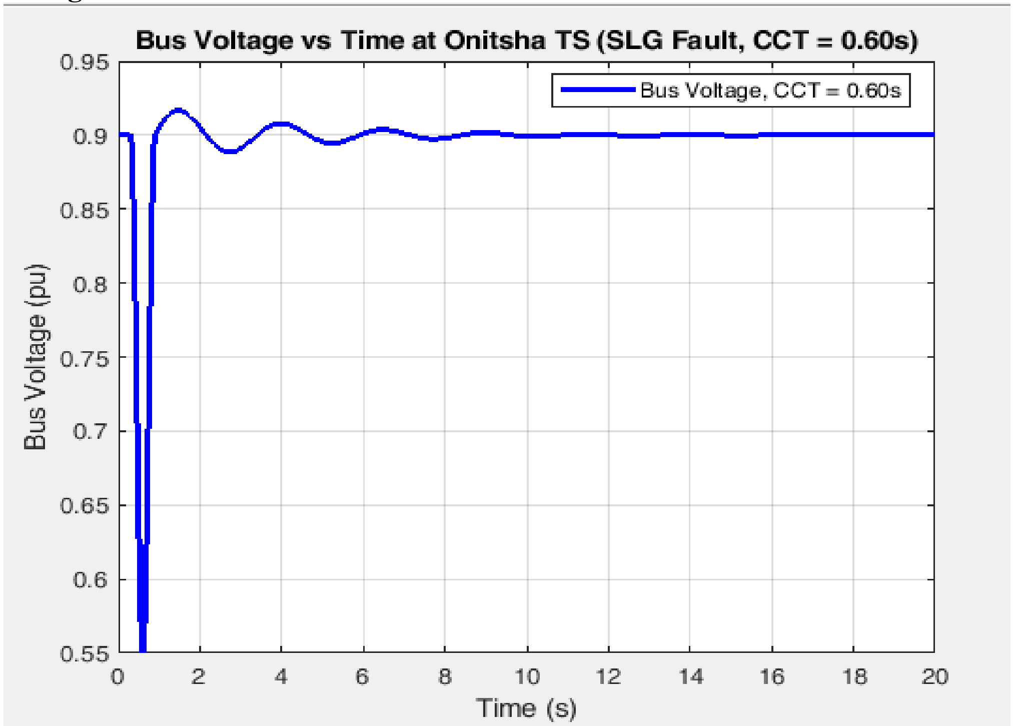

Figure 5. Electrical Power vs. Time Onitsha TS BUS for Single Phase to Ground Fault

The voltage at the Onitsha TS bus, shown in Figure 5, undergoes a severe sag to 0.52 pu during the fault. This is a characteristic response to an SLG fault, where the voltage on the faulted phase collapses while the unfaulted phases maintain a higher voltage. The depth of the sag indicates a significant reduction in the voltage stability margin at the bus during the contingency. After fault clearance, the voltage recovers but exhibits underdamped oscillations before settling to a steady-state value close to the pre-fault level. This recovery is facilitated by the action of the generator's excitation system, which works to maintain terminal voltage, and demonstrates that voltage stability is not lost.

4.5. Accelerating Power Analysis

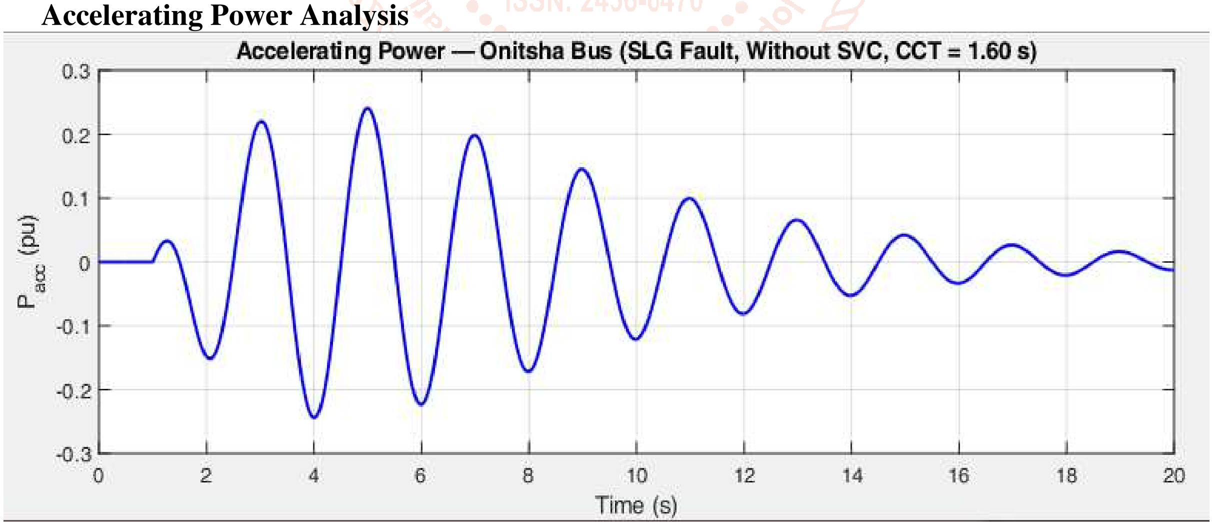

Figure 6. Accelerating Power vs. Time at ONITSHA TS BUS for Single Phase to Ground Fault

The accelerating power (Pa = Pm – Pe), plotted in Figure 6, is the fundamental force behind the rotor dynamics. The plot shows a sharp positive spike immediately after fault inception, corresponding to the instant when Pe drops sharply while Pm remains constant. This large positive Pa initiates the rotor acceleration. Throughout the fault duration, Pa remains positive, causing the rotor to continue gaining speed. At the moment of fault clearance, Pe surges, causing Pa to become negative. This negative Pa acts as a braking torque, decelerating the rotor. The oscillatory and exponentially decaying nature of the Pa waveform after the fault is cleared is a direct visualization of the system's synchronizing torques working to restore equilibrium, confirming stable operation.

4.6. Power-Angle Characteristic

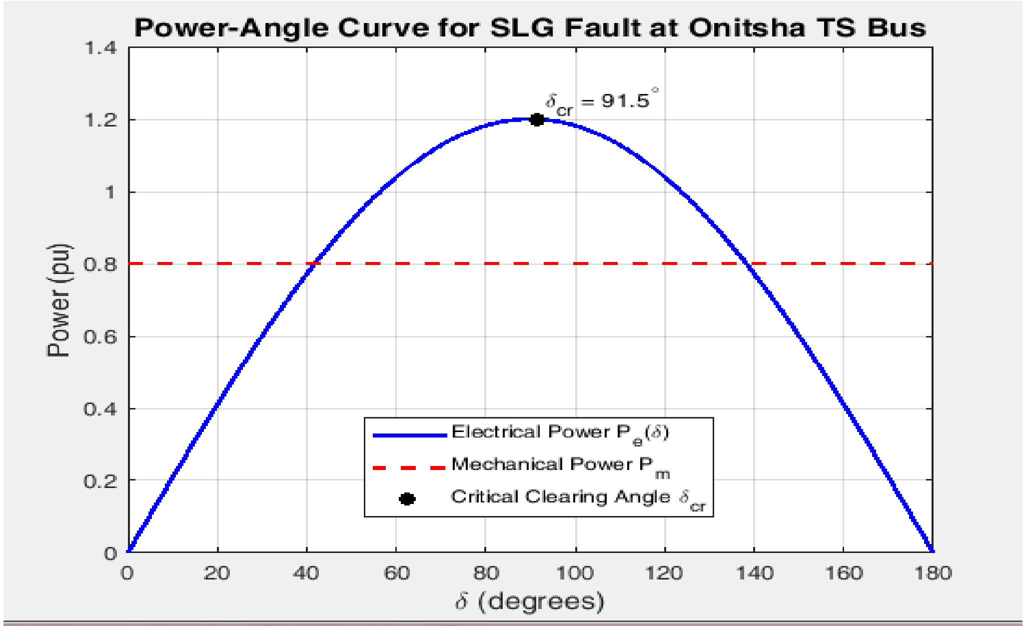

Figure 7. Power Angle Curve at ONITSHA TS BUS for Single Phase to Ground Fault

The power-angle curve (Pe vs. δ) in Figure 7 offers a consolidated phase-plane view of the transient. It plots the electrical power (Pe) directly against the rotor angle (δ). The system's operating point traces a stable, oscillatory trajectory following the fault. The clearing point at δ = 91.5° is clearly visible. The trajectory shows that the system swings out but remains within the stable region bounded by the critical clearing angle. The spiral path of the operating point back towards a stable equilibrium is a powerful visual confirmation of transient stability, illustrating how the generator's inherent synchronizing power acts to restore stability post-fault.

5. CONCLUSION AND RECOMMENDATION

This study has successfully performed a transient stability assessment of the Onitsha Transmission Station for a single line-to-ground fault. The research establishes a Critical Clearing Time of 0.60 seconds and demonstrates through comprehensive parameter analysis that the system is stable when faults are cleared within this period. The findings provide a crucial technical basis for the protection and control strategies employed at this key grid infrastructure.

Based on the insights derived from this analysis, the following recommendations are proposed:

1. **Protection System Calibration:** The protection relays governing the Onitsha TS bus and its associated feeders must be calibrated and coordinated to guarantee a total fault clearing time that is securely below the 0.60-second CCT. A comprehensive audit of existing protection settings is advised.
2. **Stability Enhancement Feasibility Study:** A follow-up study should be initiated to evaluate the techno-economic feasibility of deploying a Flexible AC Transmission System (FACTS) device, such as an SVC, at the Onitsha substation. The study should quantify the potential improvement in the CCT and overall system strength.

REFERENCES

[1] Adebayo, I. G., Adewuyi, O. B., & Awelewa, A. A. (2020). Assessment of voltage stability status of the Nigerian power system. *International Journal of Electrical and Computer Engineering, 10*(5), 5024-5033.

[2] Anderson, P. M., & Fouad, A. A. (2003). *Power system control and stability* (2nd ed.). Wiley-IEEE Press.

[3] Kundur, P. (1994). *Power system stability and control*. McGraw-Hill.

[4] Negeri, E. C., & Bongo, M. W. (2017). Power system stability analysis using ETAP. *International Journal of Engineering Research and Technology, 6*(5), 1-8.

[5] Okedu, K. E. (2015). Impact of distributed generation on the Nigerian power network. *International Journal of Electrical and Power Engineering, 9*(2), 35-41.

[6] Pai, M. A., & Carvalho, D. S. G. e. (2022). Small signal stability. In *Power system dynamics: Stability and control* (3rd ed., pp. 195-240). Springer.

[7] Saadat, H. (2010). *Power system analysis*. McGraw-Hill.