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Transient Stability Optimization after Connecting A 132MW Gas Turbine Generator to A Weak Grid

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Abstract: *Needless to say, connecting a huge size generator to a weak electric grid leads to instability if the steady and transient stability are not well-studied. This paper presents tackling the abovementioned issue and finally optimizing the stability of both grid and turbine. One of the ways to achieve the stability is by properly resetting and tuning the load shedding system based on the gas turbine control system dynamic response.*
Tackling the instability issue has been performed by studding the turbine response through the control system trends of numerated events and accordingly approaching the optimum settings of the load shedding system of the grid.
The solution of the grid instability has been validated and deemed successful after adjusting the load shedding final settings and recording that many faults were occurred on the 33KV network and also many times of partial generation loss, but no effect on the turbine and grid stability.

Keywords: Instability, tackling, load shedding, event logs and trends, dynamic response

I. INTRODUCTION

Emergency control, typically in the form of under-frequency load shedding (UFLS), is widely applied to mitigate low-frequency and instability issues in real-world power systems during contingencies, particularly in the tightly budget regions where the secondary and tertiary control system are not affordable. It serves as a critical protection mechanism to reduce the likelihood of cascading failures and large-scale blackouts, and thus is considered indispensable for resilient network operation [2]. Historical evidence shows that the root cause of most major blackouts in the past decades has been frequency instability triggered by severe contingencies such as generation loss or faults [4,5]. Consequently, power utilities worldwide have adopted both under-frequency and under-voltage load shedding (UVLS) as standard emergency control strategies to enhance system reliability [1,3].

Under-frequency load shedding remains a cornerstone of emergency control because it arrests fast frequency decline after severe contingencies, containing cascading outages and preserving system integrity when other controls saturate or respond too slowly. Classic and modern studies alike show that well-designed UFLS minimizes involuntary disconnections while securing frequency nadir and recovery, particularly in isolated or weakly interconnected systems where inertia is scarce [13]. As inverter-based resources proliferate and synchronous inertia falls, UFLS grows even more critical: standards now require coordination between DER trip/ride through behavior and bulk-system UFLS logic so that distributed plants don't disconnect exactly when load relief is needed [10]. Real events underscore the point: during the 9 August 2019 Great Britain frequency disturbance, automatic disconnections and protection actions highlighted how UFLS and DER settings materially influence system resilience and customer impact [6, 11]. Technically, moving beyond fixed-step schemes to measurement-driven designs—e.g., using PMU frequency and ROCOF estimates or wide-area measurements to adapt the shed amount and location—consistently improves selectivity, reduces total curtailed load, and speeds restoration [8, 9]. Contemporary formulations that co-consider frequency and voltage stability, or prioritize critical loads, further align UFLS with operational objectives in modern grids [7, 12]. In short, coordinated, standards-compliant, and measurement-adaptive UFLS is indispensable for today's low-inertia, high-DER power systems—both to prevent blackouts and to minimize socio-economic disruption when large imbalances strike [10].

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Although diverse cases have been recorded and analyzed during studying and tracing the stability issue of the gas turbine and the grid, in this paper only the two outstanding scenarios (1&2), which led us to come up with the final solution, have been highlighted in the following sections.

Senario#1: Fault on the 33KV Network with loss of stability

The operational trends of the turbine control system were systematically extracted and subjected to in-depth analysis to investigate its dynamic behavior under network disturbances. This examination focused on identifying the root causes of instability and assessing the turbine's response to sudden changes in system conditions. The analysis provided valuable insights into the interaction between turbine dynamics, network faults, and the broader power generation system."

The results revealed that following a trip induced by a phase fault on the 33 kV side of the network, the turbine experienced a dynamic load increase within 0.229 seconds, accompanied by a frequency drop to 49.62 Hz, as depicted in Figures 1 and 2. Shortly thereafter, a substantial loss of generation from other power plants occurred, which diverted additional load onto the turbine for 0.242 seconds until the dynamic power reached its trip set point of 182 MW. These findings clearly indicate that the principal source of instability stemmed from the loss of external generation rather than the initial 33 kV fault. In light of this, load-shedding adjustment strategies were proposed as an effective means of mitigating instability and maintaining overall system reliability."

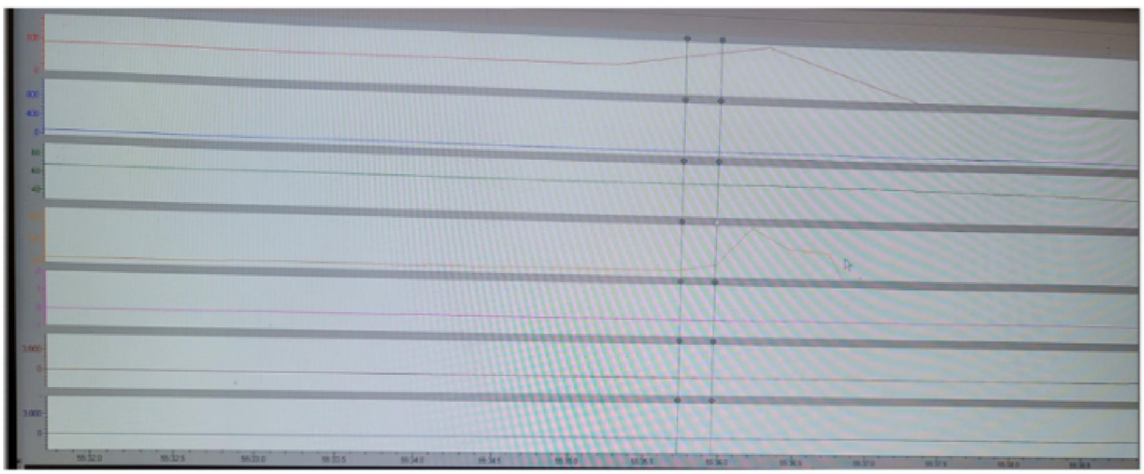

Fig 1. Overall electric quantities curves during fault on 33KV network.

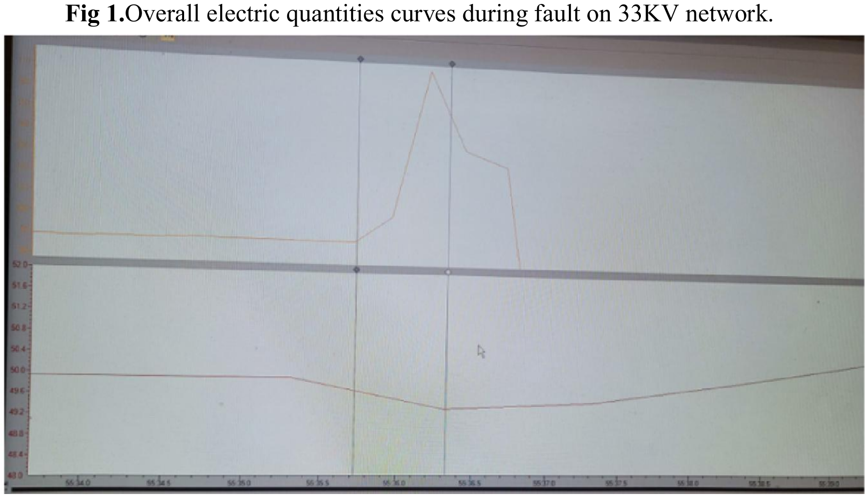

Fig 2. Power and frequency curves during fault on 33KV network.

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Senario#2: Loss of Stability Due to Partial Generation Loss

Similarly, the operational trends of the turbine control system were extracted and carefully analyzed following the complete trip of the network. This analysis aimed to capture the turbine's dynamic response under severe generation loss conditions and to identify the primary contributors to system instability. The study builds on the previous scenario, providing deeper insights into the critical role of generation adequacy in maintaining system stability.

The results indicate that after the loss of a portion of the existing generation, the turbine experienced a sharp dynamic load increase within 0.23 seconds, and the system frequency declined to 49.4 Hz within 0.65 seconds, as illustrated in Figure 3. With additional load being diverted to the turbine, frequency reduction intensified, ultimately triggering a trip command that resulted in complete instability. This behavior, consistent with the first scenario, demonstrates that the instability was primarily driven by the loss of generation from other power plants rather than the initial loss of partial generation. To address this challenge, load-shedding adjustment techniques were proposed as a viable strategy to restore system stability and ensure reliable operation under similar disturbance conditions.

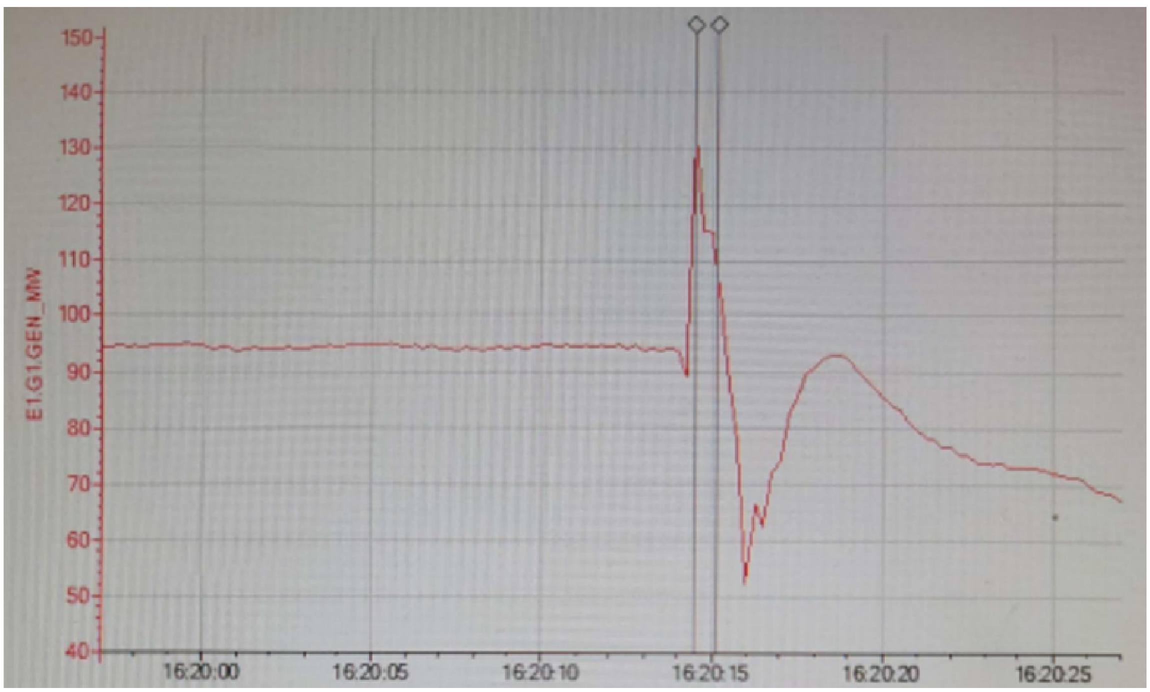

Fig 3. Power curve during partial generation loss.

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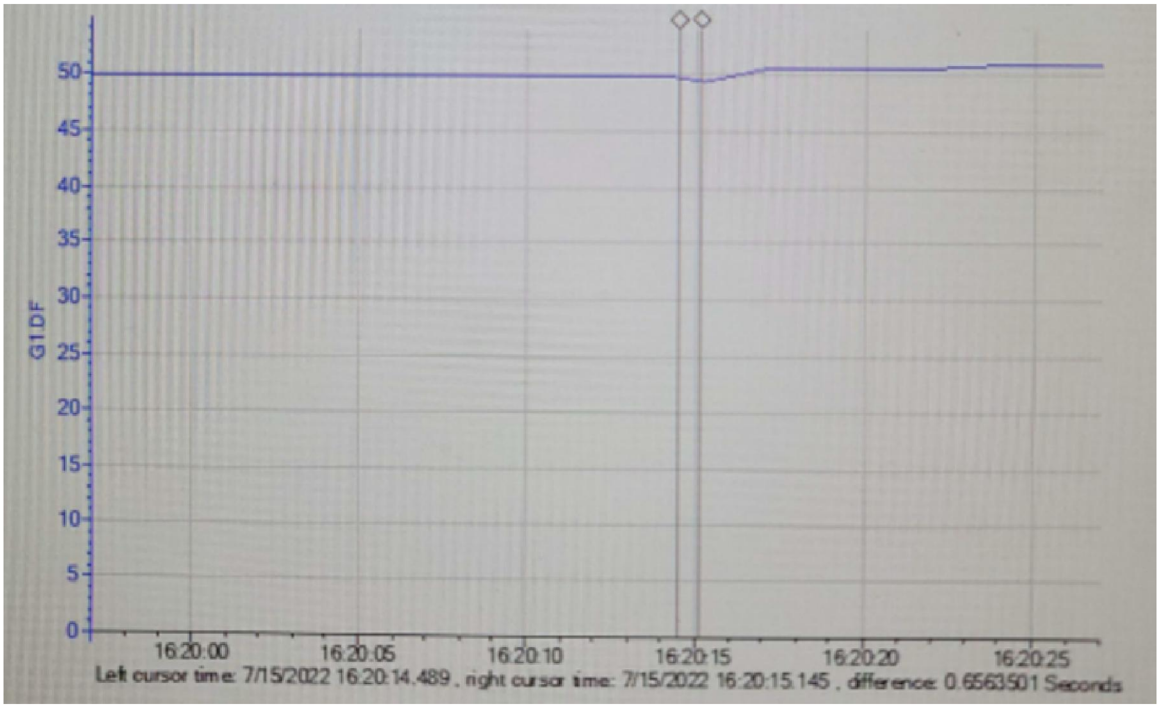

Figure 4. Frequency curve during partial generation loss.

II. METHODOLOGY

Based on the analysis of Scenarios (1&2), the interaction between the turbine's dynamic power and the corresponding frequency response was closely examined to determine the optimal frequency setting for the load-shedding system and to achieve a stable operational state. A detailed investigation of specific segments of the power and frequency graphs was carried out to better understand the relationship between post-fault dynamics and turbine trip behavior.

As illustrated in Figure 5, perpendicular intersections between the turbine power curve and the frequency response reveal three distinct operating conditions. The upper intersections (violet) correspond to a post-fault condition where turbine power increased to 100 MW—within the base load of 115 MW on crude oil—while frequency declined to 49.48 Hz. The lower intersections (red) indicate the maximum load diversion of 178 MW caused by the loss of other generating units, during which frequency decreased to 49.3 Hz, ultimately leading to turbine tripping and system instability. Between these extremes, the middle intersections (green) represent average values of both power and frequency during the transition from fault occurrence to turbine trip.

From this analysis, it is deduced that the effective frequency setting for load shedding lies between 49.3 Hz and 49.48 Hz. To ensure operational security, the average of this range, 49.4 Hz, is identified as the desired threshold. Similarly, the corresponding range of load to be shed can be defined in relation to these frequency thresholds to maintain grid stability under comparable disturbance scenarios.

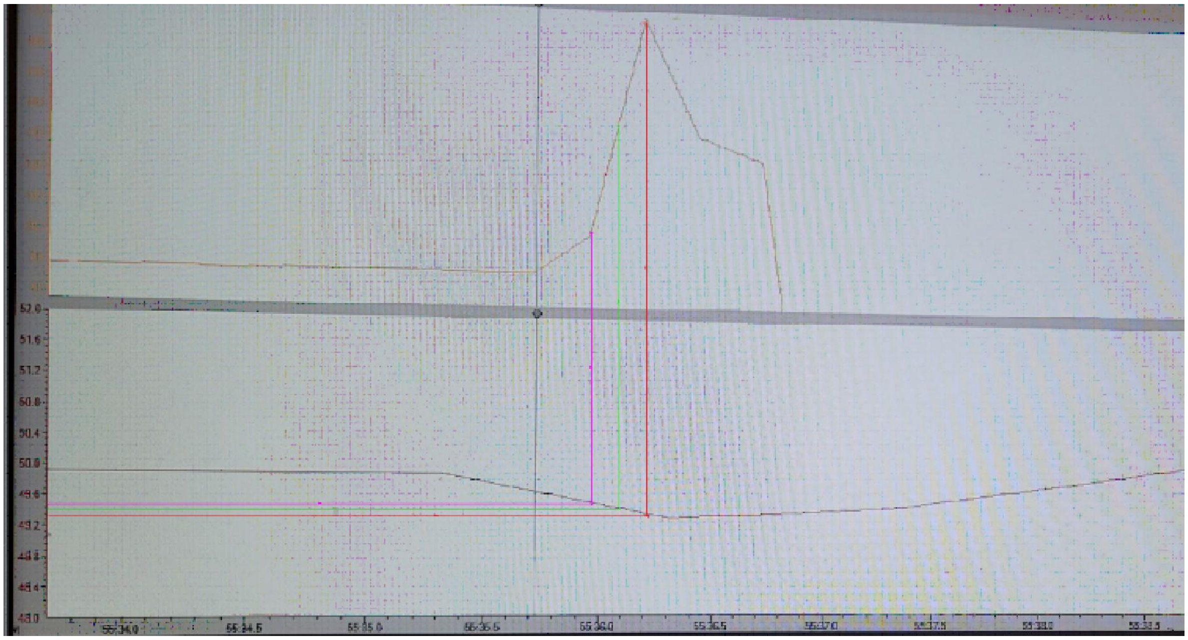

Figure 5. Power and frequency setting approach.

III. CONCLUSION

This study has demonstrated that the integration of a large-scale 132 MW gas turbine generator into a weak grid environment poses significant challenges to transient stability, particularly under contingencies involving external generation loss or network disturbances. Through detailed analysis of real turbine operational trends and fault scenarios, it was established that instability events were primarily triggered by the loss of external generation rather than by local network faults alone. By systematically examining the turbine's dynamic response and its interaction with system frequency, the research identified an optimized load-shedding threshold at 49.4 Hz as the most effective setting for mitigating instability while minimizing unnecessary disconnections. The findings underscore the crucial role of adaptive and well-calibrated load-shedding schemes in enhancing resilience, especially in weak grids where system inertia is limited and disturbances propagate rapidly. Importantly, the proposed approach not only ensured the continuous stability of the turbine and network during repeated fault events and partial generation losses but also validated its practicality by preventing cascading failures in real operational conditions. Ultimately, this work highlights that optimizing load-shedding control, grounded in data-driven dynamic analysis, is indispensable for maintaining reliable power system performance in modern, low-inertia networks, and provides a robust framework that can be extended to similar large-scale generation integration projects worldwide.

IV. FUTURE WORK

Future research should extend the proposed methodology to multi-machine systems and hybrid grids with higher shares of inverter-based resources, where stability challenges are more complex. Incorporating wide-area measurement systems and advanced optimization or machine learning techniques could enable adaptive, real-time load-shedding strategies with greater precision. Moreover, assessing the economic and reliability impacts of such schemes will be essential to balance technical robustness with operational feasibility.

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