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Power Flow Analysis of a 6-Bus System Using PowerWorld

Abstract

In this project, I utilized PowerWorld Simulator to model and analyze the performance of a 6-bus power system under various contingency scenarios, such as generator outages and significant load increases. The primary objective was to examine the system's voltage profiles, power flows, and losses under both normal and stressed operating conditions.

The study began with establishing a base case, ensuring all buses maintained acceptable voltage levels and that no transmission lines were overloaded. Subsequent simulations introduced contingencies, including the disconnection of generators and the escalation of load at specific buses. Notably, Bus 4 exhibited substantial voltage deviations and increased line loadings when its demand was doubled. Additionally, the removal of transmission line 1–4 resulted in the overloading of parallel lines, highlighting the system's vulnerability to certain failures.

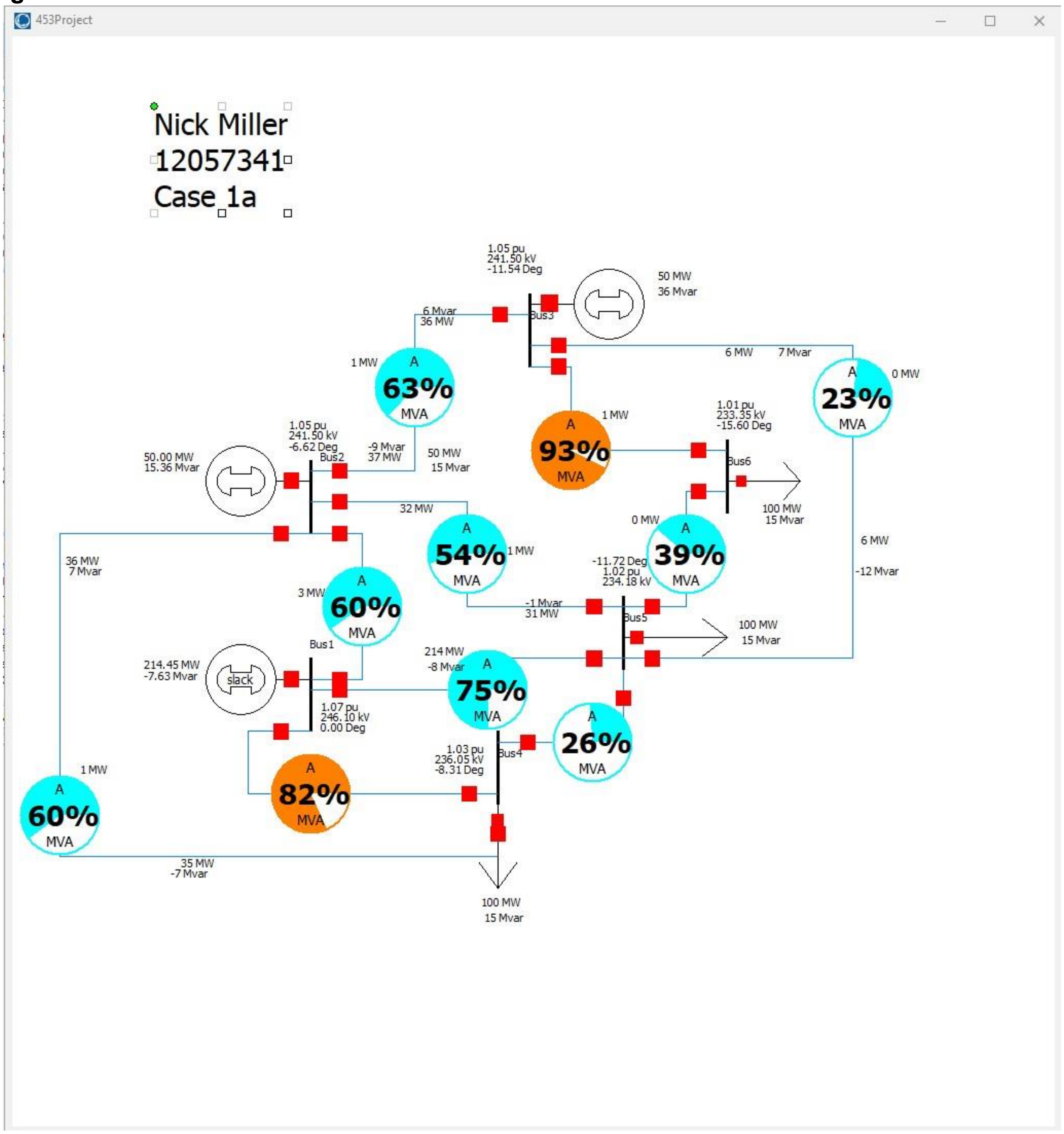
These results emphasize the critical importance of redundancy in both generation and transmission infrastructure. The slack generator at Bus 1 was frequently required to compensate for disturbances, underscoring its pivotal role in system stability. Furthermore, system losses—both real and reactive—escalated in scenarios where reactive power support was insufficient. Overall, the findings demonstrate that maintaining voltage stability and preventing thermal overloads requires deliberate system planning and robust contingency analysis.

Procedure

1. Case 1 – Base Case

This scenario served as the baseline for the entire simulation. All generators, transmission lines, and loads were fully operational, resulting in a system operating under ideal conditions. Bus voltages remained well within the standard range of 0.95 to 1.07 per unit (pu), with the slack bus (Bus 1) maintained precisely at 1.07 pu, as scheduled. No transmission line overloads or violations of reactive power limits were observed, and real power losses were minimal. Notably, the system exhibited negative reactive power losses, indicating that the network was absorbing additional vars due to the presence of capacitive elements within the transmission lines. Overall, this case represented a clean and stable system, providing an optimal reference point for subsequent contingency analyses.

Figure 1 – Case 1: Base Case Power Flow Results



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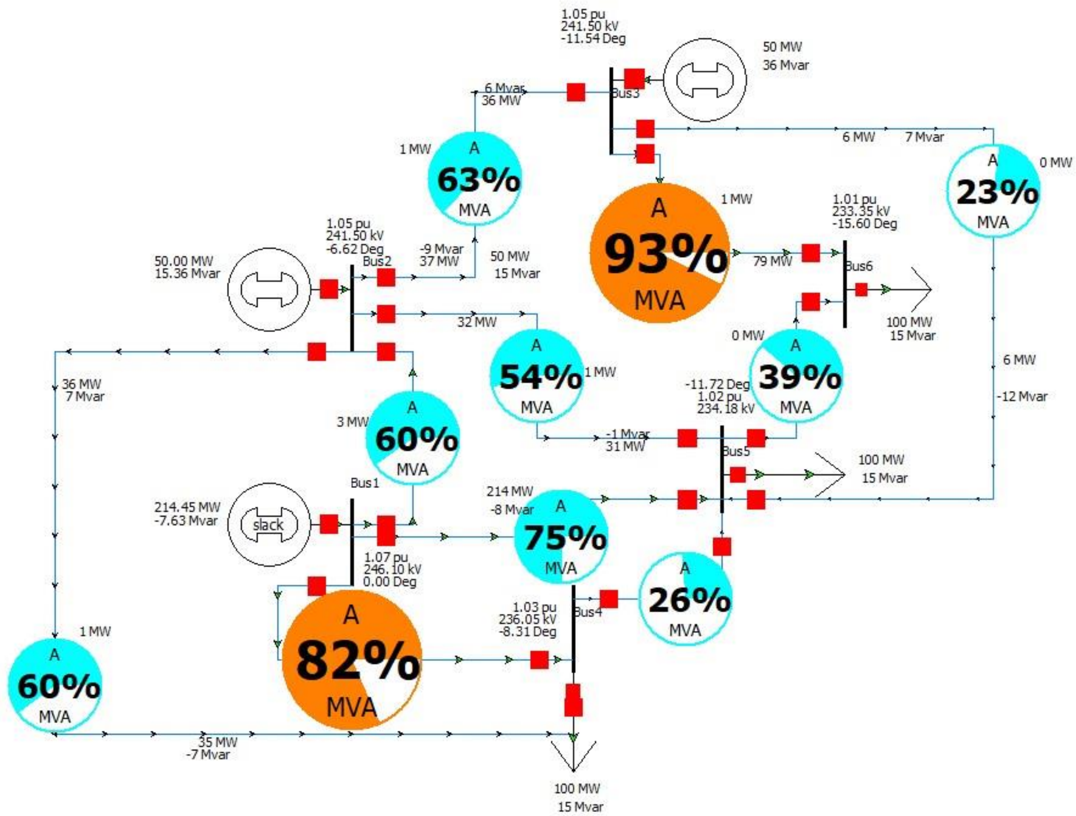
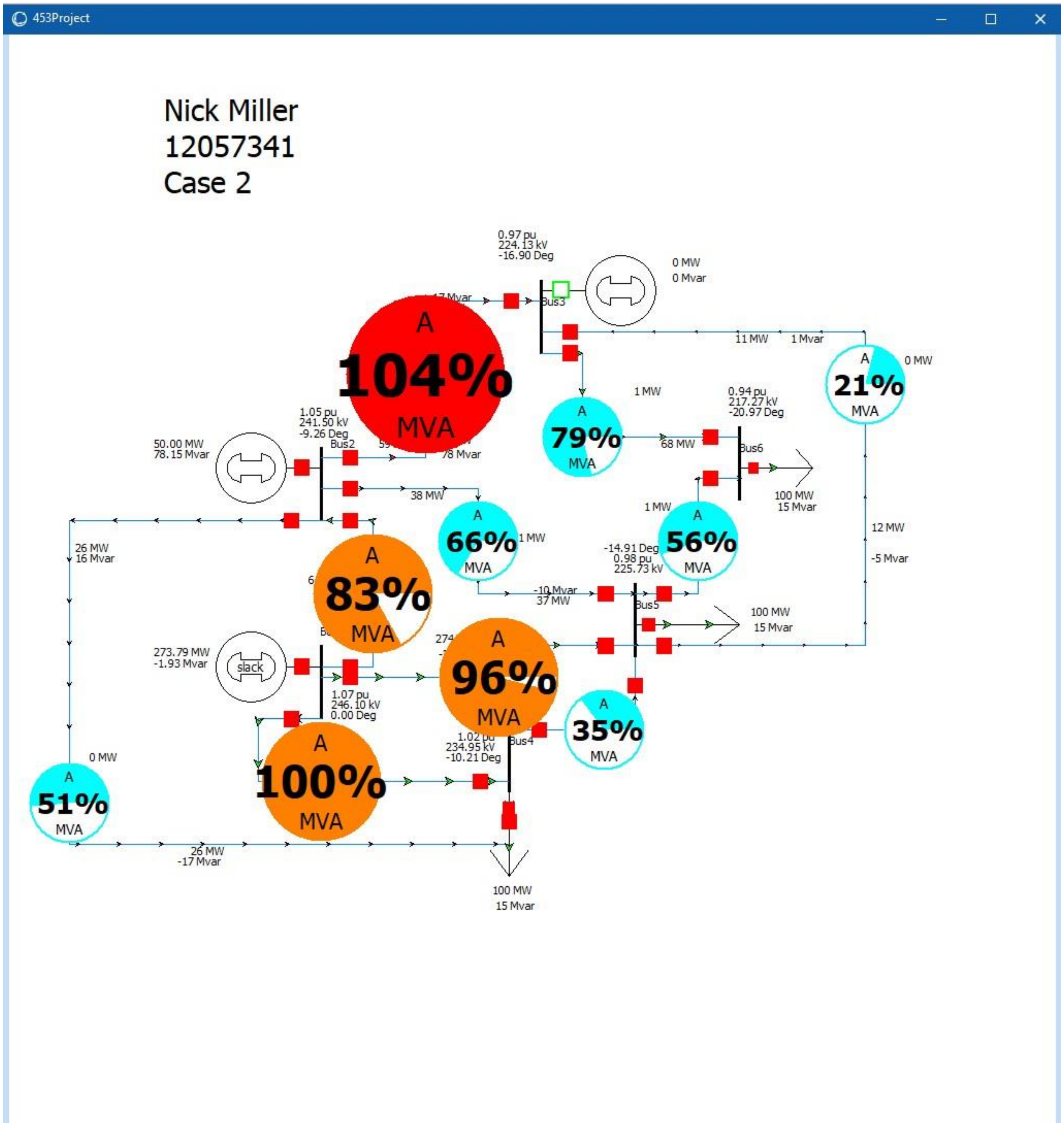
Case 1b



2. Case 2 – Generator Outage at Bus 3

In this scenario, I simulated the outage of Generator 3. Upon its disconnection, the slack generator located at Bus 1 automatically compensated by supplying the additional required power. This adjustment resulted in a slight decrease in voltage at the primary load buses (Buses 4, 5, and 6), though the deviations remained within acceptable limits. Transmission line 1–4 experienced a marginal overload, which was anticipated due to the increased power flow along this route as the system redistributed the generation shortfall. This outcome provided an initial indication of the system's susceptibility to stress, demonstrating that while the network remained operational, vulnerabilities could emerge under contingency conditions.Figure 2 – Case 2: Generator 3 Outage Results



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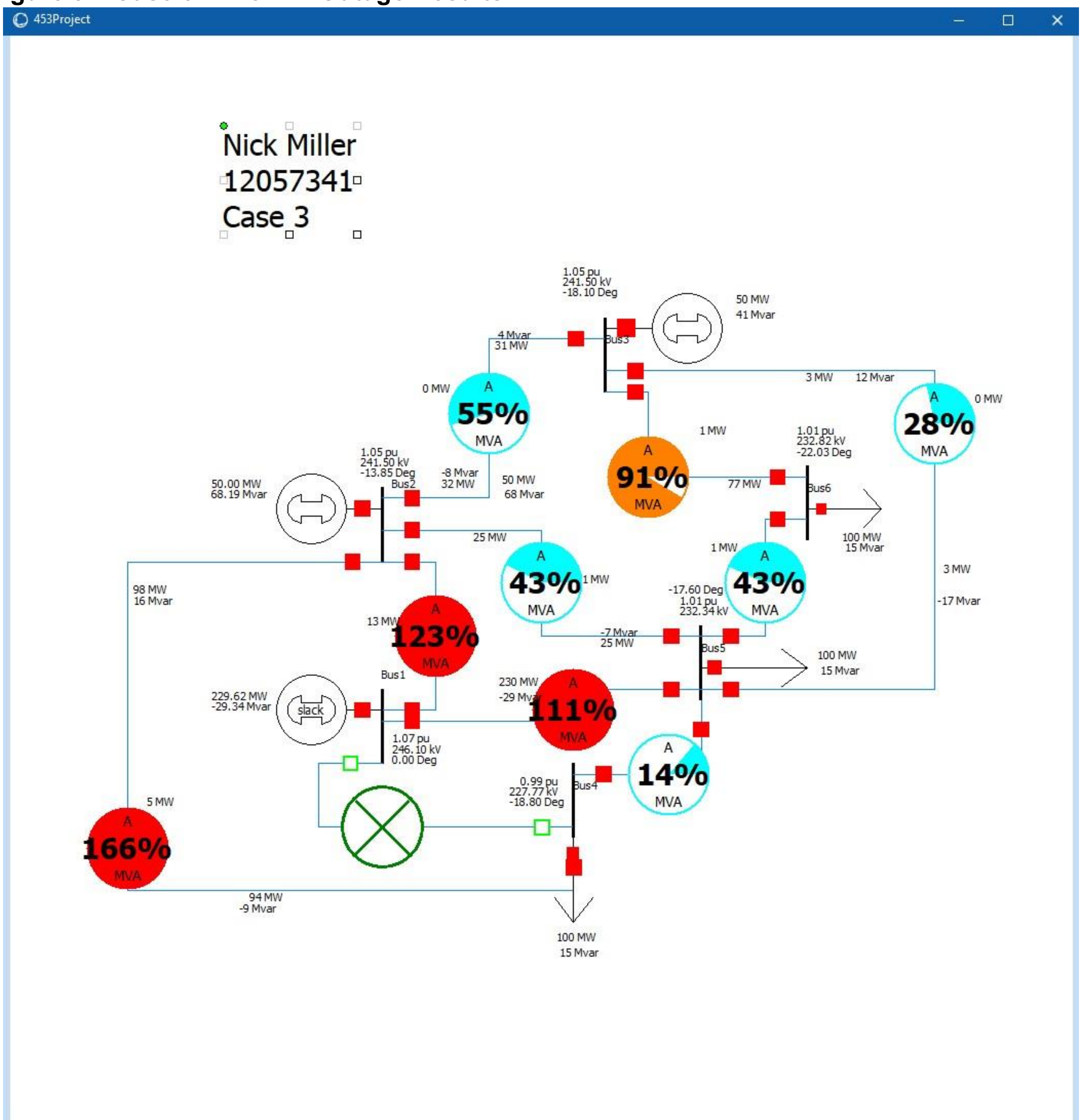
3. Case 3 – Line 1–4 Outage

In this scenario, I simulated the outage of one of the principal transmission corridors, specifically line 1–4, and observed the subsequent redistribution of power flows throughout the network. The voltages at Buses 4, 5, and 6 experienced moderate declines, yet remained above the minimum acceptable threshold of 0.95 pu. However, several transmission lines—namely 1–2, 1–5, and 2–4—became overloaded as they absorbed the additional power diverted from the outaged line. Real power losses approximately doubled compared to the base case, and reactive power losses shifted from negative values to an excess of +22 MVAR. This scenario clearly demonstrated the substantial impact that the loss of a single major transmission line can have on the overall power flow and operational security of the system.

Figure 3 – Case 3: Line 1–4 Outage Results

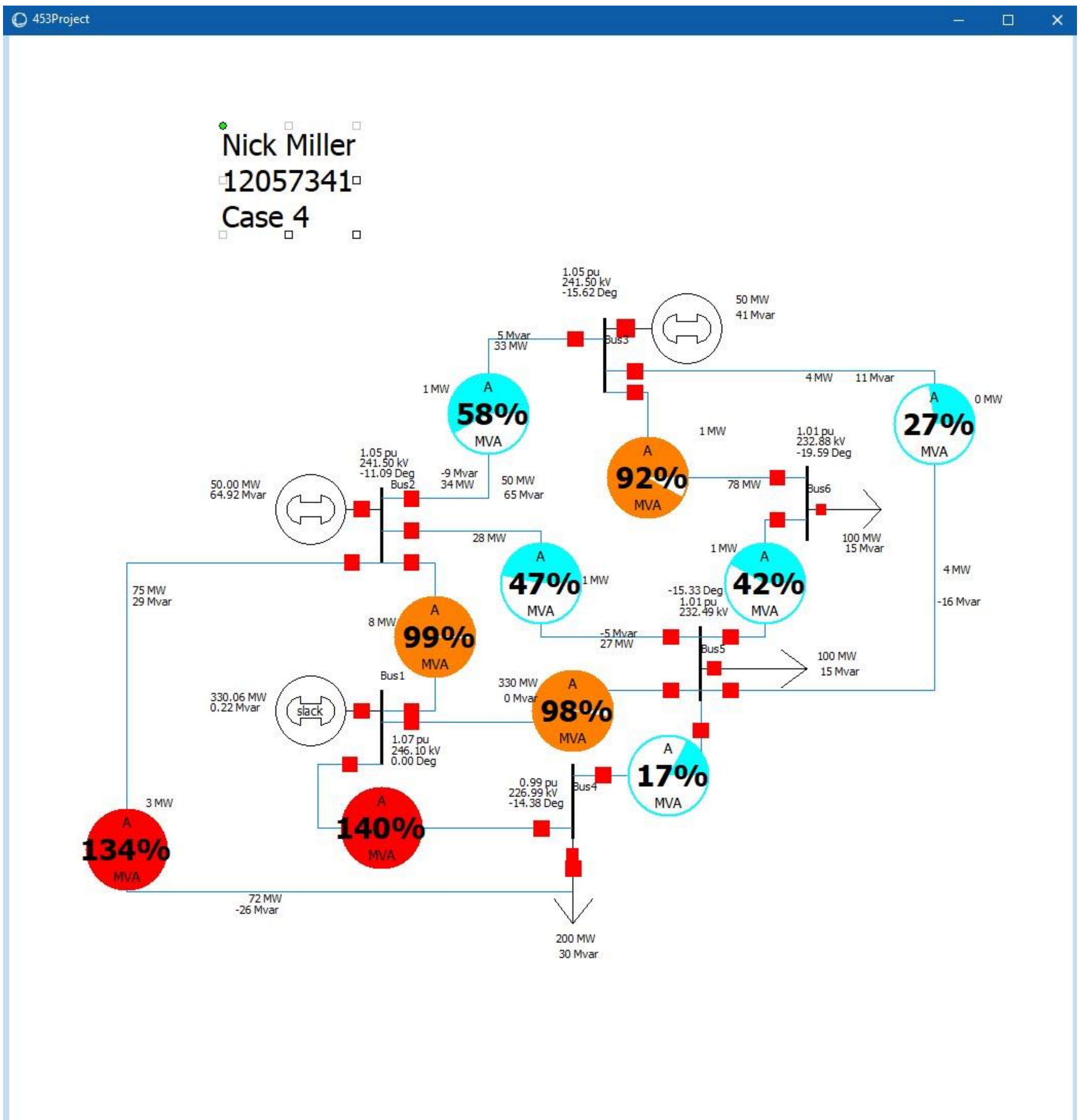


4. Case 4 – Double Load at Bus 4

I doubled the load at Bus 4 to 200 MW and 30 MVAR while keeping all lines and generators online. Voltages at Buses 4, 5, and 6 all dropped, and overloads popped up again on lines 1–4

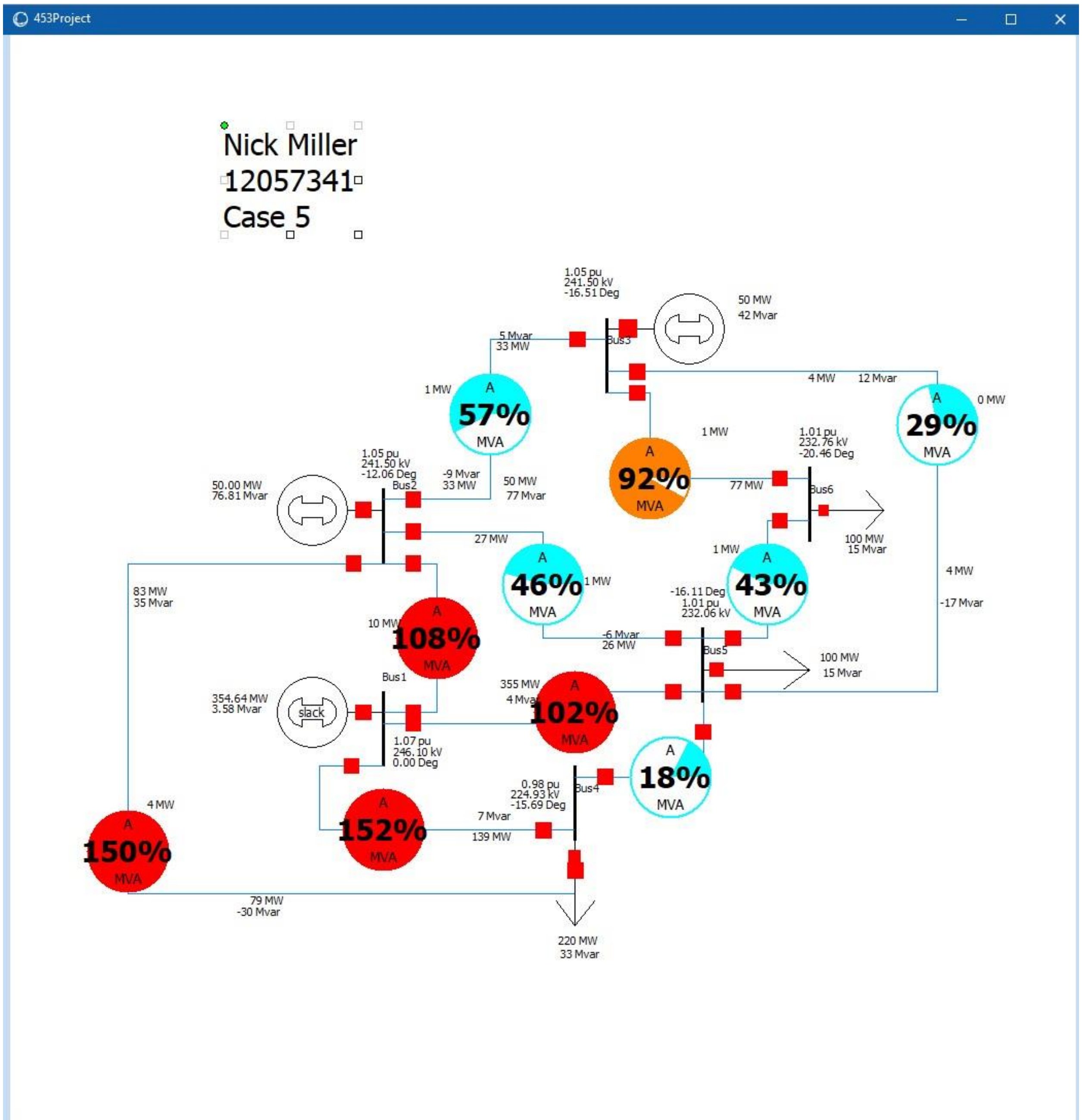
and 2–4. Reactive power losses increased a lot, showing how pushing the system harder starts to stress its voltage support and delivery paths.

Figure 4 – Case 4: Bus 4 Load Doubled



5. Case 5 – Max Load at Bus 4 (220 MW / 33 MVAR)

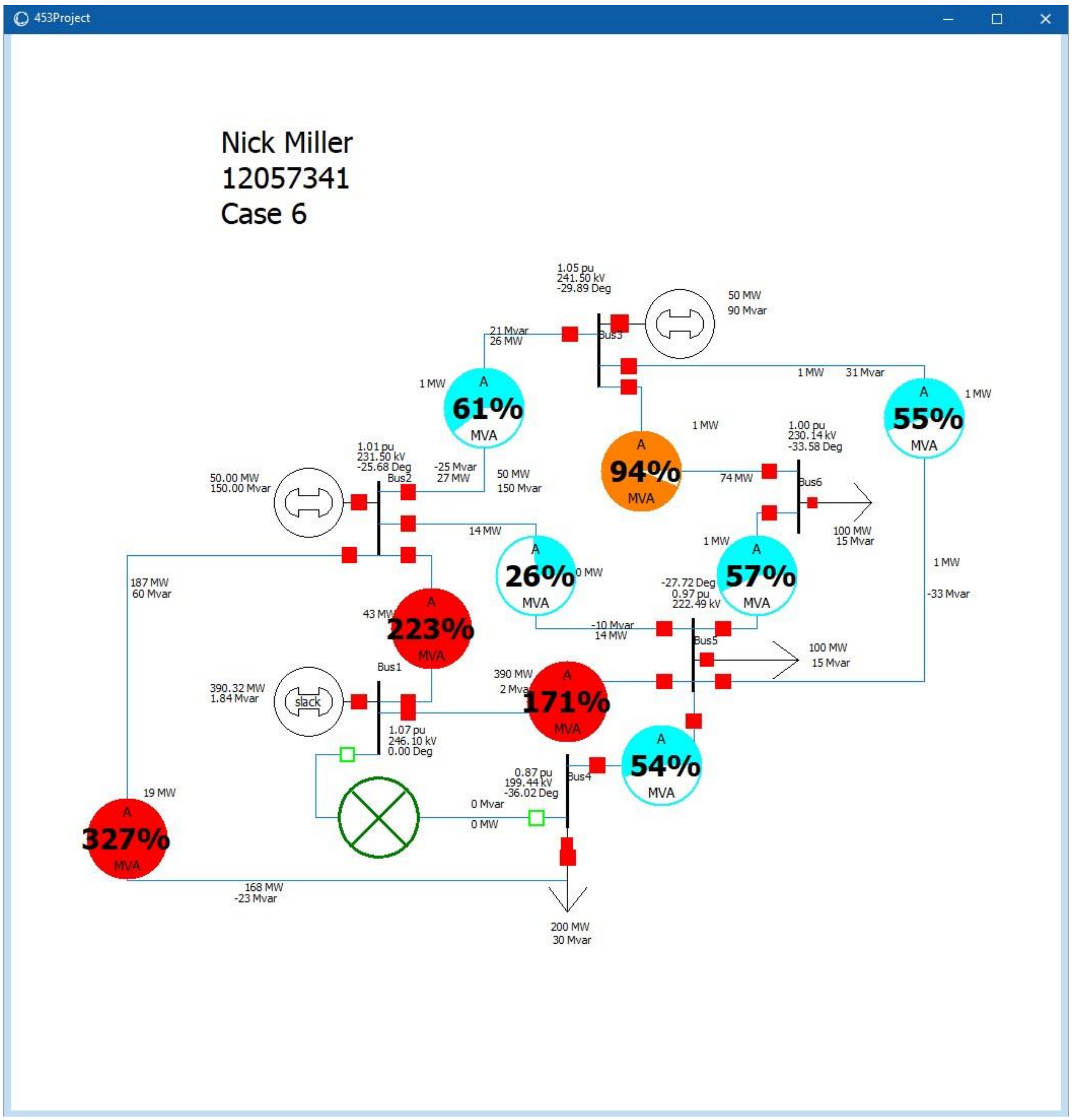
The load at Bus 4 was increased to 220 MW and 33 MVAR, causing reactive losses to rise further. Although voltages remained within acceptable limits, Bus 4 dropped to approximately 0.98 pu. This case highlighted how small load increases can significantly impact system stability when operating near capacity.Figure 5 – Case 5: Bus 4 Max Load (No Line Outage)



6. Case 6 – High Load at Bus 4 + Line 1–4 Out

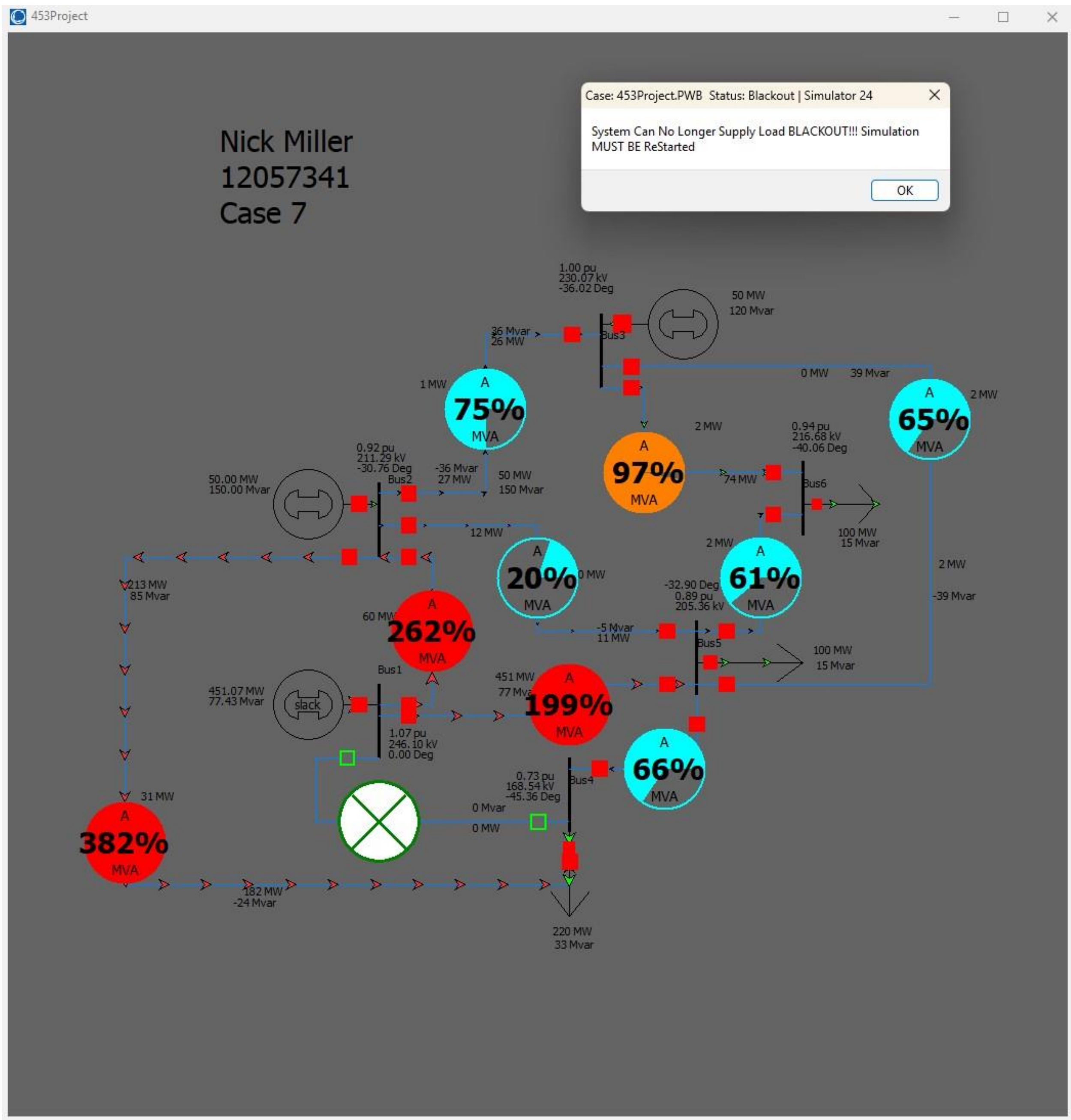
Combining load stress and a line outage made things way worse. With Bus 4 at 200 MW and Line 1–4 offline, voltage at Bus 4 sank all the way to 0.87 pu — way below the 0.95 pu minimum. Lines 1–2, 1–5, and 2–4 were all overloaded, and Generator 2 hit its VAR limit, so its voltage dropped as well. Both real and reactive losses jumped.

Figure 6 – Case 6: Bus 4 High Load + Line 1–4 Out



7. Case 7 – Max Load at Bus 4 (220 MW / 33 MVAR) + Line 1–4 Out

This scenario represented the system's operational limit. With maximum loading at Bus 4 and line 1–4 out of service, voltage at Bus 4 collapsed to 0.73 pu, while Bus 5 fell to 0.89 pu. Generators 2 and 3 reached their reactive power limits, leading to a failure in voltage regulation. The power flow solution failed to converge, indicating that the system had surpassed its stability threshold.Figure 7 – Case 7: Max Load + Line 1–4 Out – System Collapse



Conclusion

After completing all seven simulation cases, the results clearly illustrated the high sensitivity of power systems to various forms of operational stress. The base case provided a benchmark for ideal system behavior—voltage levels remained within acceptable limits, system losses were minimal, and no transmission lines experienced overload. However, once disturbances such as generator outages or load increases were introduced, system conditions changed rapidly. The disconnection of Generator 3, for instance, required immediate compensation from the slack generator, leading to noticeable voltage reductions and the initial emergence of system stress. Transmission line outages, particularly that of line 1–4, produced even more pronounced effects. The redistribution of power flows resulted in the overloading of multiple lines and a substantial rise in reactive power losses.

The most significant signs of instability became apparent during the high-load scenarios, especially in Cases 6 and 7. A critical insight gained through this analysis was the ease with which generators can reach their reactive power (VAR) limits. Once a generator is no longer able to provide reactive support, voltage regulation deteriorates, often triggering broader system instability. This experience emphasized that system reliability depends not only on having adequate real power generation but also on the ability to control reactive power flows and maintain voltage stability. Ultimately, the simulations reinforced the importance of thorough contingency planning in real-world power systems, as even a single outage or line overload can fundamentally alter system behavior.