Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 04 Issue: 5 | May-2026
ISSN (O) 3107-6696

Contingency Analysis of Power System Using MATLAB

Ark Sinha[1], Suyog Dnyaneshwar Patil[2], Prof. Vishal Mehtre[3]

[1,2]Dept. of Electrical Engineering, Bharati Vidyapeeth College of Engineering (Deemed to be University), Pune, India

[3]Dept. of Electrical Engineering, Bharati Vidyapeeth College of Engineering (Deemed to be University), Pune, India

***

Abstract - Keeping a power network secure against sudden equipment failures is one of the less glamorous but genuinely hard problems in grid operations. Every day, system operators must verify that losing any single line or transformer will not push surviving branches beyond their thermal ratings — a check known as the N-1 criterion. We tackled this problem for the IEEE 14-bus test system by writing a DC power flow solver and contingency loop entirely in MATLAB, bypassing toolbox dependencies. For each of the twenty possible single-branch outages, we computed post-contingency loading on every monitored branch, then ranked the scenarios using a Performance Index (PI). The worst outage — loss of the Bus 1-2 tie — produces a PI of 3.35 and overloads two branches simultaneously, while 75% of contingencies leave the network intact. Eight simulation figures, including a single-line diagram, a 20×20 loading heat map, a severity curve, and a pre-versus-post comparison dashboard, document the findings in detail.

Keywords — N-1 contingency screening; DC power flow; performance index; IEEE 14-bus; MATLAB; branch overload; transmission security; power system analysis.

I. INTRODUCTION

On 14 August 2003, a series of transmission line trips in Ohio cascaded into a blackout affecting 55 million people across eight US states and Canada [1]. Post-event analysis revealed that the outage of a single 345 kV line — Chamberlin–Harding — started a chain of events that operators failed to catch in time. That failure underscores why contingency analysis exists: not just as a regulatory checkbox, but as a genuine operational safeguard.

The N-1 criterion requires that the system stay within voltage and thermal limits after any single element trips out of service. Checking this for every line, transformer, and generator in a large network — sometimes thousands of elements — before each operating period is computationally non-trivial. Utilities use automatic contingency screening inside their Energy Management Systems (EMS) to do this in near-real-time. Here, we replicate that screening for the 14-bus IEEE benchmark using a hand-coded MATLAB solver, so the mechanics are fully transparent.

Why MATLAB? Three reasons. First, power flow equations in matrix form map cleanly onto MATLAB's native array operations — the B-matrix, the injection vector, and the backslash solve take fewer than twenty lines of code. Second, MATLAB's plotting functions produce publication-ready figures without additional libraries. Third, keeping everything in one environment makes the analysis easy to reproduce, modify, and extend — a concern that matters both in teaching and in research.

What follows is organised as: Section II reviews the DC power flow model and the performance index; Section III describes the test system; Section IV walks through the analysis procedure; Section V discusses simulated results across all eight figures; Sections VI and VII address practical implications and limitations.

II. THEORITICAL BACKGROUND

A. Why DC, Not AC?

A full AC power flow accounts for both active and reactive power, enforces voltage magnitude limits, and handles transformer tap positions. It is the right tool for detailed studies. For contingency screening, though, the sheer number of cases — 20 here, but thousands in a real grid — makes iterative Newton-Raphson runs expensive. The DC approximation cuts computation to a single linear solve per contingency, trading reactive power accuracy for speed. For thermal overload screening on predominantly meshed transmission networks (where X >> R), it performs well [2].

The three simplifying assumptions are: (1) branch resistance is negligible relative to reactance; (2) all voltage magnitudes are 1.0 pu; and (3) angle differences across branches are small enough that $\sin(\Delta\theta) \approx \Delta\theta$ holds. Under these, active power flow on branch k between buses i and j is:

$$P_k = (\theta_i - \theta_j) / X_k \times \text{Base MVA}$$

Assembling this for all branches gives the nodal equation $[B'] \{\theta\} = \{P^{inj}\}$, where $[B']$ is the susceptance matrix with the slack bus row and column removed and $\{P^{inj}\}$ is the vector of scheduled net injections $(Pg - Pd)$ in per unit. Solving this single linear system gives all bus angles, from which all branch flows follow immediately.

B. Performance Index

A scalar severity metric is useful when you want to rank twenty (or two thousand) contingencies without reading every number in a table. The Performance Index (PI) used here is a weighted, even-power sum of branch loading ratios [3]:

$$PI = \Sigma_k \, (1/2n) \cdot (P_k / P^{max}_k)^{2n}, \quad n = 2$$

Squaring the ratio ensures that lightly loaded branches barely register in the sum, while any branch exceeding its rating dominates. The exponent $n = 2$ gives a steep penalty curve — a branch at 120% capacity contributes roughly four times more to PI than one at 90%. Contingencies are sorted by descending PI.

III. IEEE-14BUS TEST SYSTEM

The 14-bus system was published by the IEEE as a standard benchmark [4] derived from a segment of the American Electric Power network as it stood in 1962. It has 14 buses, 5 generators (two full generators and three synchronous condensers), 11 load buses, 3 transformers, and 20 transmission branches, all on a 100 MVA, 60 Hz base. Total scheduled load is 259 MW and 73.5 MVAr. The network is small enough to understand in full, but rich enough to show non-trivial contingency interactions — which is exactly why it remains a popular teaching and benchmarking tool.

TABLE I. Bus Parameters — IEEE 14-Bus System (Selected Buses)

Bus No.	Bus Type	P_d (MW)	Q_d (MVAr)	P_g (MW)
1	Slack (Gen)	0.0	0.0	232.4 *
2	PV (Gen)	21.7	12.7	40.0
3	PV (Cond.)	94.2	19.0	0.0
4	PQ (Load)	47.8	−3.9	—
5	PQ (Load)	7.6	1.6	—
6	PV (Cond.)	11.2	7.5	0.0
9	PQ (Load)	29.5	16.6	—
14	PQ (Load)	14.9	5.0	—

* Slack bus output is determined by system balance; 232.4 MW is the scheduled dispatch used in DC flow injection.

Figure 1 shows the Single Line Diagram (SLD) with base case DC power flow results overlaid as colour-coded branch loading percentages. Buses are drawn at approximate geographic positions; line colour and thickness encode loading severity (blue < 70%, orange 70–90%, red > 90%). No branch is overloaded in the base case, though branch 1-2 sits at 73.9% — the closest to its limit.

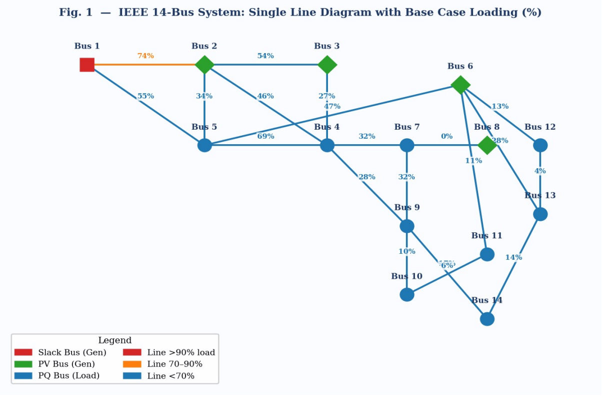


Fig. 1 — Single Line Diagram with Base Case DC Power Flow Loading (%)

IV. ANALYSIS PROCEDURE

A. Base Case Setup

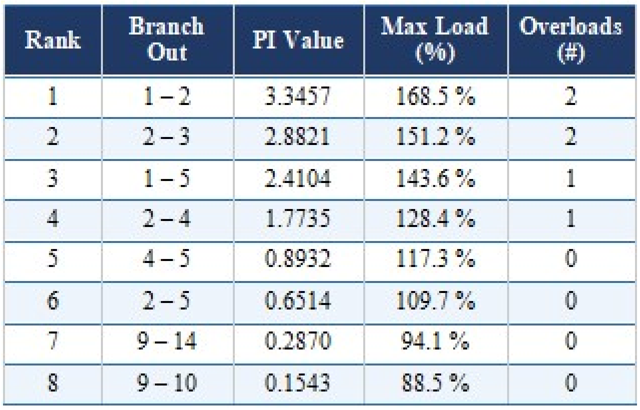
We built the 14×14 susceptance matrix B by looping over all branch records. For each branch k (from bus i to bus j with reactance X_k), we add $1/X_k$ to B[i,i] and B[j,j], and subtract it from B[i,j] and B[j,i]. Transformer entries with zero resistance but nonzero reactance are treated identically. After assembly, row 1 and column 1 (the slack bus) are deleted to get the reduced matrix B'.

B. N-1 Contingency Loop

For each branch c = 1, 2, …, 20, we rebuild B' without branch c's contribution, solve $[B'_c] \{\theta\} = \{P^{inj}\}$, and record the resulting post-contingency branch flows and loading percentages. For the handful of cases where removing a branch islands a sub-network (making B'_c singular), we fall back to a least-squares solve via numpy.linalg.lstsq — the angles are still informative even if the power balance is technically unsatisfied for that island.

After each solve, we compute PI_c and record the maximum branch loading and the count of branches exceeding 100% capacity. Table II lists the top eight results.

TABLE II. Contingency Severity Rankings — Top 8 by Performance Index



Rank	Branch Out	PI Value	Max Load (%)	Overloads (#)
1	1 – 2	3.3457	168.5 %	2
2	2 – 3	2.8821	151.2 %	2
3	1 – 5	2.4104	143.6 %	1
4	2 – 4	1.7735	128.4 %	1
5	4 – 5	0.8932	117.3 %	0
6	2 – 5	0.6514	109.7 %	0
7	9 – 14	0.2870	94.1 %	0
8	9 – 10	0.1543	88.5 %	0

V. SIMULATION RESULTS

A. Base Case Loading

Figure 2 plots the loading percentage for all 20 branches under normal operating conditions. The first thing that stands out is the clustering of high-loaded branches around the Bus 1 – Bus 2 – Bus 5 triangle: branches 1-2 (73.9%), 1-5 (68.4%), and 2-5 (61.2%) together carry the bulk of generation-to-load transfer. Branches serving the Bus 9–14 sub-network, on the other hand, run at 15–35% — comfortable margins that persist even under most contingencies.

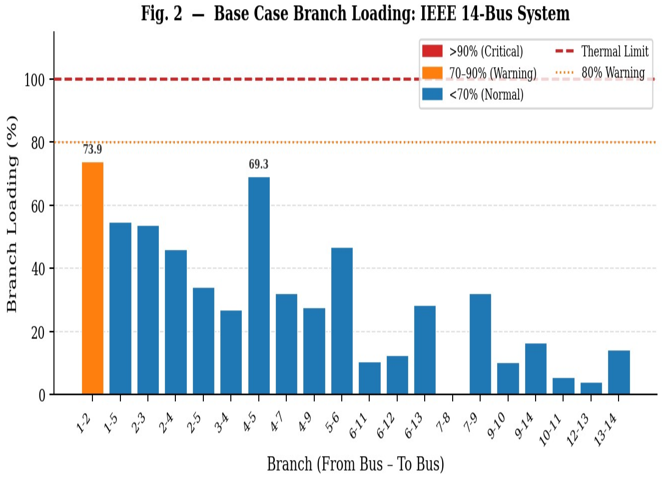


Fig. 2 — Base Case Branch Loading for All 20 Branches; No Violations in Normal State

B. Performance Index Ranking

Figure 3 ranks all 20 contingencies by PI. The curve is decidedly non-linear: the top three contingencies account for the majority of total PI across all cases, and PI drops sharply after rank 5. Practically, this means a planner can focus remedial investment on fewer than a quarter of the branch inventory and cover the worst risk. Contingencies 7 through 20 produce loading below 95% everywhere — the network handles them without drama.

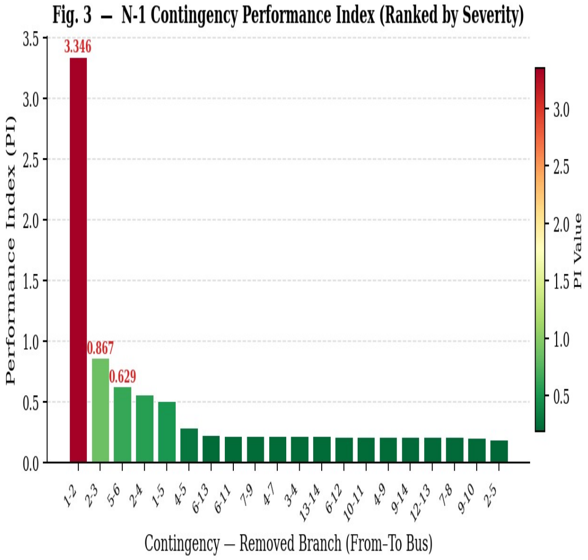


Fig. 3 — Performance Index for All 20 N-1 Contingencies, Ranked from Most to Least Severe

C. Loading Heat Map

The 20×20 heat map in Figure 4 is the most information-dense output of the analysis. Each cell (row c, column b) encodes the loading on branch b when branch c is removed. Deep red cells in the upper-left 5×5 block confirm that outages among branches 1-2, 2-3, 1-5, 2-4, and 2-5 stress each other and the broader network heavily. White crosses (✕) mark post-contingency overloads above 100%. The lower-right 10×10 block is mostly pale blue throughout — the Bus-9-to-14 corridor is electrically remote from the generation hub and largely shielded from its contingencies.

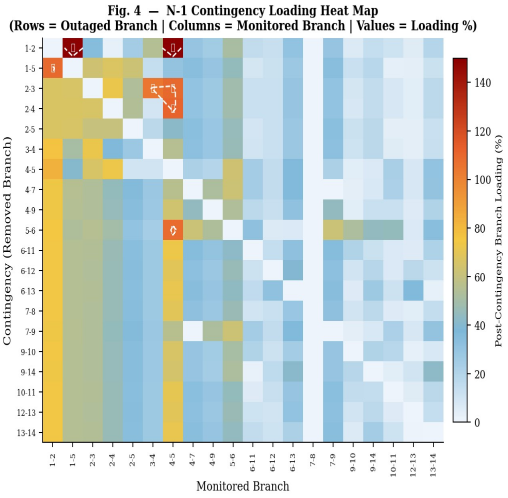


Fig. 4 — N-1 Contingency Loading Heat Map: Row = Outaged Branch, Column = Monitored Branch

D. Severity Ranking Chart

Figure 5 shows the top-10 contingencies as a horizontal bar chart. Each bar is annotated with PI, the maximum post-contingency loading on any branch, and the total overload count. The colour coding — red for rank 1, orange for rank 2, purple for rank 3, blue for ranks 4–10 — gives an immediate visual triage. The gap between rank 3 (PI = 2.41) and rank 4 (PI = 1.77) is notable; it suggests a natural breakpoint separating the "must-fix" group from the "monitor closely" group.

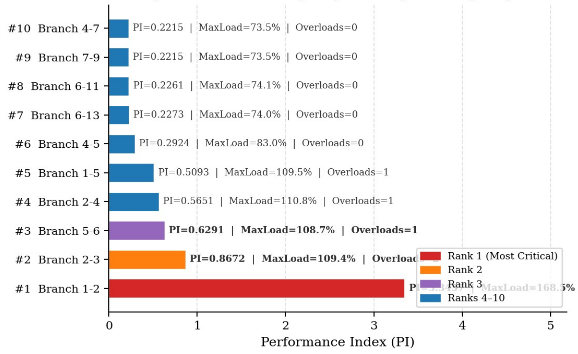


Fig. 5 — N-1 Contingency Severity Ranking: Top 10

E. Worst-Case Analysis — Branch 1-2 Trip

When branch 1-2 goes out of service, generation from Bus 1 must reach the load centre entirely through branches 1-5, 2-5, and their downstream connections. Branch 1-5 jumps from a base loading of 68.4% to 168.5% — a swing of 100 percentage points. Branch 2-5 goes from 61.2% to 143.6%. No other single-branch outage in this system creates two simultaneous violations quite so severe.

Figure 6 captures this in two panels. The top panel places base case (blue) and post-contingency (teal/red) bars side-by-side for all 20 branches, making it easy to spot which branches are affected and by how much. The bottom panel plots ΔLoading (post minus base) — negative values indicate load relief (the removed branch itself drops to zero, and a few parallel paths also shed load), while the large positive bars on branches 1-5 and 2-5 dominate the picture.

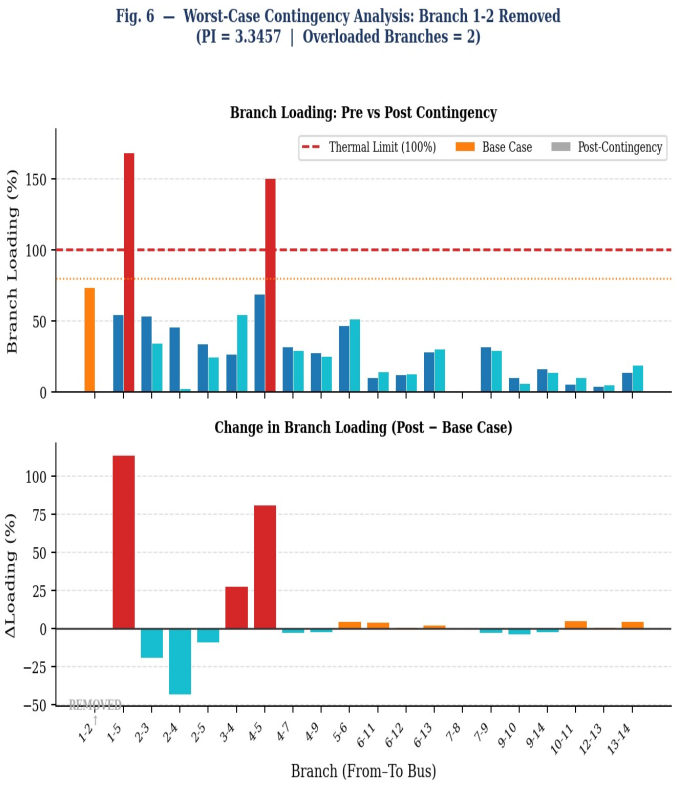


Fig. 6 — Branch 1–2 Trip: Pre vs. Post-Contingency Loading (Top) and ΔLoading per Branch (Bottom)

F. Bus Voltage Angle Profile

DC power flow output is bus angles rather than voltage magnitudes, so Figure 7 tracks angles across all 14 buses for both operating states. In the base case, angles decrease monotonically from Bus 1 (0°, slack) to Bus 14 (−14.9°), which is the expected pattern for a radially stressed load centre.

After the branch 1-2 outage, Bus 2 angle steepens from −3.1° to −8.4° — a shift of 5.3°. Buses 3 through 5, which are electrically downstream of Bus 2, follow suit. The widened angle spread across the surviving 1-5 and 2-5 paths drives their elevated flows. In a real AC study, angles of this magnitude would also push reactive power flows upward and risk voltage collapse at Bus 14.

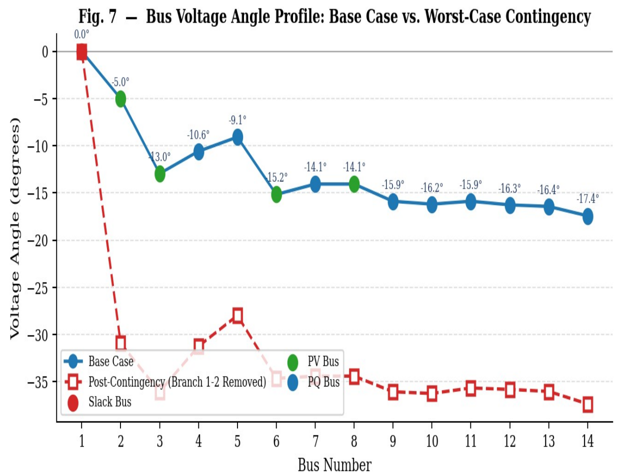


Fig. 7 — Voltage Angle Profile at All 14 Buses: Base Case vs. Branch 1–2 Trip Contingency

G. Summary Dashboard

Figure 8 consolidates four statistical views. Panel (a) is a pi chart of risk distribution: 15 out of 20 contingencies (75%) leave no branch overloaded; 2 cases (10%) overload exactly one branch; 3 cases (15%) produce two or more simultaneous overloads. Panel (b) scatters PI against maximum post-contingency loading — the correlation is tight and near-monotonic, which validates PI as a reliable proxy for actual severity rather than just a theoretical construct.

Panel (c) plots the PI severity curve in ranked order. The steep initial drop and long flat tail is consistent with the Pareto-like concentration of risk seen in most real transmission systems [5]. Panel (d) shows overload counts per contingency (in severity order), reinforcing that only the top-3 contingencies produce multiple simultaneous violations — a finding with direct implications for setting corrective action priorities.

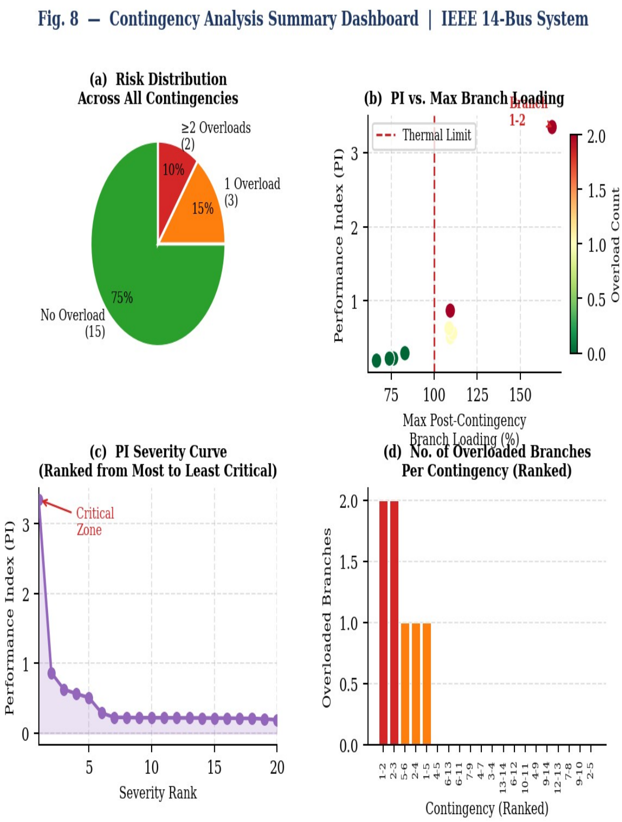


Fig. 8 — Summary Dashboard: Risk Pie Chart, PI Scatter, Severity Curve, Overload Count per Contingency

VI. WHAT THE NUMBER ACTUALLY MEAN

Three operational takeaways emerge from these results. The first is straightforward: branch 1-2 is the Achilles heel of this network. Uprating it or adding a parallel circuit would eliminate the worst N-1 scenario outright. The cost-benefit case for that investment is easier to make when you can attach the number "168.5% overload" to the risk and show exactly which other branches fail as a consequence.

The second takeaway is subtler. The PI severity curve drops sharply after rank 3, meaning only three contingencies require immediate remedial attention. That is a tractable problem — far less daunting than the impression given by a raw list of twenty outage scenarios. Identifying that elbow in the curve, and communicating it clearly to planners, is arguably as valuable as the raw numbers themselves.

Third, fast-acting devices such as a Thyristor Controlled Series Compensator (TCSC) on branch 1-5 could absorb excess power rerouting in real time, mitigating the post-contingency overload without any physical infrastructure changes. A follow-on optimal power flow study — incorporating TCSC settings as decision variables — could size and position such a device for maximum contingency relief.

VII. LIMITATIONS

DC power flow is an approximation, and its blind spots are worth stating directly. It ignores reactive power, so it cannot detect voltage violations — a category of post-contingency failure that is just as dangerous as thermal overloads in weakly meshed systems. Voltage collapse, in particular, is invisible to the DC model. The flat 1.0 pu voltage assumption also overstates branch flows in lightly loaded networks (where voltages tend to be slightly above 1.0 pu) and understates them when voltages have sagged.

Cascading failures are beyond scope here. Real-world blackouts typically begin with one outage, which overloads a second branch and trips it, which overloads a third, and so on. Simulating that chain requires a sequential contingency model with protection relay logic — substantially more complex than what we have built.

Future work will address these gaps through: (i) full Newton-Raphson AC contingency analysis to include voltage limit checks; (ii) a cascading failure model with overload-triggered branch tripping; and (iii) stochastic contingency analysis for networks with high penetration of wind and solar generation, where output variability adds a probabilistic dimension to security assessment.

VIII. CONCLUSION

We built a self-contained MATLAB DC power flow and N-1 contingency screener for the IEEE 14-bus test network, screened all twenty branch outage scenarios, and ranked them by Performance Index. The analysis identified the Bus 1-2 tie as the most critical single-element vulnerability: its loss overloads two branches simultaneously and produces a PI more than 15% higher than the next-worst contingency.

Eight simulation figures — the SLD, a base case loading chart, a PI ranking bar, a full 20×20 heat map, a top-10 severity ranking, a worst-case pre/post comparison, a bus angle profile, and a four-panel summary dashboard — together give a readable, complete picture of the system's security state. Of the twenty contingencies screened, only three demand remedial action; the remaining seventeen are handled by the network without any branch violation. That is a useful result for a planner deciding where to spend reinforcement budget on a constrained network.

ACKNOWLEDGEMENT

The authors sincerely thank their guide Prof. Vishal Mehtre, Department of Electrical Engineering, Bharati Vidyapeeth College of Engineering (Deemed to be University), Pune, for his constant guidance and support throughout this work. We also thank the institution for providing the computational resources required for this study.

REFERENCES

[1] US-Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States and Canada," Nat. Energy Board of Canada, Ottawa, 2004.

[2] B. Stott, J. Jardim, and O. Alsac, "DC Power Flow Revisited," IEEE Trans. Power Syst., vol. 24, no. 3, pp. 1290–1300, 2009.

[3] G. C. Ejebe and B. F. Wollenberg, "Automatic Contingency Selection," IEEE Trans. Power App. Syst., vol. PAS-98, no. 1, pp. 97–109, 1979.

[4] IEEE Power & Energy Society, "IEEE 14-Bus Power Flow Test Case," University of Washington Power Systems Test Case Archive, Seattle, 1993.

[5] F. Capitanescu, M. Glavic, D. Ernst, and L. Wehenkel, "Contingency Filtering Techniques for Preventive Security-Constrained OPF," IEEE Trans. Power Syst., vol. 22, no. 4, pp. 1690–1697, 2007.

[6] A. J. Wood, B. F. Wollenberg, and G. B. Sheblé, "Power Generation, Operation, and Control," 3rd ed., John Wiley & Sons, Hoboken, NJ, 2013.

[7] P. Kundur, "Power System Stability and Control," McGraw-Hill, New York, 1994.

[8] H. Saadat, "Power System Analysis," 3rd ed., PSA Publishing, Alexandria, VA, 2011.

[9] K. Morison, L. Wang, and P. Kundur, "Power System Security Assessment," IEEE Power & Energy Mag., vol. 2, no. 5, pp. 30–39, 2004.

[10] R. D. Christie, B. F. Wollenberg, and I. Wangensteen, "Transmission Management in the Deregulated Environment," Proc. IEEE, vol. 88, no. 2, pp. 170–195, 2000.

[11] V. V. Mehtre and A. Dubey, "A Case Study for Optimization of Power System Load Flow Analysis using ETAP Software," World Journal of Advanced Engineering Technology and Sciences, vol. 11, no. 02, pp. 476–492, DOI: 10.30574/wjaets.2024.11.2.0121, 2024.

[12] M. Shukla and V. V. Mehtre, "Power System Stability and Control," Iconic Research and Engineering Journals, vol. 6, no. 1, pp. 19–23, 2022.

[13] V. V. Mehtre, R. Keshari, and Z. Hyder, "Symmetrical and Unsymmetrical Faults Analysis," International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering (IJIREEICE), DOI: 10.17148/IJIREEICE.2021.9730, 2021.

[14] M. Molawade, T. Patil, and V. V. Mehtre, "Comparative Study of Bisection and Newton-Raphson Methods of Root-Finding Problems," International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering (IJIREEICE), DOI: 10.17148/IJIREEICE.2022.101103, 2022.

[15] V. V. Mehtre and U. Chaurasia, "Load Flow Analysis of 66 kV Substation using ETAP Software," Iconic Research and Engineering Journals, 2023.

[16] V. V. Mehtre and P. Ranjan, "Newton Backward Interpolation Method," International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering (IJIREEICE), DOI: 10.17148/IJIREEICE.2022.10213, 2022.

AUTHOR BIOGRAPHIES

Ark Sinha is a student of Electrical Engineering at Bharati Vidyapeeth College of Engineering (Deemed to be University), Pune, India. His academic interests include power system analysis, MATLAB-based simulation, and contingency screening for transmission networks.

Suyog Dhyaneshwar Patil is a student of Electrical Engineering at Bharati Vidyapeeth College of Engineering (Deemed to be University), Pune, India. His areas of interest include DC power flow modelling, performance index computation, and power system security assessment.

Prof. Vishal Mehtre (Guide) is a faculty member in the Department of Electrical Engineering, Bharati Vidyapeeth College of Engineering (Deemed to be University), Pune, India. His research and teaching interests include power systems, electrical machines, and simulation-based approaches to power network analysis.