

Grid Resilience under Ultra-High Renewable Penetration:

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INTRODUCTION & AIM

Engineering Challenge

Autonomous island grids with high renewable energy penetration exhibit reduced transmission security margins under N–1 contingencies. The Rhodes (Greece) 150 kV network is fully isolated with no mainland interconnection, featuring:

- ▶ Geographically distributed wind and PV generation at peripheral buses
- ▶ Limited transmission redundancy — radial and weakly-meshed corridors
- ▶ Concentrated thermal loading on specific critical corridors
- ▶ Strong seasonal demand variation due to tourism

Research Question

Can a modest corrective injection (BESS) significantly reduce post-contingency thermal overload severity in an autonomous island grid?

Scientific Novelty

A single-pass severity-weighted PTDF framework linking overload criticality with bus-level controllability — including explicit sink-bus sensitivity analysis rarely addressed in prior work.

METHOD

Network Model

6-bus, 7-branch DC equivalent of the Rhodes 150 kV network. High-RES summer dispatch scenario. Full AC topology reduced to lossless DC approximation. Implemented in PowerWorld Simulator.

Analytical Framework

$$\text{Severity}(c,e) = \max(S_{c,e} - S_{e_max}, 0) \text{ [MVA]}$$

→ How much each branch exceeds its thermal rating after a contingency

$$\text{SysAMVACO} = \sum_e \text{AMVACO}(e)$$

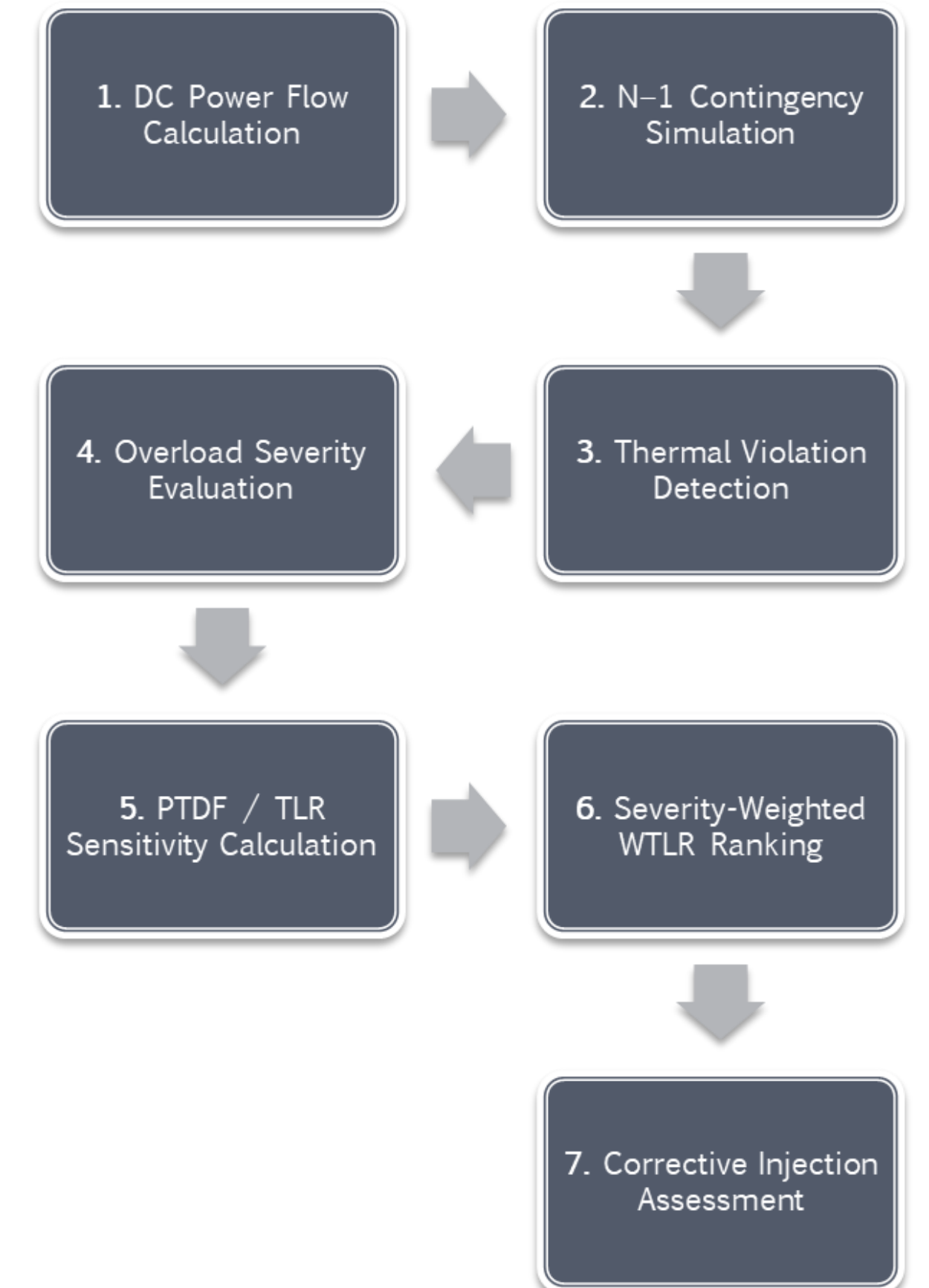
→ Aggregate severity: one number for total network thermal stress

$$\text{WTLR}(b) = \sum_c \sum_e \text{Severity} \times (-\text{Sign} \times \text{PTDF}) / 100$$

→ Bus ranking score: combines severity with directional flow sensitivity

7-Step Workflow

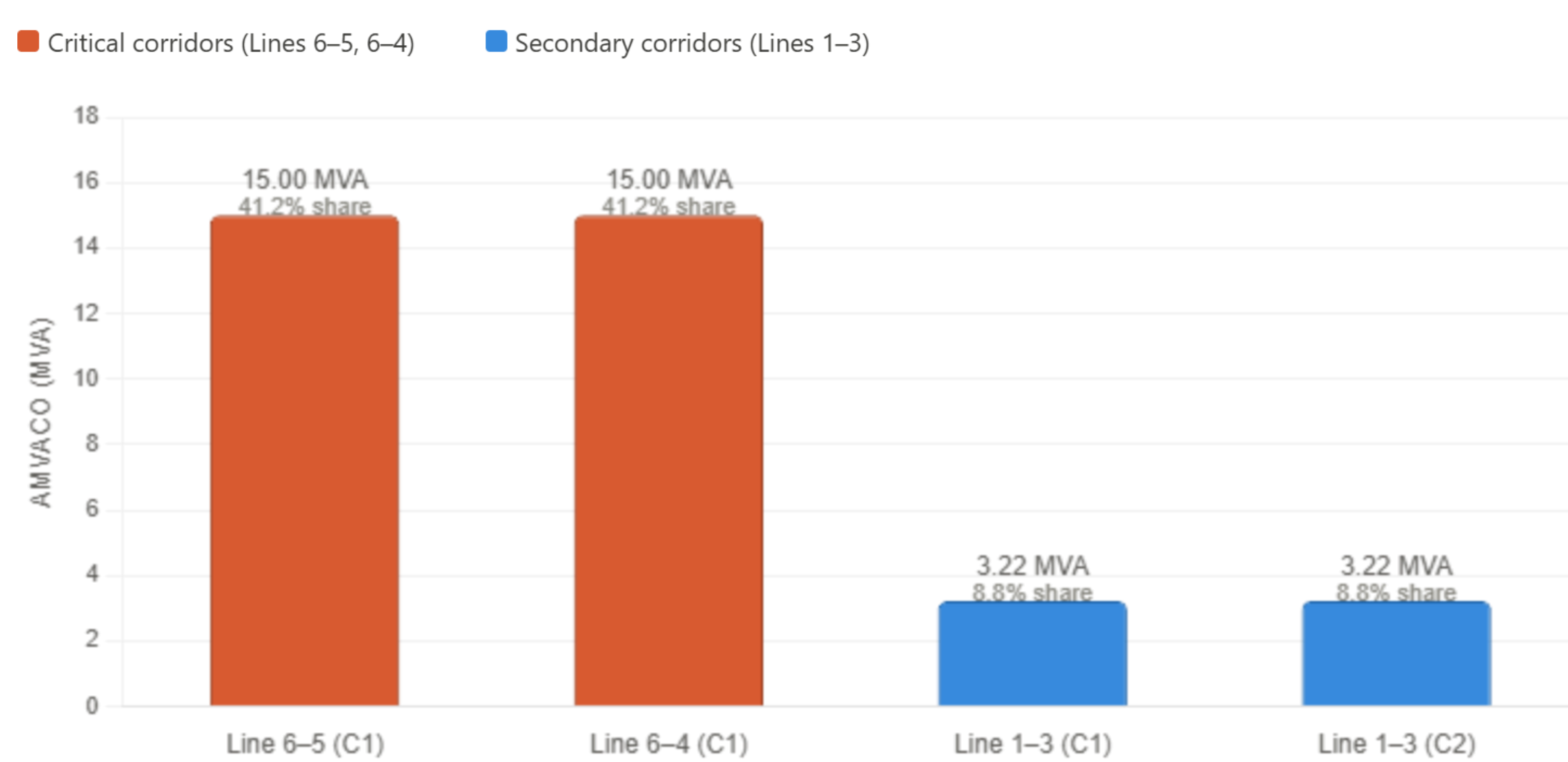
DC Power Flow → N–1 Simulation → Thermal Violation Detection → Severity Evaluation → PTDF/TLR Calculation → WTLR Ranking → Corrective Injection Assessment



RESULTS & DISCUSSION

N–1 Contingency Screening

Overload risk is highly concentrated: Lines 6–5 and 6–4 account for 82.3% of total system severity (SysAMVACO = 36.44 MVA). Each exceeds its thermal limit by ~23% (15 MVA) after a single contingency. Lines 1–3 contribute only 8.84% each.

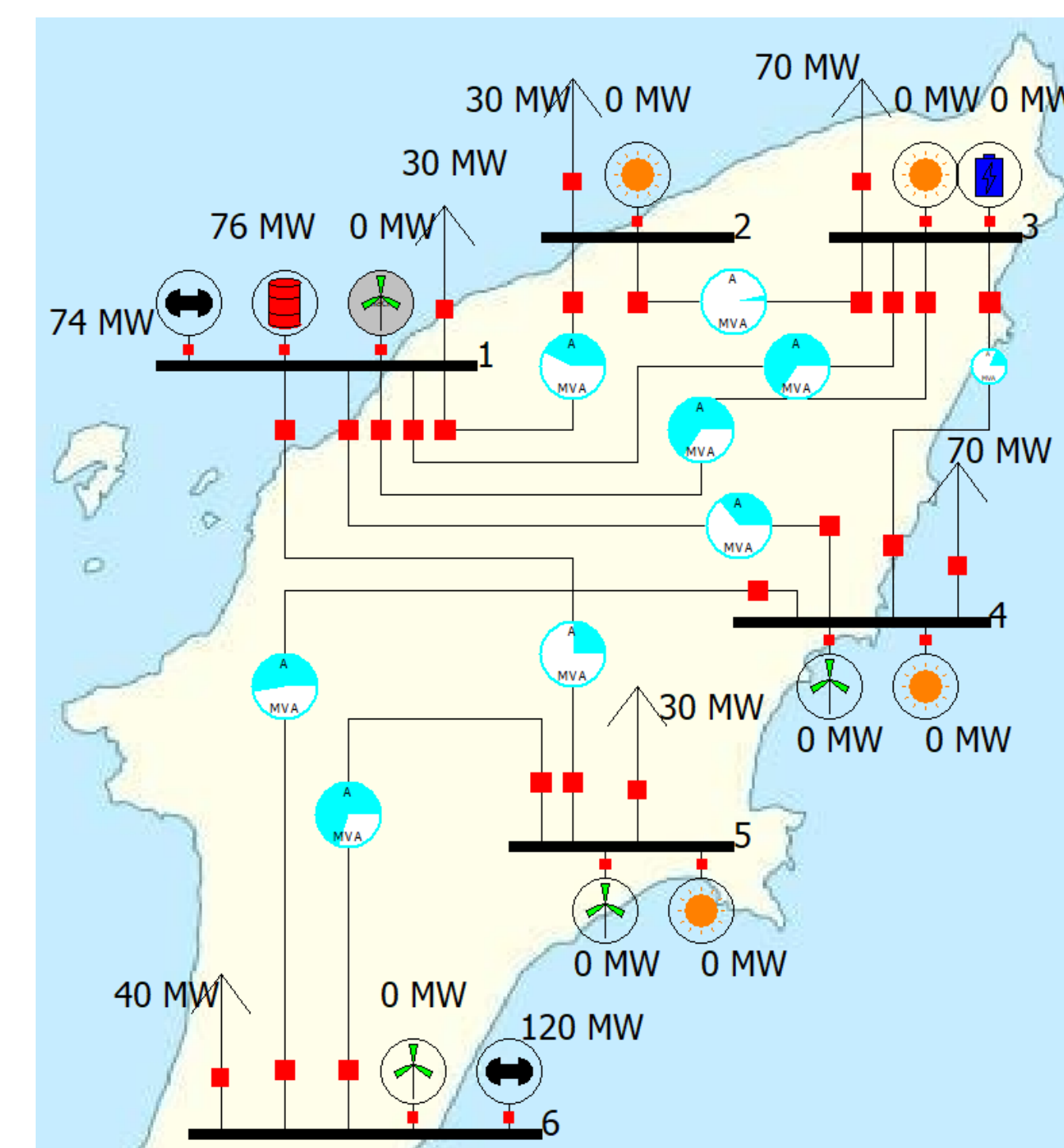
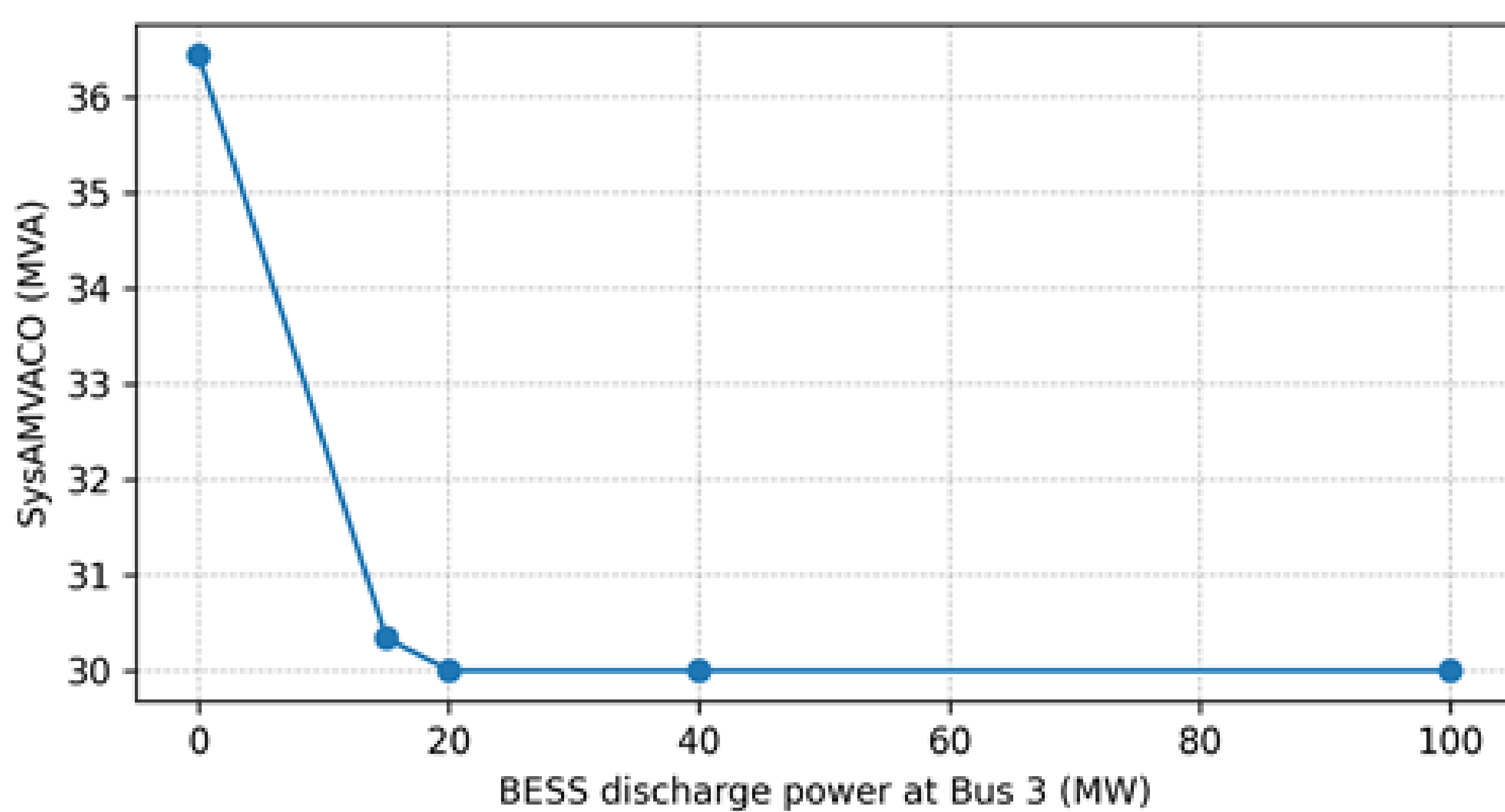


PTDF Sensitivity — Bus Ranking (WTLR)

Bus 3 (Rank 1): Highest positive WTLR — most effectively redistributes flow away from overloaded corridors. Optimal BESS location.

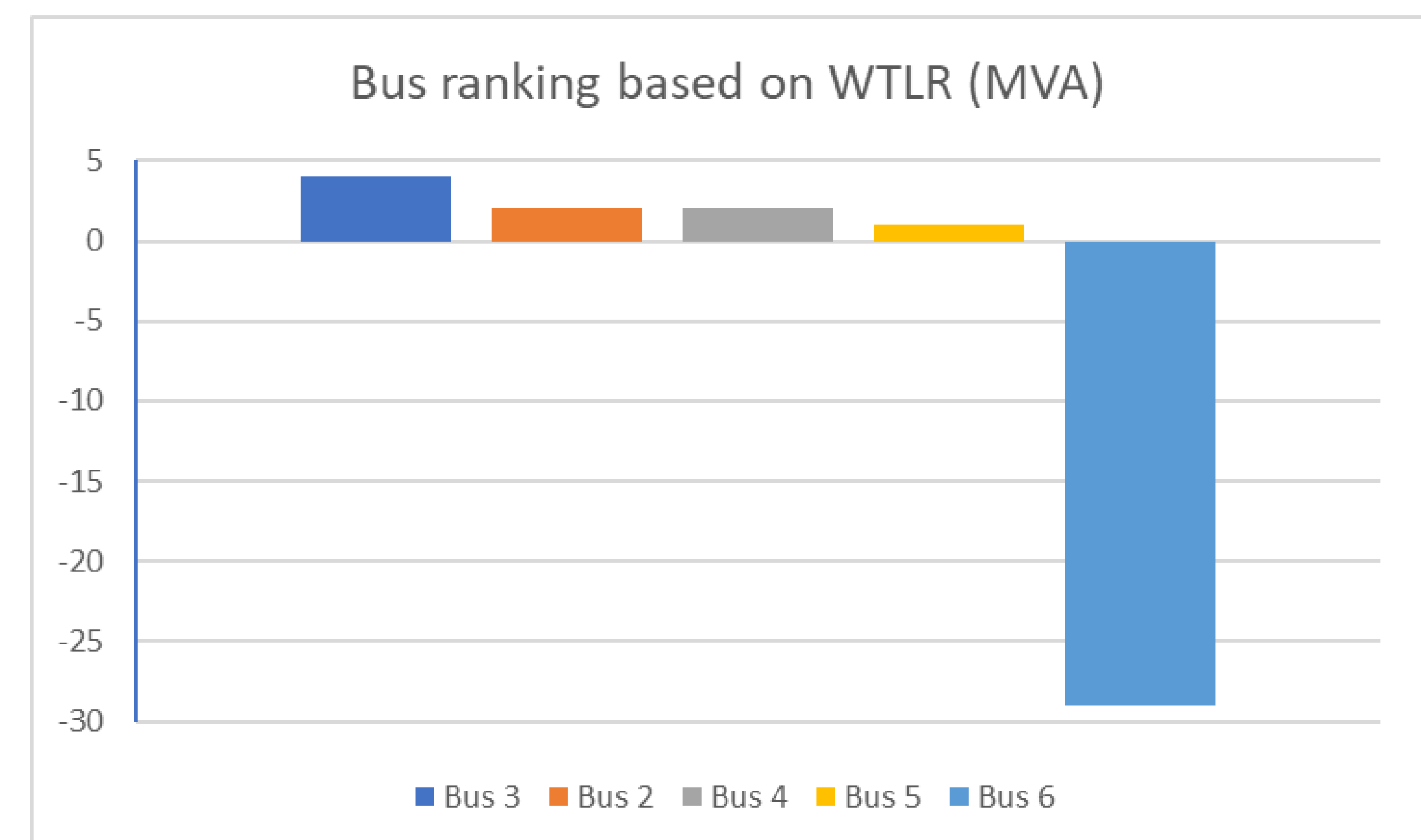
Bus 6 (Negative WTLR): Injection aggravates congestion. Must be avoided for corrective dispatch.

Buses 2, 4, 5: Positive but smaller scores — less effective than Bus 3.



BESS Corrective Action — Bus 3

15 MW injection at Bus 3 reduces SysAMVACO from 36.44 to ~30 MVA (~18% reduction). Diminishing returns beyond 20 MW — a modest battery captures most of the security benefit.



Sink-Bus Sensitivity

PTDF rankings depend on the selected sink-bus convention. Bus 3 remains consistently high-ranked and Bus 6 consistently worsens congestion across all tested configurations. Intermediate rankings (Buses 2, 4, 5) shift — multi-configuration screening is necessary for robust deployment.

CONCLUSIONS

1. Critical corridors: Lines 6–5 and 6–4 carry 82.3% of post-contingency severity — must be prioritised in any reinforcement programme.
2. Optimal BESS placement: Bus 3 (highest WTLR). A 15 MW injection reduces system severity by ~18%.
3. Bus 6 must be avoided: negative WTLR under all configurations — injection worsens overloads.
4. Sink-bus sensitivity matters: rankings shift with reference bus choice — multi-configuration screening required.

FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

Future Research Directions

- ▶ AC OPF integration (reactive power, voltage, losses)
- ▶ Dynamic security assessment (transient stability, frequency)
- ▶ Stochastic N–1 analysis (Monte Carlo, risk-weighted rankings)
- ▶ Multi-BESS optimisation (coordinated size, location, dispatch)

Key References

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- [3] Ejebe, G.C.; Wollenberg, B.F. Automatic Contingency Selection. IEEE Trans. 1979.