

GRID EMT

SIMULATION INITIATIVE

Event Detection and Contingency Selection

Tara Aryal & Shahriar Rahman Fahim

8/21/2026



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Event Detection on Partial Generator Tripping for Enhanced Grid Observability

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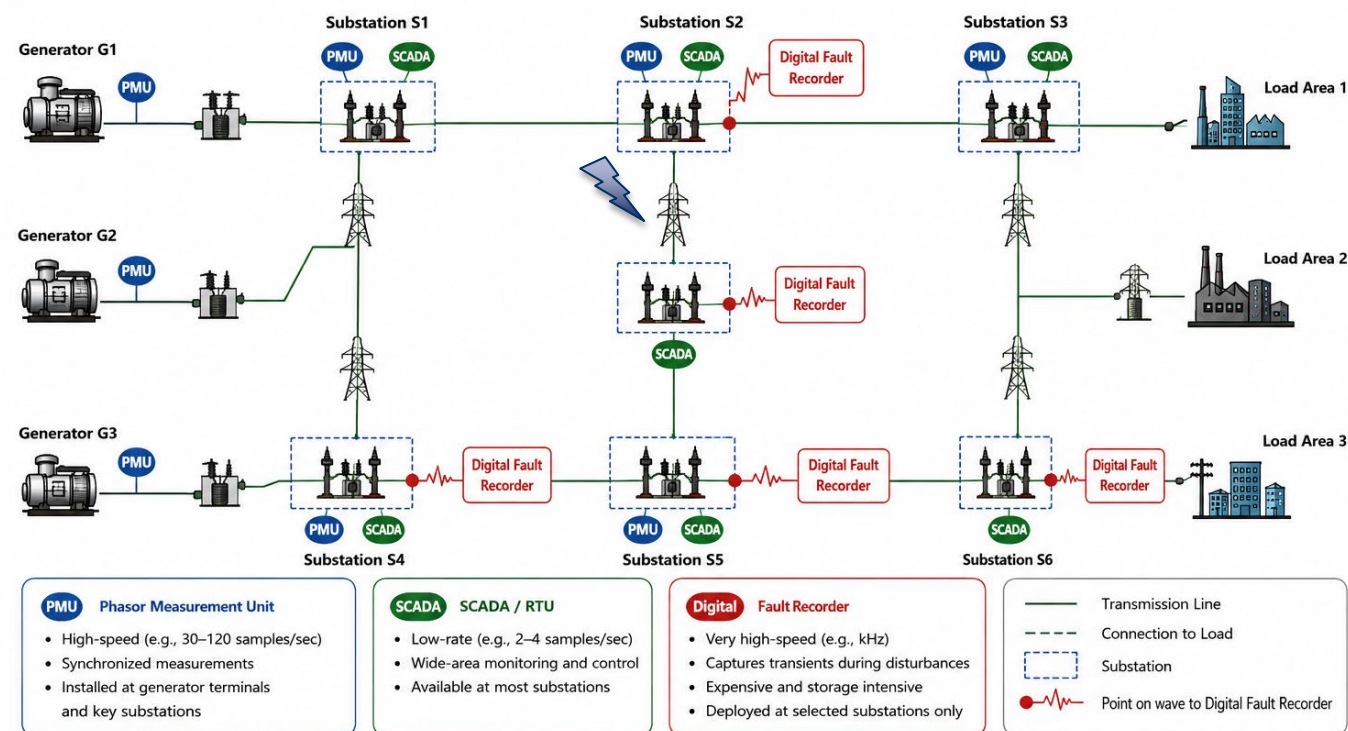
Introduction

- Event detection → improved grid observability
- Generator trips
 - immediate generation–load imbalance
 - rapid frequency/voltage fluctuations
- Fast event detection
 - Locate the disturbance
 - Identify the tripped unit
 - Estimate lost generation
- **PMU/SCADA:** wide-area, but limited resolution
- **Point on Wave:** 8–60 kHz, captures fast transients, but sparse & computationally/memory intensive

Typical Distribution of PMUs and Digital Fault Recorders in a Power Grid

PMUs: Installed at generator terminals and key substations

Digital Fault Recorders (DFRs): Deployed at selected substations only



PMUs provide wide-area, high-speed visibility at generator terminals and key substations.

Digital Fault Recorders are deployed only at selected substations and connected as point-on-wave to capture high-frequency transients.

Source: ChatGPT

Sparse DFRs and limited generator measurements challenge event localization



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Objectives

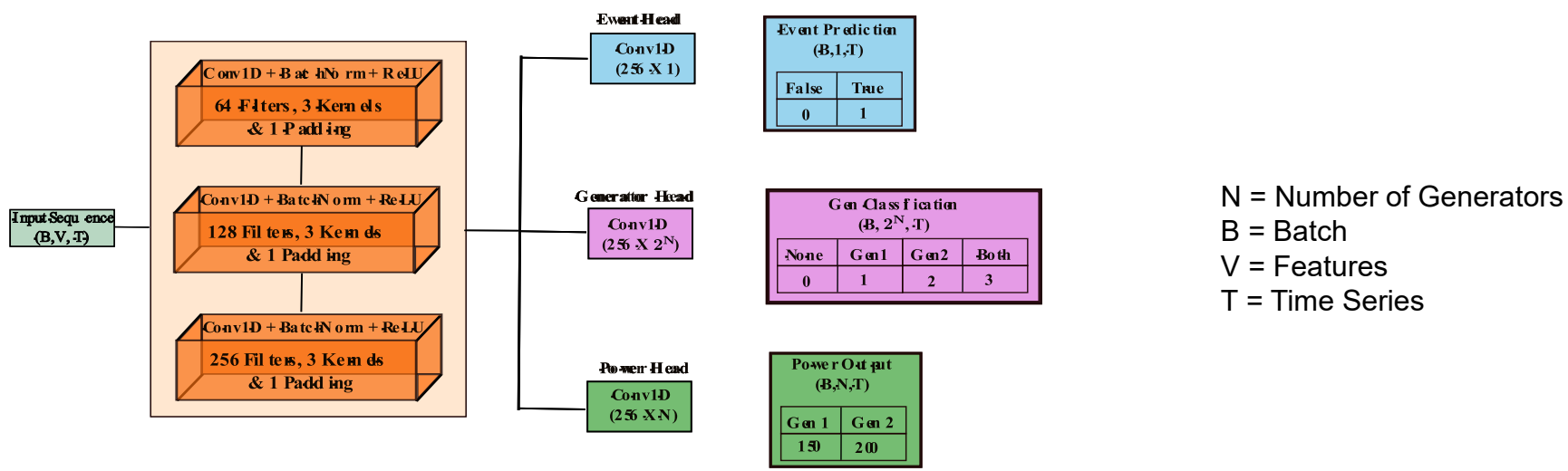
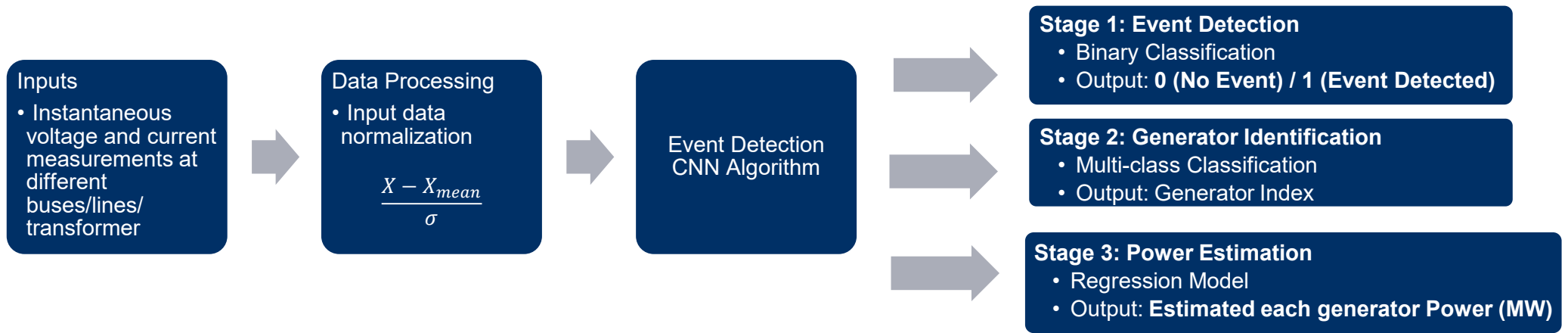
- ❑ Develop an event detection algorithm for detecting and identifying partial generator trips
 - Identify the affected generator units
 - Estimate the generator power output during disturbance
- ❑ Explore Convolution Neural Network (CNN) feasibility for generator tripping



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Proposed Event Detection Algorithm using CNN Architecture



Normalized voltage and current fed into multi-head CNN for event detection, tripped-generator identification, and MW estimation

Simulation Setup

Modified IEEE 9 bus system

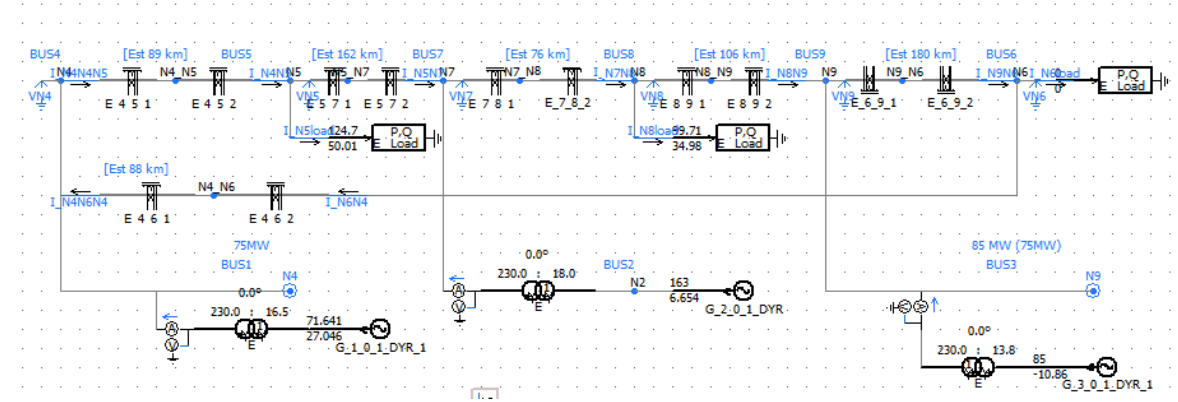
- Two inverters connected at bus 4 and bus 9
- System simulation time = $1\mu s$

DFR based measurements at 20kHz i.e. $50\mu s$

Generated training and testing datasets includes

- Bus and line faults
- Varying fault resistance

Training/testing ratio = 80/20

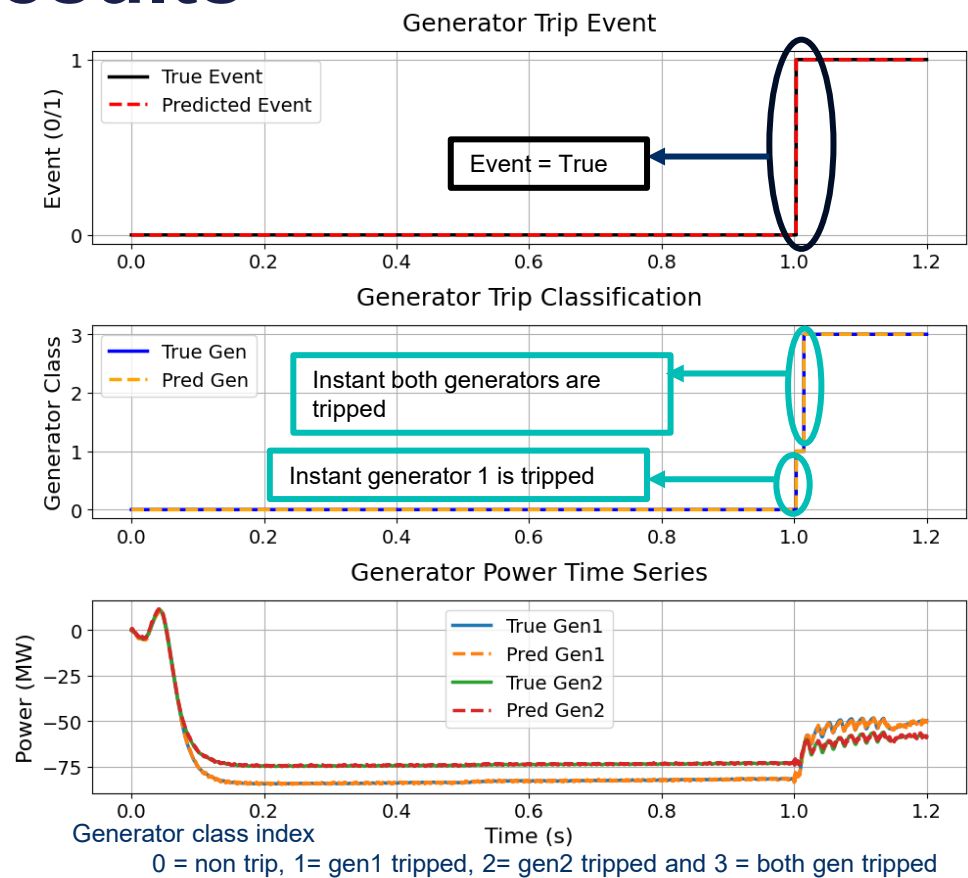


$$\text{Total Loss} = \underbrace{-[y \log(p) + (1 - y) \log(1 - p)]}_{\text{Binary Cross Entropy}} + \underbrace{-\sum_{i=0} y_i \log(p_i)}_{\text{Cross Entropy}} + \underbrace{\frac{1}{N} ||y - \hat{y}||^2}_{\text{Mean Square Error}}$$

y = true label(0 or 1)
 p = predicted probability
 i = class
 $\hat{y}$ = estimated label



Results



Estimated event, tripped generator and power closely tracks actual responses

Results demonstrate the feasibility of the CNN-based framework

CNN-Based Generator Trip Detection and Power Estimation Performance



MAE = Mean Absolute Error
MSE = Mean Square Error
RMSE = Root Mean Square Error

High classification accuracy achieved for generator trip detection and unit identification



Conclusion

- ❑ Multi-head CNN successfully demonstrated on the IEEE 9-bus system
- ❑ Promising performance in event detection, unit identification, and MW power estimation
- ❑ Future work
 - expand datasets, operating conditions, and fault scenarios
 - benchmark against other algorithms like Graph Neural Networks and validate using real PMU/DFR data



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Contingency Selection



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Avg 10s simulation time (50 μ s)

IEEE 9 Bus

Re-Integrate simulation time **40** s/case

IEEE 39 Bus

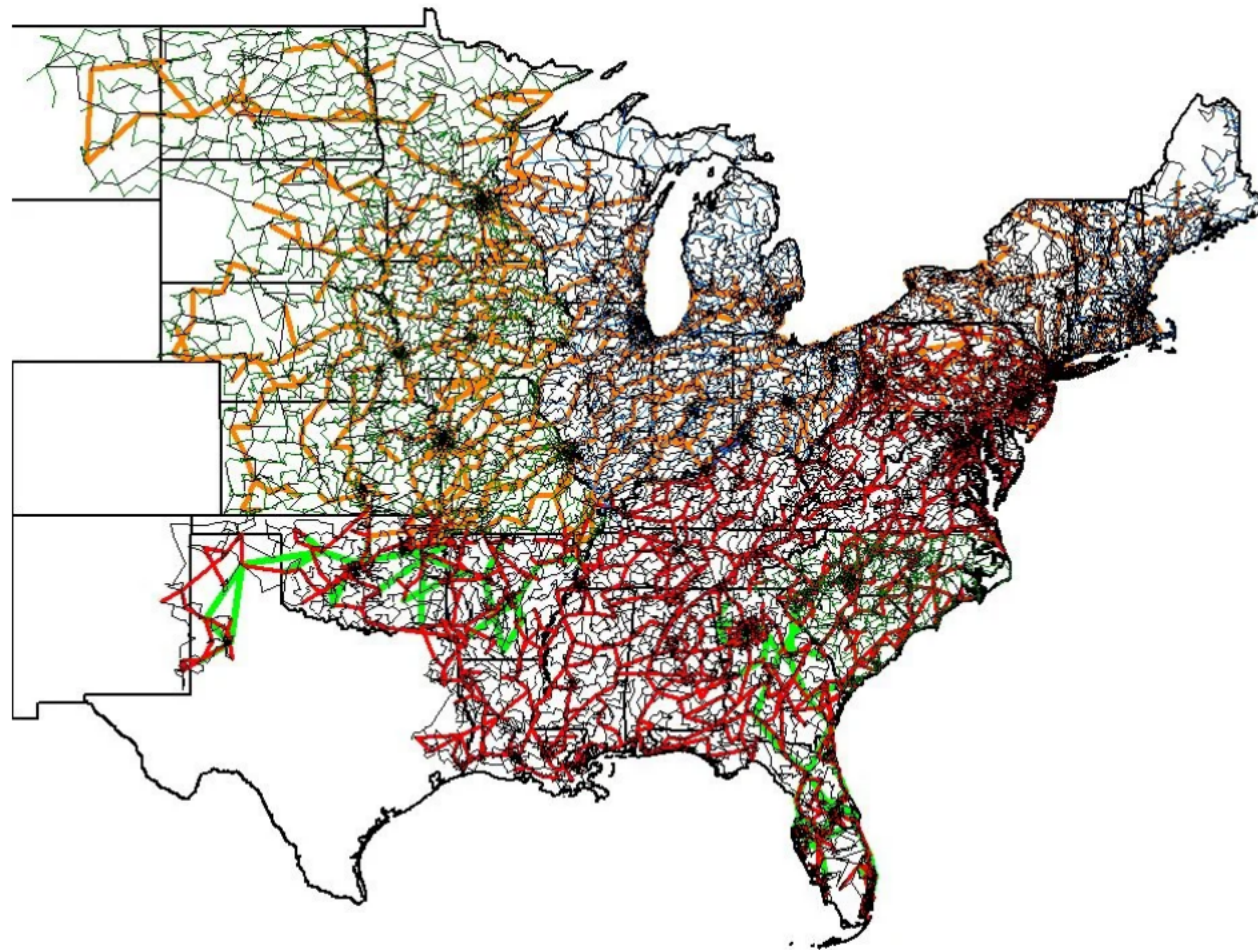
Re-Integrate simulation time **4** min/case

IEEE 118 Bus

Re-Integrate simulation time **12** min/case

ACTIVSg 70k Bus

?



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Attention-Aware Transfer Learning for Contingency Selection: From Vast Search Spaces to Vital Few

Presenter: Shahriar Rahman Fahim

8/21/2026



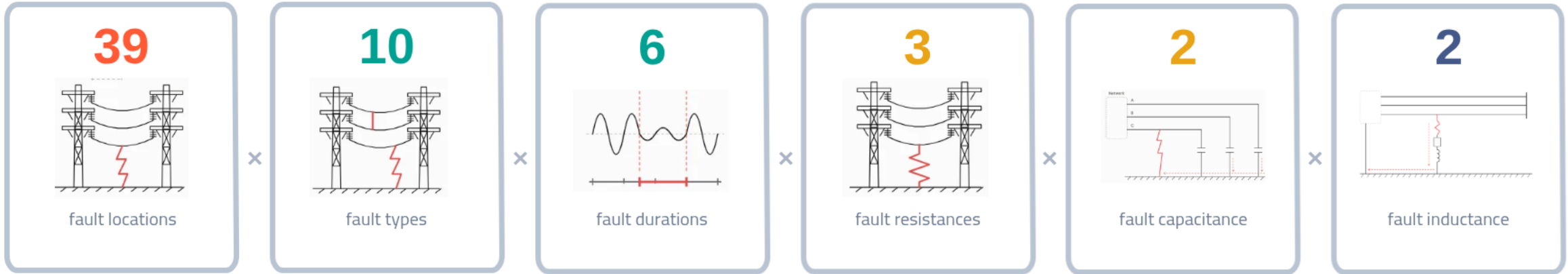
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Brute Force is off The Table

For the IEEE 39-bus system, each unique combination of fault and fault parameters is executed as one EMT simulation.



39 **390** **2340** **7020** **14040** **28080**

EMT cases EMT cases EMT cases EMT cases EMT cases EMT cases



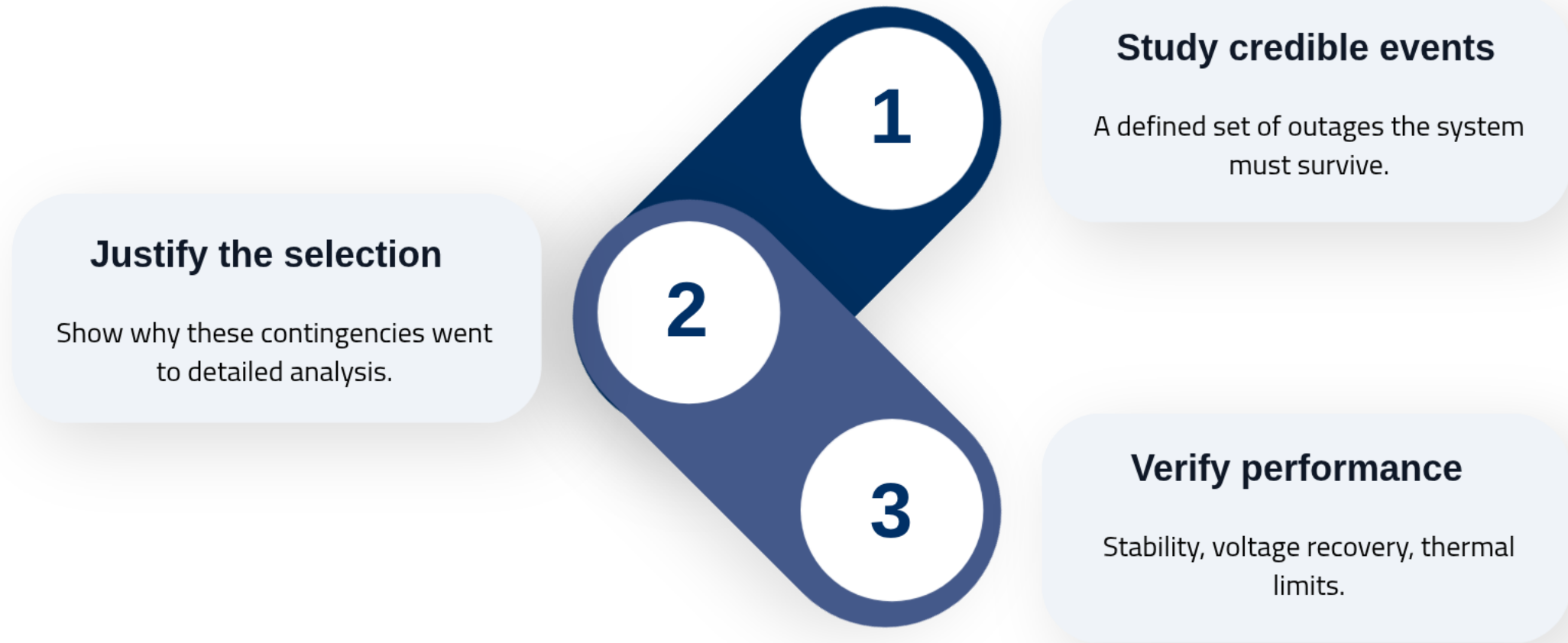
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The standard asks for it (NERC TPL-001-5)

Contingency: A credible outage or fault (line, transformer, generator, bus) that the system must survive.





Major Challenges

Labelled data

Few severe cases, and each label costs a full simulation. Extremely limited to no data for large power grids

Operating-point dependence

Ranking valid for one snapshot does not survive to another without explicit conditioning on system state.

Case count and imbalance

The fault cases grows multiplicatively, not additively. The cases that matter live in the tail.

Broken locality

Resonance and control-mode excitation let a remote contingency dominate a nearby one.



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What We are Bringing

1

Transfer learning for Contingency Selection

- Learn on the small system or a subpart of bigger system, apply to the large one or with different operating condition.
- Attention normalized within each node's own neighbourhood. Physics-informed loss acts as a prior that carries over.
- Severity ordering moves to a new system with a small fine-tuning set instead of bulk simulation.

2

Metrics That Carry Across Different Operating Conditions

- They are computed on EMT domain, so nothing is filtered before measurement.
- Self-referenced, dimensionless, size-independent and value means the same thing on any systems or operating conditions.
- Transfer degrades gracefully with distribution shift rather than breaking because the label means something different.

3

Focused Analysis

- The screener produces an ordering and the cut-off produces a working set.
- Probability aware selection: A contingency that occurs once in fifty years does not compete with one that occurs several times a year.
- Each retained case carries its own explanation: which metric drove it, which propagation path the attention map indicates.



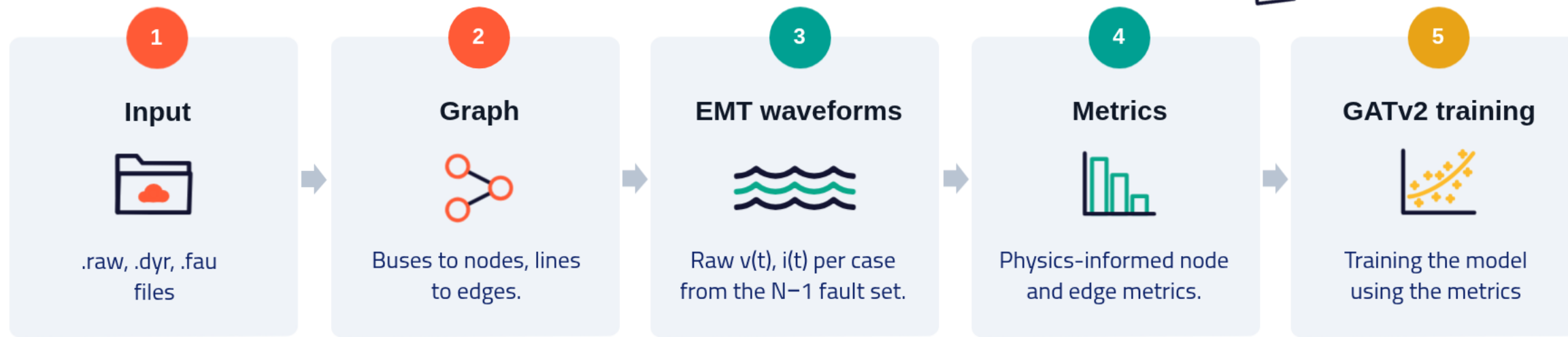
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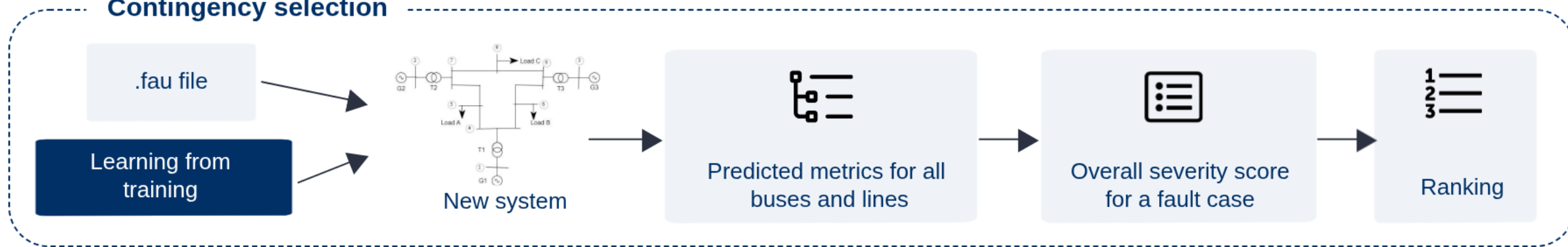


Selection Process

Training steps



Contingency selection





Metrics

NODE LEVEL · SEVEN PER BUS

- **Voltage depression energy** area of the sag over the window
- **Voltage violation duration** time spent outside the band
- **Voltage recovery time** how long to return
- **Peak instantaneous voltage** highest excursion during the fault
- **Steepest dv/dt** fastest instantaneous change
- **Frequency nadir** lowest frequency reached
- **RoCoF** rate of change of frequency

EDGE LEVEL · THREE PER LINE

- **Current-deviation integral** per phase, referenced to pre-fault
- **First-2-cycle overcurrent** per-unit, inrush window
- **Residual overcurrent** per-unit, rest of the window

WHY THESE

- Dimensionless by construction, no units to reconcile.
- Self-referenced denominators, never ensemble statistics.

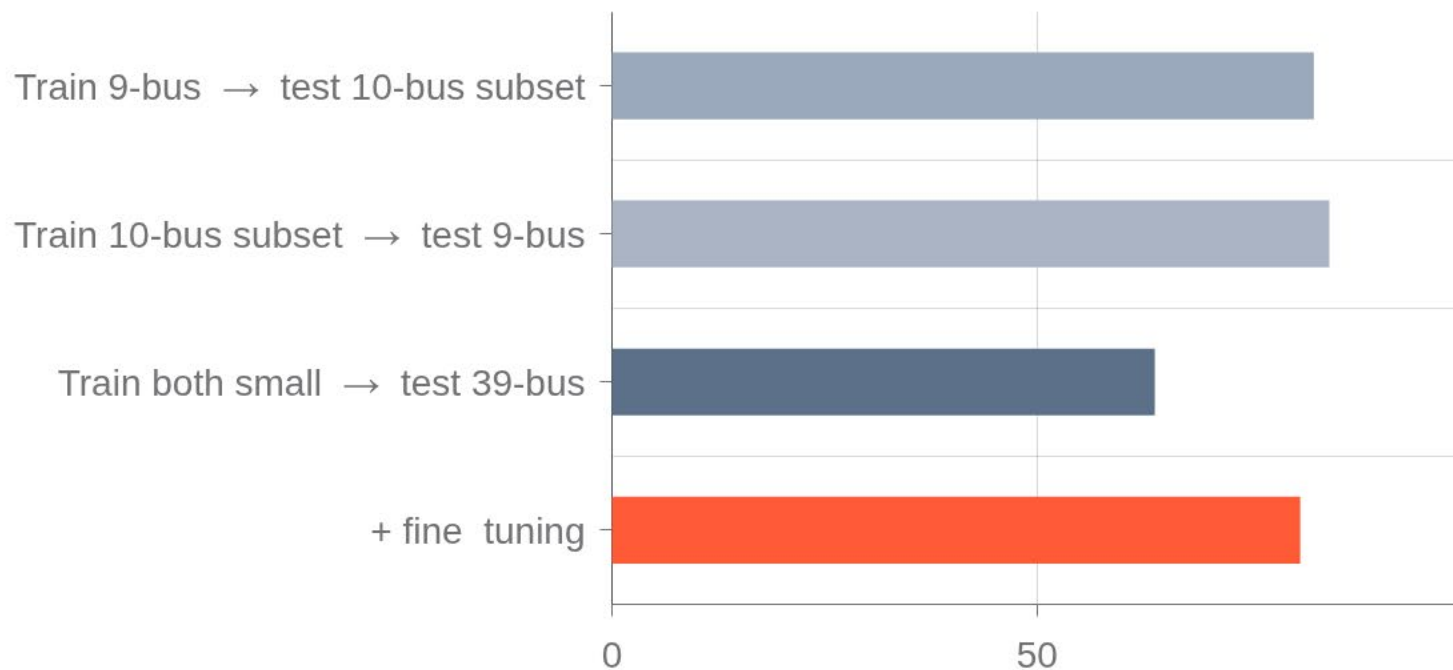


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Selection Accuracy



80.97%

on the full IEEE 39-bus system after fine-tuning on a small labelled subset



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Impacts

EMT-domain severity ranking without the exhaustive simulation behind it.
the expensive labeling happens once, not once per network.

It doesn't decide anything.

It produces an ordering. The cut-off is still an engineering judgement,

Low adoption barrier

Nothing downstream changes, the ranker sits before the analysis.

probability weighting adds

The ranking becomes expected loss, not worst-case consequence

Locally deployed LLM makes the ranking explainable without sending anything outside.

It reads structured evidence, surfaces what's relevant, compares cases, and writes it up. It never invents a severity value and never overrides one.



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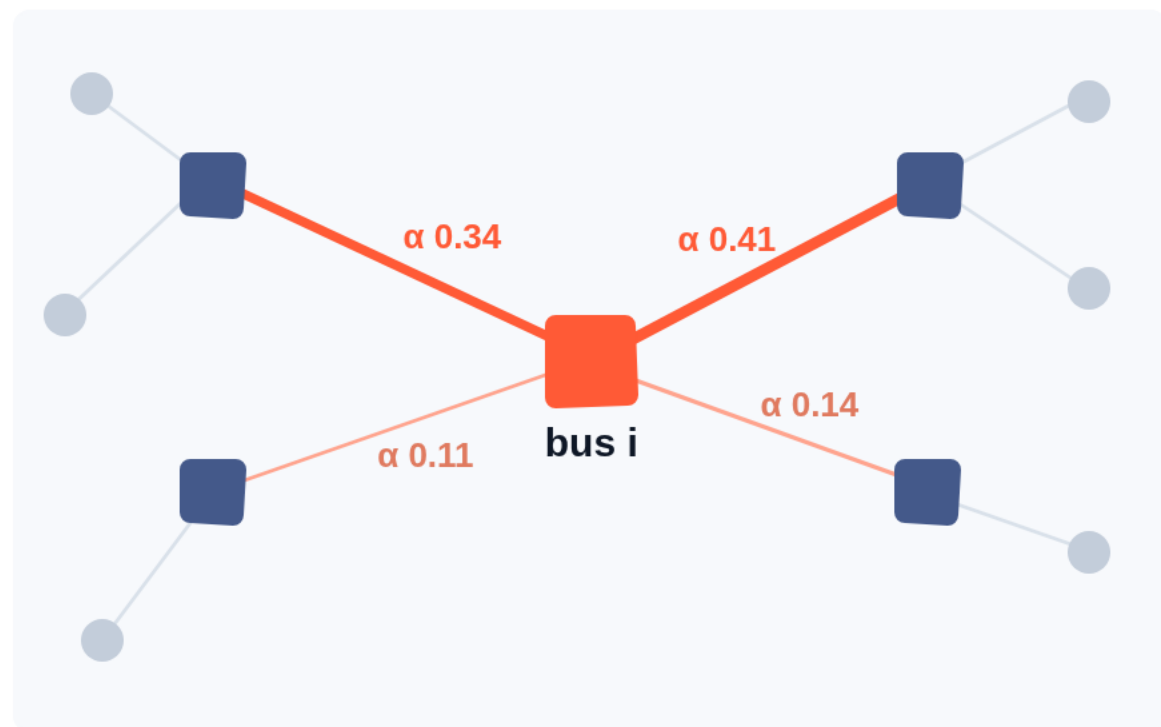


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How GATv2 works



Attention is node-dependent, and stays valid on a graph it has never seen.

- **Score the neighbours**

Attention is computed after the nonlinearity — dynamic, not fixed.

- **Aggregate by weight**

Each bus reads its neighbours in proportion to electrical influence.

- **Propagate multi-hop**

Encode, bottleneck, decode — stress travels beyond one hop.

- **Multi-head output**

All metrics predicted jointly for every bus and line.