Algorithm 1 Hazard-Informed Contingency Generation and Power-Flow Impact Analysis

Require: Grid model $G = (\text{buses}, \text{branches}, \text{transformers } T, \text{substations } S)$; Hazard grid H with PGA values and cell spacing Δ; Amplification distributions A_c for voltage classes c; Qualification threshold at bushing $\theta_{\text{bush}} \in \{1.0g, 2.0g\}$; Overload trip threshold $\rho \in \{1.25, 1.50\}$; Number of Monte Carlo samples S; solver settings.

Ensure: Per-sample results R_s (failed assets, load not served, topology status); Aggregated statistics and per-asset failure frequencies.

Initialize $R \leftarrow \emptyset$, and failure counters $\phi[i] \leftarrow 0$ for all $i \in T$
// **Map hazard to assets**
$T^* \leftarrow \emptyset$
for each transformer $i \in T$ **do**
    Locate nearest hazard cell to $(\text{lat}_i, \text{lon}_i)$ and obtain $\text{PGA}_{\text{site}}[i]$
    if distance to cell $\leq \Delta$ **then**
        $T^* \leftarrow T^* \cup \{i\}$
    else
        mark i as "out of coverage"
    end if
end for
for $s = 1 \to S$ **do** ▷ Monte Carlo loop
    $F \leftarrow \emptyset$ ▷ Initialize failure transformer set
    for each $i \in T^*$ **do**
        Determine voltage class $c(i)$
        Draw amp_ratio$[i] \sim A_{c(i)}$ ▷ bushing/base amplification
        $\text{PGA}_{\text{bush}}[i] \leftarrow \text{PGA}_{\text{site}}[i] \times$ amp_ratio$[i]$
        if $\text{PGA}_{\text{bush}}[i] \geq \theta_{\text{bush}}$ **then**
            $F \leftarrow F \cup \{i\}$; $\phi[i] \leftarrow \phi[i] + 1$
        end if
    end for
    // **Contingency setup**
    Apply outages in G corresponding to transformers in F
    // **AC power-flow with overload-trip monitors**
    status $\leftarrow$ Solve power-flow on G
    iter $\leftarrow 0$
    while status = CONVERGED **and** any element loading $> \rho$ **do**
        Trip violating element(s) according to policy
        status $\leftarrow$ Re-solve power-flow on updated topology
        iter $\leftarrow$ iter + 1
        if iter $\geq$ MaxMonitorIters **then**
            break
        end if
    end while
    // **Extract impact metrics**
    $L_s \leftarrow$ total load not served (MW)
    $K_s \leftarrow$ number of tripped elements
    $I_s \leftarrow$ identify islands and de-energized areas
    $R \leftarrow R \cup \{(s, F, \text{status}, L_s, K_s, I_s)\}$
end for
// **Aggregate statistics**
for each $i \in T^*$ **do**
    failure_frequency$[i] \leftarrow \phi[i]/S$
end for
Compute distributions of $\{L_s\}$, $\{K_s\}$, and spatial maps from $\{I_s\}$
return R, failure_frequency

Algorithm 2 Streamlined Hazard-Informed Contingency and Power-Flow Simulation

Require: Grid model G, hazard grid H with PGA values and spacing Δ, amplification distributions A_c, bushing threshold θ_{bush}, overload limit ρ, and number of Monte Carlo samples S.

Ensure: Per-sample outcomes R_s and per-transformer failure frequencies.

Initialize result container R and counters $\phi[i] = 0$ for all transformers.

// **Step 1: Map hazard intensity to assets**
for each transformer i in G **do**
    Locate nearest hazard cell to $(\text{lat}_i, \text{lon}_i)$ and get $\text{PGA}_{\text{site}}[i]$
    if distance $\leq \Delta$ **then** mark i as covered;
    elsemark as “out of range”
    end if
end for

// **Step 2: Monte Carlo sampling of component failures**
for $s = 1 \to S$ **do** ▷ Each sample = one possible event scenario
    $F \leftarrow \emptyset$ ▷ Initialize failed-transformer set
    for each covered transformer i **do**
        Draw amplification amp_ratio$[i] \sim A_{c(i)}$ by voltage class
        Compute $\text{PGA}_{\text{bush}}[i] = \text{PGA}_{\text{site}}[i] \times$ amp_ratio$[i]$
        if $\text{PGA}_{\text{bush}}[i] \geq \theta_{\text{bush}}$ **then**
            Add i to F and increment $\phi[i]$
        end if
    end for
    Apply outages in G corresponding to F ▷ Contingency realization

    // **Step 3: Power-flow analysis with overload checks**
    Solve AC power-flow on updated network using Newton–Raphson
    while solution converged **and** any element loading $> \rho$ **do**
        Trip overloaded elements; re-solve power-flow
    end while

    // **Step 4: Record scenario-level impacts**
    Measure L_s = load not served, K_s = elements tripped, I_s = islands formed
    Store results $R \leftarrow R \cup \{(s, F, L_s, K_s, I_s)\}$
end for

// **Step 5: Aggregate statistics across all samples**
for each transformer i **do**
    Compute failure_frequency$[i] = \phi[i]/S$
end for
Summarize $\{L_s, K_s, I_s\}$ for system-level performance metrics
return R, failure_frequency

Algorithm 3 Simplified Workflow for Hazard-Driven Grid Impact Simulation

Require: Grid model G, hazard grid H (PGA, spacing Δ), amplification distributions A_c, bushing threshold θ_{bush}, overload threshold ρ, and number of Monte Carlo samples S.

Ensure: Scenario outcomes R_s and per-transformer failure frequencies.

Initialize result container R and counters $\phi[i]=0$ for all transformers i.
Map each transformer to nearest hazard cell; keep only assets within coverage.
for $s = 1 \to S$ **do** ▷ Monte Carlo realizations
    Sample amplification amp_ratio[i] $\sim A_{c(i)}$ for each transformer.
    if $\text{PGA}_{\text{site}}[i] \times \text{amp\_ratio}[i] \geq \theta_{\text{bush}}$ **then** mark i as failed.
    end if
    Apply outages for failed transformers; run AC power-flow on updated G.
    while any element loading $> \rho$ and convergence maintained **do**
        Trip overloaded elements and re-solve power-flow.
    end while
    Record L_s (load lost), K_s (tripped elements), and I_s (islands).
end for
Compute per-asset failure_frequency[i] $= \phi[i]/S$.
Aggregate results $\{L_s, K_s, I_s\}$ for system-level impact analysis.