Security assessment: decision support tools for power system operators

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September 5, 2000
Overview

- Security-related decisions
- Current approach and what’s wrong with it
- Security assessment using probabilistic risk
- Illustrations
- Risk-based decision-making
- Cumulative risk assessment
- Conclusions
## Security-related decisions

<table>
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<tr>
<th>Time-frame</th>
<th>Decision maker</th>
<th>Decision</th>
<th>Basis for decision</th>
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<tr>
<td>On-line assessment (min-hours)</td>
<td>Operator</td>
<td>How to constrain the economic operation to maintain the normal state?</td>
<td>Operating rules, on-line assessment, and $$$$</td>
</tr>
<tr>
<td>Operational planning (hrs-months)</td>
<td>Analyst</td>
<td>What should be the operating rules?</td>
<td>Minimum operating criteria, reliability, and $$$$</td>
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<tr>
<td>Planning (months-years)</td>
<td>Analyst</td>
<td>How to reinforce/maintain the transmission system?</td>
<td>Reliability criteria for system design, and $$$$</td>
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Decision-Drivers

- Security
  - Overload security
    - Transformer Overload
    - Line Overload
  - Voltage Security
    - Low Voltage
    - Unstable Voltage
  - Dynamic Security
    - Transient (early-swing) instability
    - Oscillatory (damping) instability
Number of operating studies for determining security limits
National Grid Company, UK

1985: 3/quarter

1990: 120/week

2000: 1300/week
A Stressed System

Operator’s view at 2:10 pm, 8/12/99

200 MW flow

110%

0.95 pu volts

93%

94%
Simulation Results of a Preventive Action

Bus 1 500

Bus 1 230

Bus 1 115

Bus 2 500

Bus 2 230

Bus 2 115

103%

0 MW flow

101%

0.91 pu volts

104%
Power system “states” and actions

- Normal (secure)
  - Restorative
    - Extreme emergency. Separation, cascading delivery point interruption, load shedding
  - Alert, Not secure
  - Emergency
    - Other actions (e.g. switching)
    - Off-economic dispatch
    - Transmission loading relief procedures
    - Controlled load curtailment
Assessment and decision today

- Model current conditions
- Select contingencies
- Compute post-contingency performance
- Determine if alert (the action-trigger)
- Identify possible actions
- Select action

Perform assessment a-priori

Determine if alert (the action-trigger)

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Assessment and decision today

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Perform assessment a-priori

Determine if alert (the action-trigger)

Identify possible actions

Select action
What is wrong with this approach?

#1 Assessment is made of the past but the decision is made for the future.

#2 The decision is driven by the most severe credible contingency.
What is wrong with this approach?

- actions can come too late
- un-quantified future uncertainties requires large margin

#1
Assessment is made of the past but the decision is made for the future.
Actions can come too late;
Un-quantified uncertainties require large margin

Contingency-based flow limit

Line flow

MW

Time 

Assess Action trigger Identify action set Select action

Based on the previous condition
What is wrong with this approach?

- Inaccurate assessment and consequently an inconsistent action trigger
- Selection of less effective actions
Five-bus test system for illustrating concepts

Loss of cct 1 overloads cct 2

Loss of cct 6 overloads cct 7

Loss of cct 5 creates low voltage at bus 4.
What causes the inconsistency?

- Assumption that all contingencies in selected set are of equal probability

- Ignoring risk contribution from problems that are not most constraining

- Discrete quantification of severity
What do we do then?

Model a forecasted future

using probabilistic modeling of uncertainties

and assess it with

quantitative evaluation of contingency severity
for each possible condition
Forecast the future load and transactions

- Forecasted line flow
- 95% confidence limits
- Actual line flow

Time ➔

MW Loading

Assess ➔ Action trigger ➔ Identify action set ➔ Select action ➔ (Based on future Conditions)
On-line risk-based assessment

\[
Risk(Sev \mid X_{t,f}) = \sum_i \sum_j \Pr(E_i) \Pr(X_{t,j} \mid X_{t,f}) \times Sev(E_i, X_{t,j})
\]

- Forecasted operating conditions for future time \( t \)
- Uncertainty in outage conditions
- Uncertainty in operating conditions
- Severity function
Forecasted operating conditions

Possible near-future operating conditions (bus injections)

Selected near-future contingency states

- Determine voltage instability severity for the system
- Determine low voltage severity for each bus
- Determine overload severity for each circuit
- Determine cascading severity for each circuit
Uncertainty in operating conditions...

• $X_{t,f}$ is forecasted severity measures: flows, voltages, loadability

• $X_{t,j}$ is small deviation from forecasted value due to variation (or uncertainty) in parameters $k$:

\[
X_{t,j} = X_{t,f} + \frac{\partial X}{\partial k} \Delta k
\]

Then, the pdf on $X_{t+1}$ can be obtained as:

\[
\Pr(X_{t,j} \mid X_{t,f}) \sim \text{Normal}(X_{t,f}, \left[ \frac{\partial X}{\partial k} \right] C \left[ \frac{\partial X}{\partial k} \right]^T)
\]

$C$ is the covariance matrix for the vector of uncertain parameters $k$. 

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Severity modeling

Identified by CIGRE TF 38.02.21 Task Force as most difficult problem in probabilistic security assessment.

It’s modeling should NOT depend on a pre-supposed decision as this constrains the decision space, which is the space of investigation.

LOLP, EUE, Cost of re-dispatch, as indices for use in security-related decision-making, each pre-suppose a decision and are therefore inappropriate.
Severity modeling: essential features

**Definition:** Severity is an unavoidable consequence of a specified condition.

It provides a quantitative evaluation of what would happen to the power system in the specified condition.

One uses it, together with probability of the condition, to decide whether to re-dispatch, call for TLR, or interrupt load.
Severity modeling

Essential features

• Simple.
• Reasonable reflection of relative severity between outcomes to enable calculation of a composite index.
• Increase continuously as the performance indicator (e.g., flow, voltage, loading margin, cascaded lines) gets worse.
• Interpretable in physical and deterministic terms.

Economic quantification is attractive but difficult and can give a false sense of precision.
Because all severity functions evaluate to 1.0 at the deterministic threshold, a risk level \( R \) may be *roughly* thought of as the expectation of the number of violations in the next hour.
Decomposability

\[
Risk(Sev \mid X_t) = \sum_i \sum_j \Pr(E_i) \Pr(X_{t+1,j} \mid X_t) \times \\
\left\{ \sum_c Sev_c(\text{Flow}_c(E_i, X_{t+1,j})) + \sum_b Sev_b(\text{Voltage}_b(E_i, X_{t+1,j})) + Sev_{VC}(\text{VCMargin}(E_i, X_{t+1,j})) + Sev_{Cas}(\text{CasNum}(E_i, X_{t+1,j})) \right\}
\]

The above expresses system risk.

Interchanging summations allows us to obtain:

• **What incurs risk**: total risk for a single component (bus or branch risk) or a set of them (regional risk)

• **What causes risk**:
  ✓ system, regional, or component risk for a specific contingency
  ✓ system, regional, or component risk for a specific problem type
RBSA Result Visualization
- Serial Cases

Composite 2 (VC+CC+LV+OL)

- 0.19 C1
- 0.469 C2
- 0.922 C3
- 1.547 C4
- 1.537 C5
- 1.276 C6
- 0.937 C7
- 0.84 C8
- 8.697 C9
- 0.366 C10
- 0.677 C11
- 2.265 C12
- 2.939 C13
- 4.07 C14
- 4.862 C15
- 2.18 C16
- 1.304 C17
- 0.588 C18
RBSA Result Visualization - Single Case

Overall Security Level [Fair]

Current View: SBR

Voltage Collapse: Fair
Cascading: Fair
Low Voltage: Fair
Overload: Fair
Composite 1: Fair

System Risk

- VC: 0.009
- CC: 0.021
- LV: 0.019
- OL: 0.019
- Comp1: 0.019
Decision-making by RBOPF

Traditional OPF:

Minimize: generation cost

Subject to:
Power flow equations
Generation limits
Branch flow & bus voltage constraints
Other security constraints

A variation:

Minimize: \( a(\text{generation cost}) + b(\text{total system risk}) \)

Subject to:
Power flow equations
Generation limits
Regional risk constraints
Cumulative risk assessment

Graph: Load unbalance risk due to voltage lower limit

Y-axis: Expected Risk ($)
X-axis: Time (hour)
Final Comments

The “secure” and “alert” states only differ in terms of how insecure they are, and we need a measurable index to reflect this.

Risk is a computable quantity that can be used to integrate security with economics in formal decision-making algorithms.