Resilient Smart Electric Systems

PSERC Summer School
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The multi-phase resilience trapezoid:

- This curve shows the resilience of a power system to an event as a function of time.
- There are three phases in this trapezoid curve:

1) Phase I is related to disturbance progress between the time of event $t_{oe}$ and the end of the event $t_{ee}$.

2) Phase II is the post-event degraded state (after the event $t_{ee}$ and before the start of the restoration state $t_{or}$ or $t_{ir}$)

3) Phase III is the restorative state which is the recovery state of the system.

Staying in this state (Phase II) is undesirable for a system, and a resilient system should be able to recover from this state as fast as possible.

There are two types of resiliency defined in this figure:

1. **Operational resiliency**: Characteristics that secure operational strength for a power system, which means the characteristic needed for a power system to be able to supply the customer or have an available generation capacity in the face of an event.

2. **Infrastructural resiliency**: Refers to the physical strength of a power system for mitigating the portion of the system that becomes nonfunctional.

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The multi-phase resilience trapezoid

• The ΦΛΕΠ metric is proposed in [1] to capture the performance of the system in the mentioned three phases of the resilience trapezoid.

• The ΦΛΕΠ metric defines the following characteristics of the system while facing an event.

• Φ indicates that how fast resilience drop in phase I

This metric is evaluated by estimating the slope of the Resilience degradation

Operational: $\frac{R_{pdo} - R_{O0}}{t_{ee} - t_{oe}}$ (MW/hours)

Infrastructural: $\frac{R_{pdi} - R_{Oi}}{t_{ee} - t_{oe}}$ (Number of lines tripped/hours)

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• Λ indicates that how low resilience drop in phase I
  
  This metric is evaluated by resilience degradation level

  Operational: $R_{o_o} - R_{p_d0}$ (MW)

  Infrastructural: $R_{o_i} - R_{p_d_i}$ (Number of lines tripped)

• $E$ metric shows the time that the system stays in the post-disturbance degraded state in phase II
  $E$ is calculated by $t_{or} - t_{ee}$ and $t_{ir} - t_{ee}$ for operational and infrastructural resiliency respectively.

• Π indicates that how promptly the system recover to its pre-event resilient state at phase III
  Π is calculated by slopes of the operational and infrastructure recovery curves.

  Operational: $\frac{R_{o_o} - R_{p_d0}}{T_{or} - t_{or}}$ (MW/hours)

  Infrastructural: $\frac{R_{o_i} - R_{p_d_i}}{T_{ir} - t_{ir}}$ (Number of lines restored/hours)

× As a drawback of these metrics, we can mention its dependability to event type. i.e. these metrics can be different for different type of events.
• Another metric is used which is the area of the trapezoid. The area of the trapezoid can be calculated using the integral of the trapezoid for the duration of the event for both operational and infrastructural resiliency.

• If we consider different phases of this curve to be piecewise linear, the trapezoid area could be calculated using the mentioned $\Phi \Lambda E \Pi$ metrics.

Different resiliency indicators could be selected to quantify resiliency metrics. The important point is that the selected indicator should capture both infrastructural and operational resiliency. (e.g. the amount of generation capacity (MW) and load demand (MW) that are connected during the event for operational resiliency and the number of transmission lines that stay online during the event for infrastructural resiliency).

Another important point is to not be event dependent but general for the system.
Different phases of resilience

- The vertical axis shows the performance of the system such as:
  - Availability of critical facilities,
  - The number of people served,
  - The amount of flow or services delivered,
  - The level of economic activity
Different phases of resilience

- The temporal process of the system response to a severe incident can be divided into three phases:
  - Avoidance,
  - Survival, and
  - Recovery
Resilience metric

- A suitable metric for evaluating the resilience of a power network should represent the performance of the system following a High Impact and Rare event.

- Normalized metrics provides a comparable means for assessing the resilience in various operating conditions and power systems.

- Overall, the metric can be defined as follows:

\[ R = \frac{\int_{t_0}^{t_r} P(t) \, dt}{\int_{t_0}^{t_r} P_0 \, dt} = \frac{\int_{t_0}^{t_r} P(t) \, dt}{P_0 (t_r - t_0)} \]

R: the resilience metric and indicates how much our grid is resilient against a specific High Impact and Rare event.

Resilience metric

• In practice, it is difficult, if not impossible, to acquire the real performance of the system.

• To overcome this hurdle, some attempt to acquire a linear approximation of system performance, as shown below.

• This approximation can facilitate the simulations since it requires only eight points.
Boosting power systems infrastructure and operational resilience.

<table>
<thead>
<tr>
<th>Operation-Oriented Measures</th>
<th>Preventive</th>
<th>Corrective</th>
<th>Restorative</th>
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<tr>
<td>Planning-Oriented Preventive Measures (PPM)</td>
<td>Operation-Oriented Preventive Measures (OPM)</td>
<td>Planning-Oriented Corrective Measures (PCM)</td>
<td>Operation-Oriented Restorative Measures (ORM)</td>
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<tr>
<td>Planning-Oriented Corrective Measures (OCM)</td>
<td>Planning-Oriented Corrective Measures (PCM)</td>
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