Quantitative Power System Resilience Metrics and Evaluation Approach

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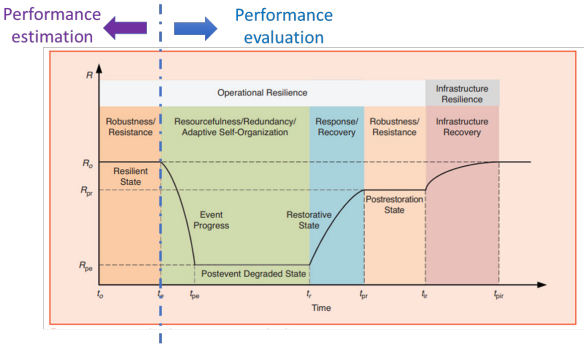
Abstract

Power system resilience is an emerging topic and plays an essential role in helping power industry understand and respond to the increasing threats of extreme weather events. The first step of power system resilience analysis is to introduce metrics to quantify the resilience reasonably. Existing resilience metrics are typically restrained by the limited data for extreme event modeling and fall short in terms of physical interpretation and comparability. This paper develops novel quantitative metrics to evaluate power system resilience in pre- and post-event contexts. The developed metrics illustrate clear physical meanings and can be effectively used to compare resilience across different systems under different extreme events. Moreover, the developed metrics can be applied to both transmission and distribution systems. Simulation on a distribution system is employed to validate the effectiveness of the proposed resilience metrics and resilience evaluation approach.

Resilience Quantification



- The **pre-event estimation** provides a general evaluation of the grid resilience in extreme conditions.
- The **post-event evaluation** is used to assess system response using the actual event data.
- Pre- and Post-event resilience quantification can provide complementary views of a power grid

Pre-event Resilience Metric

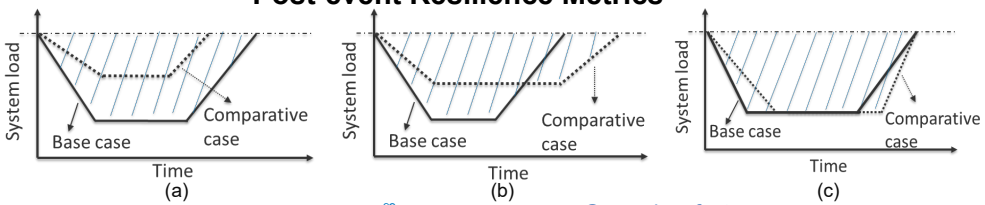
Performance-Damage-Duration (PDD):

•The PDD metric quantifies the capability of power system to maintain a certain level (*X*) of performance (e.g., load supply) when suffering from a certain level (*X*) of damage, for a predefined period of time (*Y*).

$$X := \max_{X\in[0,1]} \left\{ \inf_{s\in S, t\in[0,Y]} P_{s,t}^{1-X} \geq X \cdot P_{s,t} \right\}$$

How to use PDD metric: 1) Fixing Y when there is a specified/preferred guideline/requirement; 2) Fixing X when there is a need to maintain a minimum operating level; 3) Fixing both X and Y when setting up standard, entry qualification, etc.

Post-event Resilience Metrics



Primary factors

❑Total energy curtailment $E^{\text{shed}} = \int_{t=0}^{\infty} P^{\text{shed}}(t)dt$

❑Peak load curtailment $P^{\text{peak}} = \max_t P^{\text{shed}}(t)$

Secondary factors

❑Outage duration T^{r}

❑Degradation duration T^{d}

$$R^s = \frac{T^{\text{d}}}{T^{\text{r}}}$$

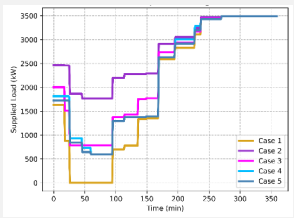
Simulation Results

Case	Description
1	0% photovoltaic (PV) penetration
2	50% PV penetration with scattered deployment
3	25% PV penetration with scattered deployment
4	50% PV penetration with grouped deployment
5	25% PV penetration with grouped deployment

➢ Pre-event evaluation

Case	Branch count effect	Repetition of sources	Proposed PDD metric (%)
1	131	0.01	**8.59**
2	131	0.92	**50.99**
3	131	0.92	**22.50**
4	131	0.08	**29.41**
5	131	0.08	**22.21**

➢ Post-event evaluation



Case	E^{shed} (kWh)	P^{peak} (kW)	R^S
1	8814	3490	0.10
2	4443	1723	0.17
3	6894	2705	0.10
4	7236	2895	0.23
5	7387	2895	0.23

➢ Pre- and Post-event evaluation validation

Case	Pre-event ranking	Average post-event ranking	Highest post-event ranking	Lowest post-event ranking
1	5	5	5	5
2	1	1.1	1	2
3	3	3.1	2	4
4	2	2.3	1	3
5	4	3.5	3	4

The developed pre- and post-event metrics perform quite consistently, although pre-event evaluation does not consider event information at all.

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