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SCED Formulation

This document illustrates the formulation for one single period RT SCED model. This model is for deterministic SCED. Interface is not considered here.

Sets

A: Areas.

D: Loads.

N: Buses.

K: Branches.

KM: Branches under monitor.

KM(c): Branches for monitor under contingency c.

G: Generators.

G(a): Units in area *a*.

GD: Dispatchable units.

GR: Units qualified for regulation reserve.

GS: Units qualified for spinning reserve.

Parameters

T_{ED}: Look-ahead time for one period RT SCED.

T_{RR}: Time for regulation reserve requirements.

T_{SR}: Time for spinning reserve requirements.

T_{PR}: Time for primary reserve requirements.

$T_{PR,g}$: Time required for unit *g* to start providing reserve.

$F_{PR,g}$: 1 indicates unit *g* is an off-line fast start unit.

P_d: Active load of load *d*.

U_g: Commitment status of unit *g*.

P_{g0}: Total initial output of unit *g*.

NS_g: Number of cost segments for unit *g*.

$BS_{g,i}$: Breadth of segment *i* for unit *g*.

MRR_g: Energy ramp rate for unit *g*.

SRR_g: Spinning ramp rate for unit *g*.

RR_a: Regulation reserve requirement for area *a*.

SR_a: Spinning reserve requirement for area *a*.

PR_a: Primary reserve requirement for area *a*.

$RR_{g,o}$: Regulation reserve amount that unit *g* offer.

$SR_{g,o}$: Spinning reserve amount that unit *g* offer.

$C_{g,i}$: Cost for segment *i* of unit *g*.

CRR_g: Regulation reserve price that unit *g* offer.

CSR_g: Spinning reserve price that unit *g* offer.

$RateA_k$: Normal flow limit of branch *k*.

$RateC_k$: Emergency flow limit of branch *k*.

$P_{g,max}$: Maximum output for unit *g*.

$P_{g,min}$: Minimum output for unit *g*.

$RR_{penalty}$: Penalty price for not meeting the regulation reserve requirement.

$SR_{penalty}$: Penalty price for not meeting the spinning reserve requirement.

$PR_{penalty}$: Penalty price for not meeting the primary reserve requirement.

Variables

P_k: Flow on branch *k*.

P_g: Total output of unit *g*.

$P_{g,i}$: Output on segment *i* of unit *g*.

RR_g: Regulation reserve that unit *g* provides.

SR_g: Spinning reserve that unit *g* provides.

PR_g: Primary reserve that unit *g* provides.

$P_{g,c}$: Total output of unit *g* under contingency c.

$P_{k,c}$: Flow on branch *k* under contingency c.

RR_{slack}: Slack variable for the regulation reserve requirement.

SR_{slack}: Slack variable for the spinning reserve requirement.

Code on Github: https://github.com/rpglab/RT-SCED

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PR_{slack}: Slack variable for the primary reserve requirement.

Formulation

Objective function

$$\min \sum_{g\in G}\sum_{i=1}^{NS_g} P_{g,i}\cdot C_{g,i} + \sum_{g\in G} RR_g \cdot CRR_g + \sum_{g\in G} SR_g\cdot CSR_g + RR_{slack} \cdot RR_{penalty} + SR_{slack}\cdot SR_{penalty} + PR_{slack}\cdot PR_{penalty}$$

Base case constraints

1) Power balance equation

$$\sum_{g\in G} P_g = \sum_{d\in D} P_d$$

2) Branch flow limit

$$-RateA_k \le P_k \le RateA_k\,, \qquad k\in KM$$

3) Branch flow calculation

$$P_k = P_{k0} + \sum_{g\in G} DFAX_{g,k}\cdot \Delta P_g \quad ,k\in KM$$

where, $\Delta P_g = P_g - P_{g0}$.

4) Unit generation equation

$$P_g = \sum_{i=1}^{NS_g} P_{g,i}\,, \qquad g\in GD\ and\ unit\ g\ is\ online$$

$$0\le P_{g,i}\le BS_{g,i}\,, \qquad g\in GD$$

5) Ramping rate limit

$$-MRR_g\cdot T_{ED} \le P_g - P_{g0} \le MRR_g\cdot T_{ED}\,, \quad unit\ g\ is\ online$$

6) Reserve limit

$$0\le RR_g \le SRR_g\cdot T_{RR}\cdot U_g$$

$$0\le SR_g \le SRR_g\cdot T_{SR}\cdot U_g$$

$$0\le PR_g\le SRR_g\cdot (T_{PR}\cdot U_g + (T_{PR} - T_{PR,g})\cdot F_{PR,g}\cdot (1-U_g))$$

7) Generation limits

$$P_{g,min}\cdot U_g \le P_g \le P_{g,max}\cdot U_g$$

$$P_g + RR_g \le P_{g,max}$$

$$P_g + SR_g \le P_{g,max}$$

$$P_g + PR_g \le P_{g,max}$$

8) Reserve requirements

$$\sum_{g\in G(a)} RR_g + RR_{slack} \ge P_{RR,a}\,, a\in A$$

$$\sum_{g\in G(a)} SR_g + SR_{slack} \ge P_{SR,a}\,, a\in A$$

$$\sum_{g\in G(a)} PR_g + PR_{slack} \ge P_{PR,a}\,, a\in A$$

9) Offer constraints

$$RR_g \le RR_{g,o}$$

$$SR_g \le SR_{g,o}$$

10) Additional constraints

$$RR_g = 0\,,\ \ g\in (G-GR)$$

$$SR_g = 0\,,\ \ g\in GR\ or\ g\in (G-GS)$$

$$P_{gc} = P_g = P_{g0}\,,\ \ g\in (G-GD)$$

$$P_{gc} = P_g\,,\ \ if\ c\ is\ base\ case$$

$$P_{gi} = 0\,,\ \ if\ g\ is\ offline$$

Contingency case constraints

1) Power balance equation

$$\sum_{g\in G} P_{g,c} = \sum_{d\in D} P_d$$

2) Branch flow calculation

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$$P_{k,c} = P_{k0} + \sum_{g \in G} DFAX_{g,k} \cdot \Delta P_{g,c}\,, \qquad k \in KM(c)$$

where, $\Delta P_{g,c} = P_{g,c} - P_{g0}$.

3) Branch flow limit

$$-RateC_k \leq P_{k,c} \leq RateC_k \quad k \in \mathrm{KM(c)}$$

4) Generator output limits

$$-SRR_g \cdot T_{SR} \leq P_{g,c} - P_g \leq SRR_g \cdot T_{SR}$$

5) Generator limits

$$P_{g,min} \cdot U_g \leq P_{g,c} \leq P_{g,max} \cdot U_g$$

References:

[1] Xingpeng Li and Kory W. Hedman, "Enhanced Energy Management System with Corrective Transmission Switching Strategy— Part I: Methodology," *IEEE Transactions on Power Systems*, vol. 34, no. 6, pp. 4490-4502, Nov. 2019.

[2] Xingpeng Li and Kory W. Hedman, "Enhanced Energy Management System with Corrective Transmission Switching Strategy— Part II: Results and Discussion," *IEEE Transactions on Power Systems*, vol. 34, no. 6, pp. 4503-4513, Nov. 2019.

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