RIM Model Description

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This document describes the RIM model as it is of June 22, 2021 and changes anticipated in the near future. The descriptions of the current implementation of unit commitment and economic dispatch are based on Cesar A. Silva Monroy's reports from 2016 and the 2016 RIM Final Report with modifications where changes have been made.

1 Unit Commitment

This section describes the current implementation of unit commitment (UC), which has one balancing authority (BA) and potentially multiple zones. The unit commitment is currently run over a one day time horizon.

1.1 Sets

Data and variables are indexed over these sets.

set	**range**	**description**
T	$t \in \{1, \ldots, 24\}$	The set of time steps in unit a commitment optimization
G	4000	The set of generators in available to a unit commitment optimization $\{1, \ldots, g\}$
S	4	Piecewise linear segments describing each generator's input-output curve $\{1, \ldots, s\}$
Z	40	Set of zones in which each generator is stationed $\{1, \ldots, z\}$

1.2 Data

The following data are given for a unit commitment problem.

$P_{t,z}^{demand}$ The power demand at time t in zone z

$L_{z_{from},z_{to}}$ The maximum line capacity for transferring power between zones

$P_{g,s}^{minimum}$ The minimum power output for a segment in the generator's input-output curve

$P_{g,s}^{maximum}$ The maximum power output for a sgement in the generator's input-output curve

$F_{g,s}^{minimum}$ The minimum fuel input for a segment in the generator's input-output curve

$F_{g,s}^{maximum}$ The maximum fuel output for a segment in the generator's input-output curve

δ_g^{up} The ramp up rate for a generator

δ_g^{down} The ramp down rate for a generator

T_g^{down} The minimum down time for a generator

T_g^{up} The minimum up time for a generator

C_g^{start} The cost to start a generator

C_g^{stop} The cost to stop a generator

C_g^{fuel} The fuel cost for a generator

C^{CO_2} The cost of CO_2 emissions per ton

C^{NO_x} The cost of NO_x emissions per ton

C^{SO_x} The cost of SO_x emissions per ton

$E_g^{CO_2}$ The rate of CO_2 emissions per fuel input

$E_g^{NO_x}$ The rate of NO_x emissions per fuel input

$E_g^{SO_x}$ The rate of SO_x emissions per fuel input

R The percentage of load to keep in reserve as unused capacity of active generators

1.3 Variables

$a_{g,s,t}$	The status of segment on a generator's input-output curve (active/inactive).
$P_{g,s,t}^{segment}$	The power supplied by a segment of the power generation curve for a generator.
$T_{g,t}$	Number of time steps until the on/off status of a generator may toggle.
$su_{g,t}$	Indicates if a generator starts up during a time step.
$sd_{g,t}$	Indicates if a generator shuts down during a time step.
$P_{t,z_{from},z_{to}}^{transferred}$	The power transferred from one zone to another.

1.4 Constraints and Expressions

$a_{g,s,t}$ is 0 to indicate an inactive segment, and 1 to indicate an active segment.

$$a_{g,s,t} \in \{0,1\} \tag{1}$$

A generator is on if any of its power-curve segments is active. Only a single segment is active for each generator in any step.

$$u_{g,t} = \sum a_{g,s,t} \tag{2}$$
$$u_{g,t} \leq 1 \tag{3}$$

Active generators provide power within the limits of the active segment of their input-output curve.

$$P_{g,s,t}^{segment} \leq a_{g,s,t} \cdot P_{g,s}^{maximum} \tag{4}$$

$$P_{g,s,t}^{segment} \geq a_{g,s,t} \cdot P_{g,s}^{minimum} \tag{5}$$

$$P_{g,t}^{generated} = \sum_{s=1}^{S} P_{g,s,t}^{segment} \tag{6}$$

Power generated, used, and transferred must balance. Power transferred between zones may not exceed line capacity.

$$P_{t,z}^{demand} + \sum_{z_{to} \in Z} P_{t,z,z_{to}}^{transferred} = \sum_{g \in z} P_{g,t}^{generated} + \sum_{z_{from} \in Z} P_{t,z_{from},z}^{transferred} \tag{7}$$

$$P_{t,z,z'}^{transferred} - P_{t,z',z}^{transferred} \leq L_{z,z'} \tag{8}$$

Switching on/off happens when the active state changes between on and off from one time step to the next. A generator may switch on or off in a time step, not both.

$$su_{g,t} - sd_{g,t} = u_{g,t} - u_{g,t-1} \tag{9}$$

$$su_{g,t} + sd_{g,t} \leq 1 \tag{10}$$

$$su_{g,t} \in \{0,1\} \tag{11}$$

$$sd_{g,t} \in \{0,1\} \tag{12}$$

$$\tag{13}$$

A counter is used to determine when a generator may be switched on/off based on it's minimum up and down times. It may decrease once per time step. When it reaches 1, the generator may be switched on or off. The counter is reset when the generator is switched on/off.

$$T_{g,t} \geq T_{g,t-1} - 1 \tag{14}$$

$$max(T_g^{up} + T_g^{down}) \cdot su_{g,t} + T_{g,t-1} \leq max(T_g^{up} + T_g^{down}) + 1 \tag{15}$$

$$max(T_g^{up} + T_g^{down}) \cdot sd_{g,t} + T_{g,t-1} \leq max(T_g^{up} + T_g^{down}) + 1 \tag{16}$$

$$T_{g,t} \geq T_g^{up} \cdot su_{g,t} \tag{17}$$

$$T_{g,t} \geq T_g^{down} \cdot sd_{g,t} \tag{18}$$

$$T_{g,t} \leq max(T_g^{up} + T_g^{down}) \tag{19}$$

Spare capacity in active generators equal to a percentage of the load is kept in reserve.

$$\sum_{g} (u_{g,t} \cdot max_{s \in S}(P_g^{maximum}, s)) \geq \sum_{z=1}^{Z} P_{t,z}^{demand} \cdot (1 + R) \tag{20}$$

A generator's change in generation from step to step is limited by the ramp-up and ramp-down rates. Generators start near minimum power and must stop near minimum power.

$$P_{g,t}^{generated} \leq P_{g,t-1}^{generated} + \delta_g^{up} + su_{g,t} \cdot min_{s \in S}(P_g^{minimum}, s) \tag{21}$$

$$P_{g,t}^{generated} \leq P_{g,t-1}^{generated} - \delta_g^{down} - sd_{g,t} \cdot min_{s \in S}(P_g^{minimum}, s) \tag{22}$$

1.5 Objective

The fuel rate for a segment is 0 if inactive, and based on slope and intercept of the segment otherwise. The cost for a generator is based on the fuel rate, emissions rate, emissions cost, fuel cost, and startup/shutdown costs. Minimize the total cost of all generators in all time steps.

$$m_{g,s} = (P_{g,s}^{minimum} - P_{g,s}^{maximum})/(F_{g,s}^{minimum} - F_{g,s}^{maximum}) \tag{23}$$

$$b_{g,s} = P_{g,s}^{minimum} - m_{g,s} * F_{g,s}^{minimum} \tag{24}$$

$$F_{g,s,t}^{rate} = a_{g,s,t} \cdot b_{g,s} + P_{g,s,t}^{segment} \cdot m_{g,s} \tag{25}$$

$$C_g^{input} = C_g^{fuel} + C^{NO_x} \cdot E_g^{NO_x} + C^{SO_x} \cdot E_g^{SO_x} + C^{CO_2} \cdot E_g^{CO_2} \tag{26}$$

$$C_{g,t}^{generator} = su_{g,t} \cdot C_g^{start} + sd_{g,t} \cdot C_g^{stop} + F_{g,s,t}^{rate} \cdot C_g^{input} \tag{27}$$

$$minimize(C = \sum_g \sum_t C_{g,t}^{generator}) \tag{28}$$