**SETS (index)**

*H* (*h*) – timepoints

Notes on timepoints:

* *hf* will designate the first timepoint*; hl* will designate the last timepoint
* *hp* will designate the previous timepoint for timepoint h
* Periodic boundary constraints are enforced, so *hl* is considered the previous timepoint for *hf*

*Ph (ph)* – set of timepoints preceding timepoint *h* for the purposes of the cumulative energy constraints on flexible loads and EV loads (e.g. if optimizing over a week and starting the constraint on hour 7 of the week, the preceding timepoints set for hour 7 will be hour 7 only; for hour 50, the set will include timepoints 7 through 50; for timepoint 6, the set will include timepoints 7-168 and 1-6). Set is within *H*.

*R* (*r*) – regions

*A* (*a*) – all resources

*S* (*s*) – storage resources, within A

*G* (*g*) – generation resources, within A

*V* (*v*) – large storage resources, within S

*D* (*d*) – shorter duration storage resources, within S

For less cumbersome notation, subsets of resources will be designated with superscripts. Superscripts used will include:

* *r*: resources in region *r*
* *b*: bulk resources
* *d*: distributed resources

E.g. the set of resources in region *r* will be *Ar*, the set of bulk storage resources in region *r* will be *Sr,b*, etc.

*L* (*l*) – transmission lines

*Lr1,r* – transmission lines from region *r1* to region *r*

*Lr,r1* – transmission lines from region *r* to region *r1*

**Parameters**

*capa –* capacity of resource *a*

*durs –* duration of storage resource *s*

*t\_capl* – capacity of transmission line l

*v\_cg* – variable cost for generation resources (note: variable cost is input via a technology index and each resource is assigned a technology)

*c\_effs* – discharging efficiency for resources (note: efficiencies are input via a technology index and each resource is assigned a technology)

*d\_effs* – charging efficiency for storage resources (note: efficiencies are input via a technology index and each resource is assigned a technology)

*min\_cml\_flex\_loadr,h* – minimum cumulative flexible load in region *r* through timepoint *h*

*max\_cml\_flex\_loadr,h*– maximum cumulative flexible load in region *r* through timepoint *h*

*max\_flex\_loadr* – maximum cumulative flexible load in region *r* (in any timepoint)

*min\_cml\_ev\_loadr,h* – minimum cumulative EV load in region *r* through timepoint *h*

*max\_cml\_ev\_loadr,h*– maximum cumulative EV load in region *r* through timepoint *h*

*max\_ev\_loadr* – maximum cumulative EV load in region *r* (in any timepoint)

*o\_c* – curtailment cost

*u\_c* – unserved energy cost

*d­\_c* – distribution system penalty cost

*b\_c* – bulk system penalty cost

*t\_d* – transmission and distribution loss factor

*rnwr,h –* bulk renewable power in region *r* in timepoint *h*

*lr,h* – net distributed load (the static distributed load minus any fixed distributed generation)

*dtr* – distributed load threshold (penalty applied if exceeded)

*btr* – bulk load threshold (penalty applied if exceeded)

**Variables**

*Pa,h* – power

*Cs,h* – charging

*Es,h* – energy in storage

*Tl,h* – transmitted power

*Fr,h* – flexible load

*Er,h* – EV load

*Or, h* – overgeneration/curtailment

*Ur, h* – unserved energy

*Dr,h* – exceed distribution system threshold

*Br,h* – exceed bulk system threshold

**Objective Function**

**minimize *Total Cost* =**

*Generation Cost*

+ *Curtailment Cost*

+ *Unserved Energy Cost*

+ *Distribution System Capacity Penalty Cost*

+ *Bulk System Penalty Capacity Penalty Cost*

**Constraints**

***Meet\_Loadr,h:***

In each region and timepoint, net bulk power minus curtailment must equal the bulk load. Bulk load is assumed simply as the distributed load plus an adjustment for T&D losses. The distributed load is equal to the static load plus flex/EV load plus any other distributed loads (e.g. distributed storage charging) minus any power available at the distribution level. Bulk power is equal to bulk generation plus net bulk storage plus imports/exports.

This assumes we won't be charging bulk storage with distributed power – in that situation, this constraint will break, as the direction of losses would need to be reversed.

*Bulk Power*

*– Bulk Charging*

+ *Imports/Exports*

*– Curtailment*

(*Net distributed load*

*– Distributed Power*

*+ Distributed Charging*

*+ Flexible Load*

*+ EV Load*

*– Unserved Energy) \* (1+t&d\_losses)*

***Gas\_and\_Storage\_Powera,h:***

Resources can’t produce more power than their power capacity.

***Storage\_Chargings,h:***

Storage cannot charge at a higher rate than implied by its total installed power capacity. Charge and discharge rate limits are currently the same.

***Storage\_Energys,h:***

Energy in storage cannot exceed the storage capacity times the storage duration.

***Storage\_Energy\_Trackingd,h*:**

The energy in storage at the start of the current timepoint must equal the energy in storage at the start of the last timepoint plus charging in the last timepoint, adjusted for charging efficiency, minus discharging in the last timepoint, adjusted for the discharging efficiency.

***Very\_Large\_Storage\_Energy\_Trackingv,h*:**

For “very large” storage resources, the energy in storage in the first timepoint must equal a pre-specified value. The energy in storage at the end of the last timepoint must equal in the pre-specified value. For the middle timepoints, energy is tracked as for regular storage resources.

***Cumulative\_Flexible\_Loadr,h:***

The cumulative flexible load through each timepoint *h* (sum over all previous timepoints for timepoint *h*) must be between a pre-specified minimum and maximum.

***Max\_Flex\_Loadr,h:***

No more flexible load can be shifted to timepoint h than a pre-specified value.

***Cumulative\_EV\_Loadr,h:***

The cumulative EV load through each timepoint *h* (sum over all previous timepoints for timepoint *h*) must be between a pre-specified minimum and maximum.

***Max\_EV\_Loadr,h:***

No more EV load can be shifted to timepoint h than a pre-specified value.

***Transmitted\_Powerl,h:***

Transmitted power cannot exceed transmission capacity.

***Distribution\_System\_Capacity\_Penaltyr,h:***

A penalty is applied whenever a distributed load exceeds a pre-specified threshold.

*Net distributed load*

*– Distributed Power*

*+ Distributed Charging*

*+ Flexible Load*

*+ EV Load*

*– Distributed Load Threshold*

***Bulk\_System\_Capacity\_Penaltyr,h:***

A penalty is applied whenever a bulk load exceeds a pre-specified threshold. Bulk load is calculated as net distributed load plus transmission and distribution losses. T&D losses are estimated as a percent of net distributed load.

*Net distributed load*

*(*

*– Distributed Power*

*+ Distributed Charging*

*+ Flexible Load*

*+ EV Load*

*– Distributed Load Threshold*