

# Model Formulation

Table 1: List of Variables

Variable	Definition	Unit
$k_s^B$	Battery power rating at charging station $s$	MW
$e_s^B$	Energy capacity for battery at charging station $s$	MWh
$g_{st}^B$	Battery electricity generation at charging station $s$ at time $t$	MWh
$d_{st}^B$	Inflow demand for battery at charging station $s$ at time $t$	MWh
$x_{st}^B$	State of charge for battery at charging station $s$ at time $t$	MWh
$k_s^H$	H <sub>2</sub> power rating at charging station $s$	MW
$e_s^H$	Energy capacity for H <sub>2</sub> at charging station $s$	kg
$g_{st}^H$	H <sub>2</sub> electricity generation at charging station $s$ at time $t$	kg
$x_{st}^H$	State of charge for H <sub>2</sub> at charging station $s$ at time $t$	kg
$d_{st}^H$	Inflow demand for H <sub>2</sub> at charging station $s$ at time $t$	kg
$k_s^P$	Solar capacity at charging station $s$	MW
$g_{st}^P$	Solar electricity generation at charging station $s$ at time $t$	MWh
$g_{st}^M$	SMR electricity generation at charging station $s$ at time $t$	MWh
$u_s^M$	Number of SMR modules to build at charging station $s$	Whole number
$u_{si}^W$	Whether to build (1) or not build (0) transmission line of capacity group $i$ at station $s$	Binary
$g_{st}^W$	Electricity generation purchased from wholesale markets to charging station $s$ at time $t$	MWh

Table 2: List of Parameters and Sets

Parameter/Set	Definition	Unit
<i>Parameters:</i>		
$p^{BK}$	Battery annual capital cos	\$/MW
$p^{BC}$	Battery energy cost	\$/MWh
$p^{BE}$	Battery operating cost	\$/MWh
$h^B$	Battery hour	hour
$p^{HK}$	H <sub>2</sub> capital cost	\$/MW
$p^{HC}$	H <sub>2</sub> energy cost	\$/kg
$p^{HE}$	H <sub>2</sub> operating cost	\$/kg
$\bar{d}_{st}^H$	H <sub>2</sub> demand at charging station $s$ at time $t$	kg
$c^H$	Conversion factor from 1 MWh to kg of H <sub>2</sub> (= 49.3)	—
$p^{PK}$	Solar capital cost	\$/MW
$p^{PE}$	Solar operating cost	\$/MWh
$f_{st}^P$	Solar capacity factor at charging station $s$ at time $t$	%
$\delta_{min}^M$	SMR minimum stable load	MWh
$p^{MK}$	SMR capital cost	\$/MW
$p^{ME}$	SMR operating cost	\$/MWh
$\bar{k}^M$	SMR module capacity	MW
$\bar{k}_{si}^W$	Effective capacity of transmission line at charging station $s$ in group $i$	MW
$p_{si}^{WK}$	Annualized capital cost for transmission capacity group $i$ at charging station $s$	\$/MW
$p_{st}^{WE}$	Wholesale electricity cost at charging station $s$ at time $t$	\$/MWh
$p_s^{WO}$	Overhead add-ons at charging station $s$	%
$d_{st}^E$	Electricity demand at charging station $s$ at time $t$	MWh
<i>Sets:</i>		
$\mathbb{I}$	Set of transmission line capacity levels, index $i = \{1, 2, 3, \dots, 7\}$	—
$\mathbb{S}$	Set of stations, index $s = \{1, 2, 3, \dots, 170\}$	—
$\mathbb{T}$	Set of hours, index $t = \{1, 2, 3, \dots, 24\}$	—
$\mathbb{Z}_0^+$	Set of whole numbers, $\mathbb{Z}_0^+ = \{0, 1, 2, 3, \dots\}$	—
$\mathbb{Z}_2$	Set of binary numbers, $\mathbb{Z}_2 = \{0, 1\}$	—

$$\begin{aligned}
\min_{\substack{u_{si}^W, k_s^B, k_s^H, k_s^P, u_s^M, \\ e_s^B, e_s^H, \\ g_{st}^W, g_{st}^B, g_{st}^H, g_{st}^P, g_{st}^M, \\ d_{st}^B, d_{st}^H}} \quad & \sum_s \left\{ \underbrace{\left[ p^{BK} k_s^B + p^{BC} e_s^B + \sum_t p^{BE} g_{st}^B \right]}_{\text{Battery Expansion and Operating Costs}} + \underbrace{\left[ p^{HK} k_s^H + p^{HC} e_s^H + \sum_t p^{HE} g_{st}^H \right]}_{\text{H}_2 \text{ Expansion and Operating Costs}} + \underbrace{\left[ p^{PK} k_s^P + \sum_t p^{PE} g_{st}^P \right]}_{\text{Solar PV Expansion and Operating Costs}} \right. \\
& \left. + \underbrace{\left[ p^{MK} u_s^M \bar{k}^M + \sum_t p^{ME} g_{st}^M \right]}_{\text{SMR Expansion and Operating Costs}} + \underbrace{\left[ \sum_i \left( 1 + p^{WO} \right) p_{si}^{WK} \bar{k}_{si}^W u_{si}^W + \sum_t p_{st}^{WE} g_{st}^W \right]}_{\text{Transmission Expansion and Operating Costs}} \right\} \quad (1)
\end{aligned}$$

s.t.

$$\text{General Non-negativity: } k_s^B, k_s^H, k_s^P, k_s^W, e_s^B, e_s^H \geq 0, \quad \forall s \in \mathbf{S} \quad (2)$$

$$\text{Market Clearing Conditions: } g_{st}^B + g_{st}^P + g_{st}^M + g_{st}^W \geq d_{st}^E + d_{st}^B + \left( \frac{1}{c^H} \right) d_{st}^H, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (3)$$

$$\text{Battery Constraints: } 0 \leq d_{st}^B \leq k_s^B, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (4)$$

$$0 \leq g_{st}^B \leq k_s^B, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (5)$$

$$0 \leq g_{st}^B \leq x_{st}^B, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (6)$$

$$e_s^B = h^B k_s^B, \quad \forall s \in \mathbf{S} \quad (7)$$

$$0 \leq x_{st}^B \leq e_s^B, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (8)$$

$$x_{st}^B = x_{s(t-1)}^B + d_{st}^B - g_{st}^B, \quad \forall s \in \mathbf{S}, \forall t > 1 \in \mathbf{T} \quad (9)$$

$$x_{s(t=1)}^B = 0.5 \times e_s^B, \quad \forall s \in \mathbf{S} \quad (10)$$

$$\text{Hydrogen Constraints: } 0 \leq \left( \frac{1}{c^H} \right) d_{st}^H \leq k_s^H, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (11)$$

$$0 \leq \left( \frac{1}{c^H} \right) g_{st}^H \leq k_s^H, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (12)$$

$$0 \leq g_{st}^H \leq x_{st}^H, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (13)$$

$$0 \leq x_{st}^H \leq e_s^H, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (14)$$

$$x_{st}^H = x_{s(t-1)}^H + d_{st}^H - g_{st}^H, \quad \forall s \in \mathbf{S}, \forall t > 1 \in \mathbf{T} \quad (15)$$

$$x_{s(t=1)}^H = 0, \quad \forall s \in \mathbf{S} \quad (16)$$

$$g_{st}^H \geq \bar{d}_{st}^H, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (17)$$

$$\text{Solar PV Constraints: } 0 \leq g_{st}^P \leq f_{st}^P k_s^P, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (18)$$

$$\text{SMR Constraints: } 0 \leq g_{st}^M \leq u_s^M \bar{k}^M, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (19)$$

$$u_s^M \in \mathbb{Z}_0^+, \quad \forall s \in \mathbf{S} \quad (20)$$

$$g_{st}^M \geq g_{min}^M, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (21)$$

$$\|g_{st}^M - g_{s(t-1)}^M\| \leq r_s^M u_s^M \bar{k}^M, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (22)$$

$$\text{Wholesale Power Constraints: } 0 \leq g_{st}^W \leq \sum_i u_{si}^W \bar{k}_{si}^W, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (23)$$

$$u_{si}^W \in \mathbb{Z}_2, \quad \forall s \in \mathbf{S}, \forall i \in \mathbf{I} \quad (24)$$

$$\sum_i u_{si}^W \leq 1, \quad \forall s \in \mathbf{S}, \forall i \in \mathbf{I} \quad (25)$$