

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 ₂ power rating at charging station s	MW
e_s^H	Energy capacity for H ₂ at charging station s	kg
g_{st}^H	H ₂ electricity generation at charging station s at time t	kg
x_{st}^H	State of charge for H ₂ at charging station s at time t	kg
d_{st}^H	Inflow demand for H ₂ 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 cost	\$/MW
p^{BC}	Battery energy cost	\$/MWh
p^{BE}	Battery o (= 4)	hour
p^{HK}	H ₂ capital cost	\$/MW
p^{HC}	H ₂ energy cost	\$/kg
p^{HE}	H ₂ operating cost	\$/kg
\bar{d}_{st}^H	H ₂ demand at charging station s at time t	kg
c^H	Conversion factor from 1 MWh to kg of H ₂ (= 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	%
\mathcal{S}_{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 $i = \{1, 2, 3, \dots, 10\}$	—
\mathbb{S}	Set of stations, index $s = \{1, 2, 3, \dots, 170/161/152\}$	—
\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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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