

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	MWh
g_{st}^H	H ₂ electricity generation at charging station s at time t	MWh
x_{st}^H	State of charge for H ₂ at charging station s at time t	MWh
d_{st}^H	Inflow demand for H ₂ at charging station s at time t	MWh
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_s^{BK}	Battery capital cost at charging station s	\$/MW
p_s^{BC}	Battery energy cost at charging station s	\$/MWh
p_{st}^{BE}	Battery operating cost at charging station s at time t	\$/MWh
r_s^B	Battery ramp rate at charging station s at time t	MWh
p_s^{HK}	H ₂ capital cost at charging station s	\$/MW
p_s^{HC}	H ₂ energy cost at charging station s	\$/MWh
p_{st}^{HE}	H ₂ operating cost at charging station s at time t	\$/MWh
r_s^H	H ₂ ramp rate at charging station s at time t	MWh
r_s^{HE}	H ₂ inflow ramp rate at charging station s at time t	MWh
p_s^{PK}	Solar capital cost at charging station s	\$/MW
p_{st}^{PE}	Solar operating cost at charging station s at time t	\$/MWh
f_{st}^P	Solar capacity factor at charging station s at time t	%
p_s^{MK}	SMR capital cost at charging station s	\$/MW
p_{st}^{ME}	SMR operating cost at charging station s at time t	\$/MWh
\bar{k}_s^M	SMR capacity at charging station s	MW
\bar{l}_{si}^W	Length of transmission line of capacity group i built to connect to charging station s	Miles
\bar{k}_i^W	Effective capacity of transmission line in group i	MW
p_{si}^{WK}	Transmission capital cost for transmission capacity group i at charging station s	\$/MW
p_{si}^{WI}	Transmission infrastructure cost for transmission capacity group i at charging station s	\$/mile
p_{si}^{WC}	Conductor cost for transmission capacity group i at charging station s	\$/mile
p_{si}^{WL}	Land cost for transmission capacity group i at charging station s	\$/mile
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, $\mathbb{Z}_2 = \{0, 1\}$	–

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

s.t.

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

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

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

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

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

$$0 \leq x_{st}^B \leq e_s^B, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (7)$$

$$x_{st}^B = x_{s(t-1)}^B + d_{st}^B - g_{st}^B, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (8)$$

$$\|g_{st}^B - g_{s(t-1)}^B\| \leq r_s^B, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (9)$$

$$\text{Need to add initial SOC conditions} \quad (10)$$

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

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

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

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

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

$$\|g_{st}^H - g_{s(t-1)}^H\| \leq r_s^H, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (16)$$

$$\|e_{st}^H - e_{s(t-1)}^H\| \leq r_s^{HE}, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (17)$$

$$\text{Need to add initial SOC conditions} \quad (18)$$

$$\text{Solar PV Constraints: } 0 \leq g_{st}^P \leq f_{st}^P k_s^P, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (19)$$

$$\text{SMR Constraints: } 0 \leq g_{st}^M \leq u_s^M \bar{k}_s^M, \quad \forall s \in \mathbf{S}, \forall t \in \mathbf{T} \quad (20)$$

$$u_s^M \in \mathbb{Z}_0^+, \quad \forall s \in \mathbf{S} \quad (21)$$

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

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

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

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