Power dispatch optimization for an EV fleet

April 17, 2023

1 Model

1.1 Variables

Index sets :

$\mathcal{I}$, the set of plugged EV

$T = \{0, 1, \ldots, T\}$

$\Sigma = \{chg, dischg\}$ (i.e., $\{charging, discharging\}$)

$\Omega = \{bsl, up, dn\}$ (i.e., $\{baseline, FCR_{up}, FCR_{down}\}$)

Let $p^{max} = \max\{\overline{p^{charging}}, \overline{p^{discharging}}\}$, then $\forall i \in \mathcal{I}$, we define:

$$x_i = \begin{pmatrix} \left(u_{i,t}^{\sigma,\omega}\right)_{\sigma,\omega,t} & \in \{0,1\}^{\Sigma\times\Omega\times(T+1)} \\ \left(p_{i,t}^{\sigma,\omega}\right)_{\sigma,\omega,t} & \in [0, p^{max}]^{\Sigma\times\Omega\times(T+1)} \\ \left(SOC_{i,t}^{\omega}\right)_{\omega,t} & \in [0, SOC^{max}]^{\Omega\times(T+1)} \end{pmatrix}$$

where

- $u_{i,t}^{\sigma,\omega} \in \{1, 0\}$ signifies, at instant t, whether the EV i is charging ($\sigma = chg$) (resp. discharging ($\sigma = dischg$)) according to its baseline power consumption ($\omega = bsl$) (resp. power consumption while doing FCR up service ($\omega = up$), power consumption while doing FCR down service ($\omega = dn$));
- $p_{i,t}^{\sigma,\omega}$ is the baseline/FCR up service/FCR down service power consumption of EV i at instant t;
- $SOC_{i,t}^{\omega}$ is the state of charge of EV i at instant t when it has not done any FCR service till t ($\omega = bsl$) (resp. it has not done till any service till $t-1$ but has done a FCR up service at t ($\omega = up$, it has not done till any service till $t-1$ but has done a FCR down service at t ($\omega = dn$).

1.2 Constraints

The domain of x_i is X_i, defined by the following constraints

$$u_{i,t}^{\sigma,\omega} \in \{0,1\}, \qquad \forall t \in T, \forall \sigma \in \Sigma, \forall \omega \in \Omega \tag{1.1a}$$
$$u_{i,t}^{chg,\omega} + u_{i,t}^{dischg,\omega} \leq 1, \qquad \forall t \in T, \forall \omega \in \Omega \tag{1.1b}$$
$$0 \leq p_{i,t}^{\sigma,\omega} \leq \overline{p_i^{\sigma}}, \qquad \forall t \in T, \forall \sigma \in \Sigma, \forall \omega \in \Omega \tag{1.1c}$$
$$p_{i,t}^{\sigma,\omega} \leq \overline{p_i^{\sigma}} \cdot u_{i,t}^{\sigma,\omega}, \qquad \forall t \in T, \forall \sigma \in \Sigma, \forall \omega \in \Omega \tag{1.1d}$$
$$p_{i,t}^{\sigma,bsl} \geq p\_charge_{i,t}^{min} \cdot u^{\sigma,bsl}, \qquad \forall t \in T, \forall \sigma \in \Sigma \tag{1.1e}$$
$$\textstyle\sum_{t\in T} p_{i,t}^{dischg,bsl} \leq E\_discharge_i^{max}, \tag{1.1f}$$
$$p_{i,t}^{chg,bsl} - p_{i,t}^{dischg,bsl} \geq p_{i,t}^{chg,up} - p_{i,t}^{dischg,up}, \qquad \forall t \in T \tag{1.1g}$$
$$p_{i,t}^{chg,bsl} - p_{i,t}^{dischg,bsl} \leq p_{i,t}^{chg,dn} - p_{i,t}^{dischg,dn}, \qquad \forall t \in T \tag{1.1h}$$
$$SOC_{i,0}^{\omega} = SOC_i^{initial}, \qquad \forall \omega \in \Omega \tag{1.1i}$$
$$0 \leq SOC_{i,t}^{\omega} \leq capacity_i, \qquad \forall t \in T, \forall \omega \in \Omega \tag{1.1j}$$
$$SOC_{i,t}^{\omega} = SOC_{i,t-1}^{bsl} + \left[\rho_{ad}\, p_{i,t}^{chg,\omega} - \tfrac{1}{\rho_{da}}\, p_{i,t}^{dischg,\omega}\right] \delta_t, \qquad \forall t \in T \setminus \{0\}, \forall \omega \in \Omega \tag{1.1k}$$

1.3 Objective function

$$\begin{aligned}
FCR_up_t &= \sum_{i\in I} \left[\left(p_{i,t}^{chg,bsl} - p_{i,t}^{dischg,bsl}\right) - \left(p_{i,t}^{chg,up} - p_{i,t}^{dischg,up}\right)\right] \\
FCR_down_t &= \sum_{i\in I} \left[\left(p_{i,t}^{chg,dn} - p_{i,t}^{dischg,dn}\right) - \left(p_{i,t}^{chg,bsl} - p_{i,t}^{dischg,bsl}\right)\right] \\
penalty_{i,t}^{SOC,\omega} &= \left(\left[SOC_{i,t}^{\omega} - SOC_{i,t}^{min}\right]^- + \left[SOC_{i,t}^{\omega} - SOC_i^{max}\right]^+\right)^2, \quad \forall \omega \in \Omega \\
customer_energy_cost &= \sum_{t\in T} \sum_i p_{i,t}^{bsl}\, \delta_t\, \pi_t^{\mathrm{elec}} - \sum_i SOC_{i,T}\, \pi_T^{\mathrm{elec}}
\end{aligned}$$

$$g_i(x_i) = \begin{pmatrix} g_i^{up}(x_i) \\ g_i^{dn}(x_i) \end{pmatrix} = \begin{pmatrix} \left(\left(p_{i,t}^{chg,bsl} - p_{i,t}^{dischg,bsl}\right) - \left(p_{i,t}^{chg,up} - p_{i,t}^{dischg,up}\right)\right)_t \\ \left(\left(p_{i,t}^{chg,dn} - p_{i,t}^{dischg,dn}\right) - \left(p_{i,t}^{chg,bsl} - p_{i,t}^{dischg,bsl}\right)\right)_t \end{pmatrix} \in \mathbb{R}^{2(T+1)}$$

$$\begin{aligned}
y &= ((y_t^{up})_t, (y_t^{dn})_t) \in \mathbb{R}^{2(T+1)} \\
f_0(y) &= \sum_t \alpha^{up}\, (y_t^{up} - demand_t^{up})^2 + \sum_t \alpha^{dn} \left(y_t^{dn} - demand_t^{dn}\right)^2
\end{aligned}$$

$$f_0(\sum_i g_i(x_i)) = \sum_t \alpha^{up} \left(\sum_i g_{i,t}^{up}(x_{i,t}) - demand_t^{up}\right)^2 + \sum_t \alpha^{dn} \left(\sum_i g_{i,t}^{dn}(x_{i,t}) - demand_t^{dn}\right)^2$$

$$
\begin{aligned}
f_i(x_i) = &\sum_{t\in T}\sum_{\omega\in\Omega}\beta^{min}\left(\left[SOC^{\omega}_{i,t} - SOC^{min}_{i,t}\right]^{-}\right)^2 + \sum_{t\in T}\sum_{\omega\in\Omega}\beta^{max}\left(\left[SOC^{\omega}_{i,t} - SOC^{max}_{i}\right]^{+}\right)^2 \\
&+ \sum_{t\in T} p^{bsl}_{i,t}\,\delta_t\,\pi^{\text{elec}}_t - SOC_{i,T}\,\gamma\,\pi^{\text{elec}}_T
\end{aligned}
$$

Objective function is

$$
F(x) = f_0\Big(\sum_i g_i(x_i)\Big) + \sum_i f_i(x_i)
$$