Charging schedule optimization

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1 Problem set-up

1.1 Task information

Arrival time: T_v^{arr}
Departure time: T_v^{dep}
Departure SOC: SOC_v^{dep}
initial SOC: $SOC_{-1,v}$
Current SOC: SOC_v^{cur}
Arrival SOC: SOC_v^{arr}

1.2 Parameters

1.2.1 General

Monotonically decreasing Weights: $w_{i,v}$
Timeslot id: i
Starting time of optimization implementation: t_s
Length of a Timeslot: Δt
State of charge at timeslot, i for vehicle, v: $SOC_{i,v}$

1.2.2 Electric Vehicle, EV

index of vehicle, v: v
Maximum battery current rating: I_{max}
Total number of timeslots for a vehicle v: TT_v
Battery nominal Coulomb capacity: C_{bat}
Extra SOC: SOC_{xtra}
Total cycling capacity loss in a schedule: $C_{loss,cyc}$
Cyclic Battery degradation coefficient 1: k_1
Cyclic Battery degradation coefficient 2: k_2
Cyclic Battery degradation coefficient 3: k_3
Cyclic Battery degradation coefficient 4: k_4
SOC deviation at timeslot, i for vehicle, v: $SOC_{dev,i,v}$

SOC average at timeslot, i for vehicle, v: $SOC_{avg,i,v}$
Charge processed at timeslot, i for vehicle, v: $Ah_{i,v}$
Ambient temperature of the battery: T_{amb}

1.2.3 Utility provider

Wholesale Electricity Price at timeslot, i: WEP_i

1.2.4 Charging station

Maximum charging current of station c: $I_{c,max}$
Set of occupied slots at charging station, c: $CS_c^{occ} \in \{\ldots\}$
Constant voltage at the charging outlet: V

1.3 Decision variables

Charging current at timeslot, i for vehicle, v: $I_{i,v} \in [0, I_{max}]$

2 Multi-objective Optimization

2.1 Fleet operator concerns

2.1.1 Minimization of EV charging Cost:

◇ **Objective:**

$$\min_{I_{i,v}} \sum_{i}^{TT_v} \sum_{v}^{N_v} (WEP_i) \cdot I_{i,v} \cdot V \cdot \Delta t \tag{1}$$

◇ **Constraints:**

$$0 < I_{i,v} < I_{max} \quad \forall i, v$$

$$0 \leq \sum_{v} I_{i,v} \leq I_{c,max} \quad \forall i$$

$$\lceil \frac{T_v^{dep} - t_s}{\Delta t} \rceil = TT_v \quad \forall v$$

$$\sum_{i}^{TT_v} I_{i,v} \cdot \Delta t \geq (SOC_v^{dep} - SOC_{-1,v}) \cdot C_{bat} \quad \forall v$$

$$\sum_{i}^{TT_v} I_{i,v} \cdot \Delta t \leq (SOC_v^{dep} - SOC_{-1,v}) \cdot C_{bat} + SOC_{xtra} \quad \forall v$$

◇ **State update:**
(Done during optimization implementation)

$$SOC_{-1,v} = SOC_v^{cur} \;\; \forall\, v \in CS_c^{occc} \;\; (if\ v = charging\ vehicle)$$

$$SOC_{-1,v} = SOC_v^{arr} \;\; \forall\, v \rightarrow CS_c^{occc} \quad (if\ v = new\ vehicle)$$

$$SOC_{i,v} = SOC_{i-1,v} + \frac{I_{i,v} \cdot \Delta t}{C_{bat}}$$

2.1.2 Minimization of overall battery capacity degradation Cost:

- **Objective:**

$$\min_{I_{i,v}} \sum_{v}^{N_v} \sum_{i}^{TT_v} ln(C_{loss,cyc}) \tag{2}$$

$$C_{loss,cal} = C_{bat} \cdot ((\frac{K(T_{amb}, SOC_{i,v}) \cdot (1 + \alpha(T)) \cdot t}{C_{bat}} + 1)^{\frac{1}{1+\alpha(T)}} - 1)$$

$ln(C_{loss,cyc}) = ln(K_1 \cdot SOC_{dev,i,v} \cdot e^{K_2 \cdot SOC_{avg,i,v}} + K_3 \cdot e^{K_4 \cdot SOC_{dev,i,v}}) + ln(Ah_{i,v})$

Approximate objective:

$$\min_{I_{i,v}} \sum_{v}^{N_v} \sum_{i}^{TT_v} p_{00} + p_{10} \cdot SOC_{avg,v,i} + p_{01} \cdot I_{v.i} + p_{11} \cdot SOC_{avg,v,i} \cdot I_{v,i} + p_{02} \cdot I_{v,i}^2 + p_1 \cdot SOC_{avg,v,i} \cdot adj_{var} + p_2 + q1 \cdot (\frac{I_{v,i}}{C_{bat,v}})^2 + q2 \cdot \frac{I_{v,i}}{C_{bat,v}} + q3$$

- **Constraints:**

$$0 < I_{i,v} < I_{max} \quad \forall i, v$$

$$0 \leq \sum_{v} I_{i,v} \leq I_{c,max} \quad \forall i$$

$$\lceil \frac{T_v^{dep} - t_s}{\Delta t} \rceil = TT_v \quad \forall v$$

$$\sum_{i}^{TT_v} I_{i,v} \cdot \Delta t \geq (SOC_v^{dep} - SOC_{-1,v}) \cdot C_{bat} \quad \forall v$$

$$\sum_{i}^{TT_v} I_{i,v} \cdot \Delta t \leq (SOC_v^{dep} - SOC_{-1,v}) \cdot C_{bat} + SOC_{xtra} \quad \forall v$$

$$SOC_{i,v} = SOC_{i-1,v} + \frac{I_{i,v} \cdot \Delta t}{C_{bat}}$$

$$SOC_{avg_i,v} = SOC_{i-1,v} + \frac{0.5 \cdot I_{i,v} \cdot \Delta t}{C_{bat}}$$

$$SOC_{dev_i,v} = \frac{0.5 \cdot I_{i,v} \cdot \Delta t}{C_{bat}}$$

$$Ah_{i,v} = \ I_{i,v} \cdot \Delta t$$

- ◇ **State update:**
  (Done during optimization implementation)

$$SOC_{-1,v} = SOC_v^{cur} \ \ \forall\ v \in CS_c^{occc} \ \ (if\ v = charging\ vehicle)$$

$$SOC_{-1,v} = SOC_v^{arr} \ \ \forall\ v \rightarrow CS_c^{occ} \quad (if\ v = new\ vehicle)$$

2.2 Customer concerns

2.2.1 Maximization of EV rental availability

- **Objective:**

$$\min_{I_{i,v}} \sum_{v}^{N_v} \sum_{i}^{TT_v} -w_{i,v} \cdot I_{i,v} \cdot V \tag{3}$$

- **Constraints:**

$$w_{i,v} = \frac{1}{i + TT_v} \quad \forall v,\ i \in [0, TT_v - 1]$$

$$0 < I_{i,v} < I_{max} \quad \forall i, v$$

$$0 \leq \sum_{v} I_{i,v} \leq I_{c,max} \quad \forall i$$

$$\lceil \frac{T_v^{dep} - t_s}{\Delta t} \rceil = TT_v \quad \forall v$$

$$\sum_{i}^{TT_v} I_{i,v} \cdot \Delta t \geq (SOC_v^{dep} - SOC_{-1,v}) \cdot C_{bat} \quad \forall v$$

$$\sum_{i}^{TT_v} I_{i,v} \cdot \Delta t \leq (SOC_v^{dep} - SOC_{-1,v}) \cdot C_{bat} + SOC_{xtra} \quad \forall v$$

- **State update:**
  (Done during optimization implementation)

$$SOC_{-1,v} = SOC_v^{cur} \quad \forall\ v \in CS_c^{occ} \quad (if\ \ v = charging\ vehicle)$$

$$SOC_{-1,v} = SOC_v^{arr} \quad \forall\ v \to CS_c^{occ} \quad (if\ \ v = new\ vehicle)$$

$$SOC_{i,v} = SOC_{i-1,v} + \frac{I_{i,v} \cdot \Delta t}{C_{bat}}$$