Electric Vehicle Charging Scheduling Scheme

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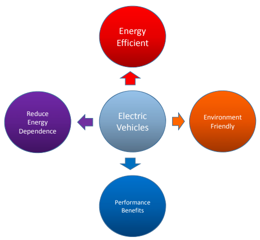
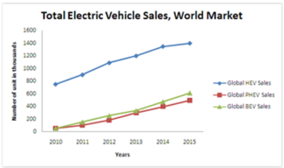
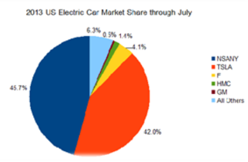
Motivation

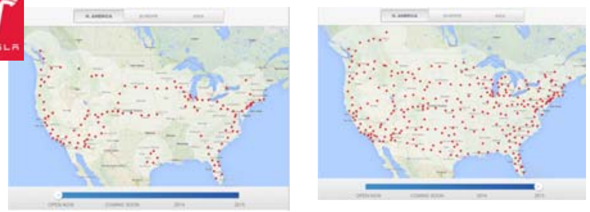
Energy Saving and Emission Reduction
- Government Policy (Economic Growth)
- Global Impact (Clean Energy)
- Energy Independence (Price Volatility)
- Climate Change (CO2 Global Warm)







EV Penetration



TESLA super charger placement in NA

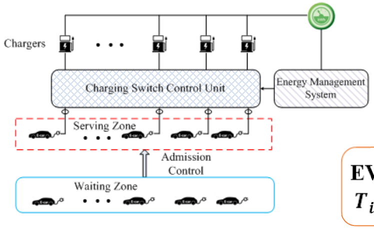
Problems with Uncoordinated charging
- Power loss
- Voltage variation
- Grid overloading
- Charging station revenue loss
- Customer's charging demand affected

Objective: *coordinate* multi-EV charging to avoid above issues.

Limitations of existing works

- Negotiate charging profiles one day ahead
- Ignore customers' interest
- Single charger only
- Unfair for each customer

System Model



M: Charger number
Δt: Slot duration
T: Total slot number
λ : Arrival rate

EV Charing Task

$$T_i = (i, t_i^a, t_i^d, r_i^{min}, r_i^{desired})$$

Utility Model

$$U = F_U(R, r_{min}, r_{desired})$$

Decision for all incoming EVs at t-th time slot

$$A(t) = \{a_1(t), a_2(t), \cdots, a_N(t)\}$$

$$a_i(t) = \begin{cases} 1, & \text{the } i\text{th EV is on charge,} \\ 0, & \text{the } i\text{th EV is NOT on charge.} \end{cases}$$

$$\sum_{i=1}^{N_t} a_i(t) \le M$$

Decision for i-th EV at time slot t

$$A_i(t) = \{a_1(t_i^a), \cdots, a_i(t_i^a)\}, t_i^a \le t \le t_i^d.$$

Accumulated served requirement

$$R_i(t) = \sum_{k=t_i^a}^{t} a_i(k).$$

Utility Maximization Problem

$$\max \sum_{t=1}^{T} \sum_{i=1}^{N_t} U_i(t) \cdot a_i(t)$$

$$\text{s.t. } a_i(t) \in \{0, \ 1\},$$

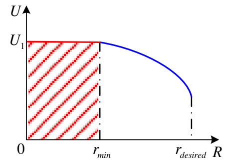
$$\sum_{i=1}^{N_t} a_i(t) \le M,$$

$$r_i^{\min} \le R_i(t_i^d) \le r_i^{desired}.$$

unseparated random optimization problem

Sample Utility Function

$$U_i(t) = \begin{cases} U_1, & R_i(t) \le r_i^{\min} \text{ and } t < t_i^d, \\ aR_i(t)^b + c, & R_i(t) \ge r_i^{\min} \text{ and } t < t_i^d, \\ 0, & \text{otherwise.} \end{cases}$$



Admission Control and Scheduling Algorithms

- **Task Energy State**
  $E_i(t) = r_i^{min} - R_i(t).$
- **Flexibility**
  $\phi_i(t) = t_i^d - t - E_i(t).$

modify

$$\Phi_i(t) = \frac{\phi_i(t)}{E_i(t)} = \frac{(t_i^d - t)}{E_i(t)} - 1.$$

Admission Control

Algorithm 1 MLLF Admission Control Algorithm

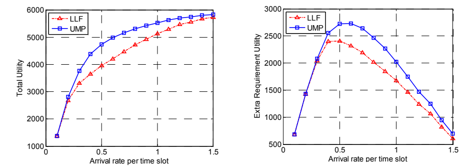
```
Input: Energy state E_i and departure time t_i^d of new task
    i, the set S_a, current time slot index t.
Output: The decision of whether to admit the new task.
procedure MLLF(E_i, t_i^d, S_a, t)
    Add the new task {E_i, t_i^d} and existing tasks to set S_a
    Get the maximum deadline t_max^d for all tasks in S_a.
    for k = t to t_max^d do
        Compute flexibility Φ_j(k) for each task j ∈ S_a
        Get m-th minimum flexibility Φ_m^min
        for Each task j ∈ S_a do
            if Φ_j(k) ≤ Φ_m^min then
                Update E_j(k+1) ← E_j(k) − 1
                if E_j(k+1) == 0 then
                    Remove task j from set S_a
                    Set finish time t_j^f = k for task j
                end if
            else
                E_j(k+1) ← E_j(k)
            end if
        end for
    end for
    for each task j in set S_a do
        if t_j^f > t_j^d then
            return Decline the new task
        end if
    end for
    return Accept the new task
end procedure
```

Scheduling

$$I^a(t) = \arg \min_{i \in 1,\cdots,N_t} \Phi_i(t).$$

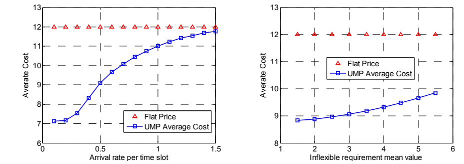
$$I^s(t) = \arg \max_{i \in 1,\cdots,N_t} U_i(t).$$

Simulations



(a) total utility (b) extra requirement utility

The influence of arrival rate on the total and extra utilities.



(a) $\lambda = 0.5$ (b) avg. $r_{min} = 3$

The influence of avg. r_{min} and arrival rate on the average cost.

Conclusion

- Classify the charging requirement into non-flexible and flexible parts
- Formulate a utility optimization problem, develop admission control and scheduling algorithms
- Outperform the state-of-the-art solution
- Charging station and customers win-win solution