Energy Management Methods of Distributed Energy Resources in Grid-Connected Microgrids to Achieve Economic Operation

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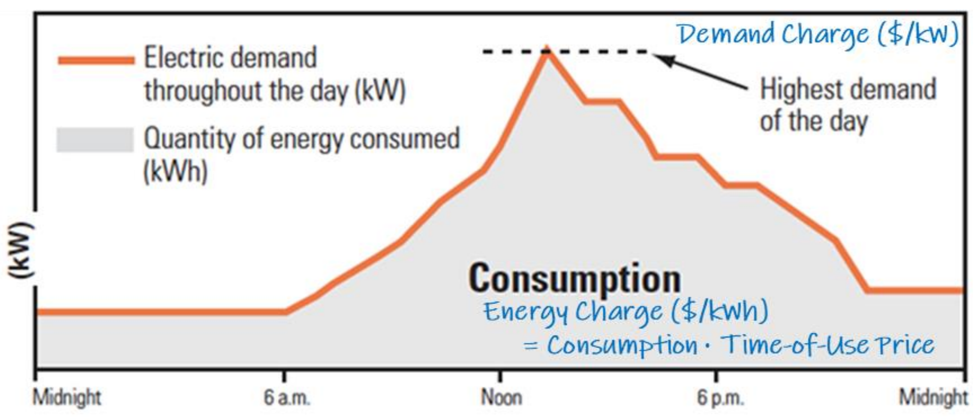
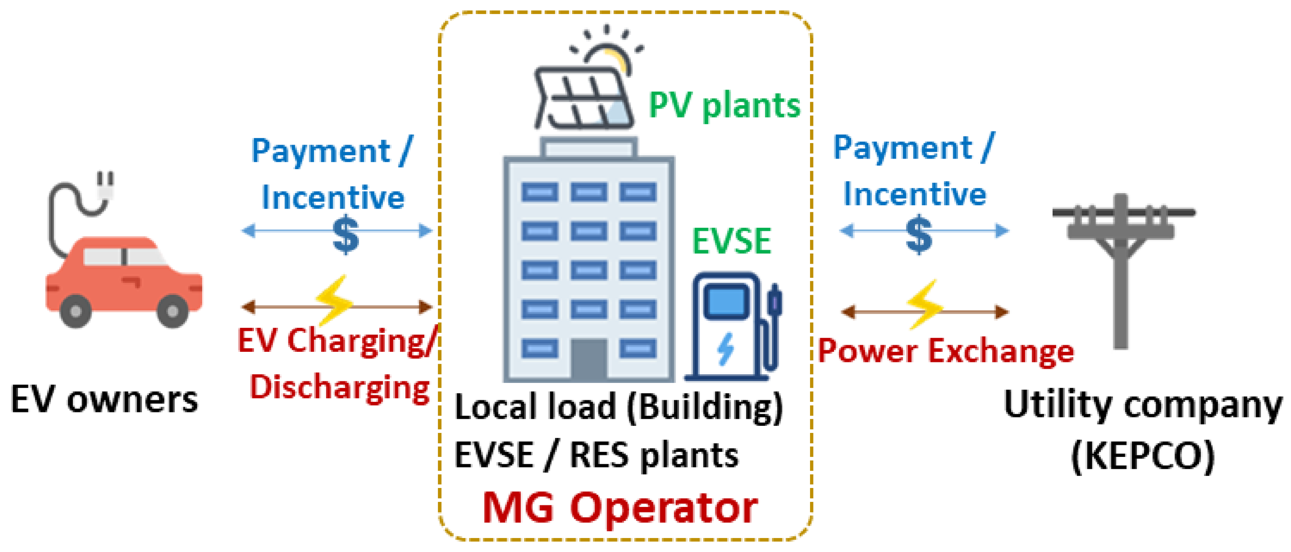
Objectives

- **Optimal control for operation cost minimization in a grid-connected microgrid (MG)**
  - Reduction in electricity consumption in microgrid (Energy charge reduction)
  - Peak load reduction in microgrid (Demand charge reduction)
  - EV charging price saving
  - Benefits from renewable energy generation and EV discharge



Microgrid Model

- **Grid-connected MG consists of**
  - Microgrid operator and its control system (MG-EMS)
  - Renewable energy sources (RESs: PV plants, WTs, etc)
  - EV charging/discharging station (EVSE)
  - Power grid connection (Bi-directional power exchange)
  - Electric loads and EVs (Customers)



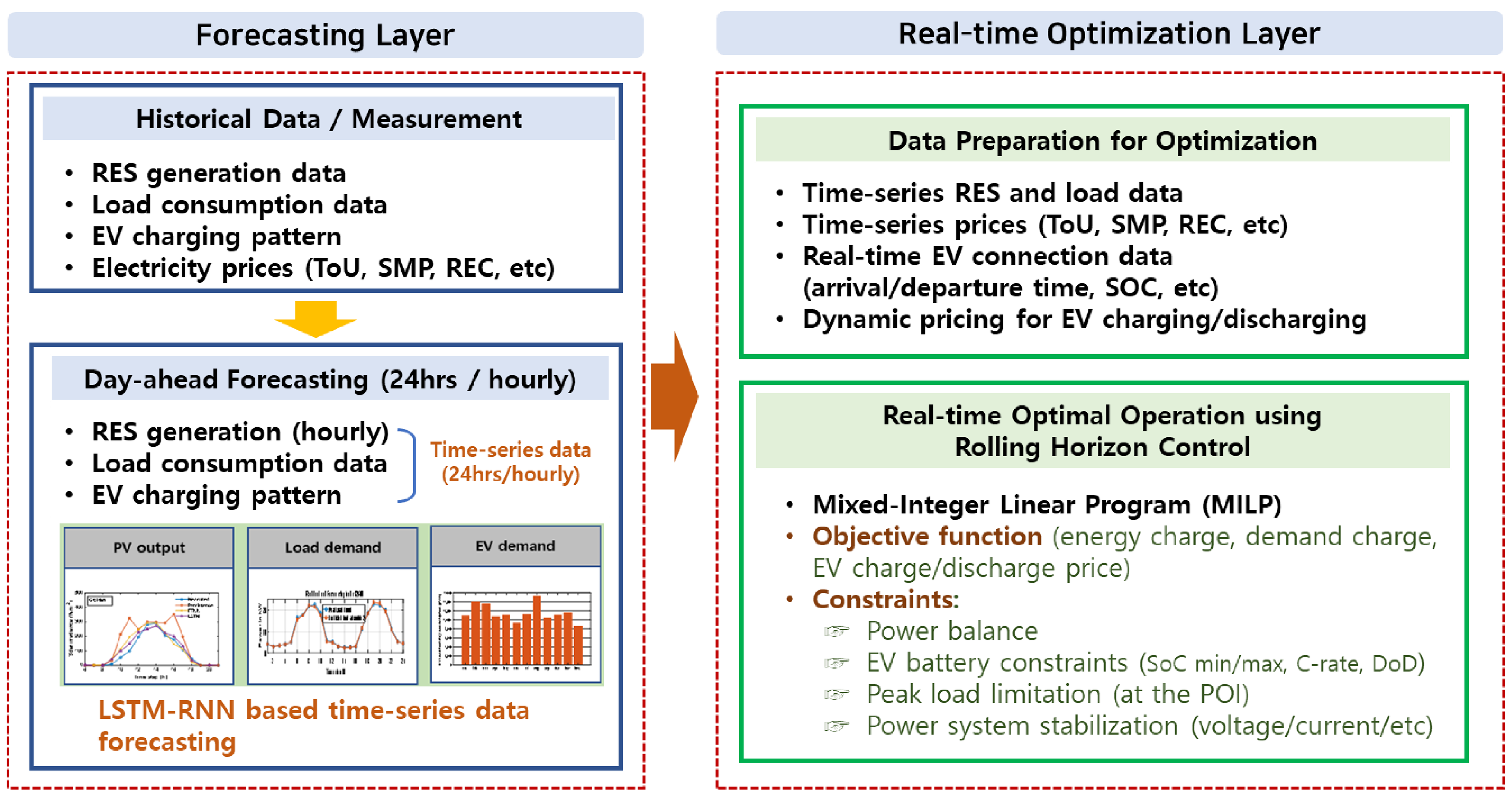
Problem Statement

- **Scheduling for MG operation with optimization algorithm (using mixed integer linear/nonlinear programming)**
  - Use RES generation for local load management
  - Smart EV charging / discharging (V1G/V2G)
  - Load shifting with dynamic pricing
- **However, uncertainty and variation cause difficulties in optimization process:**
  - Load power consumption
  - Renewable energy generation
  - EV arrival time and their initial SOC (State-of-Charge)

Real-time Rolling Horizon Control with AI-based Forecasting!

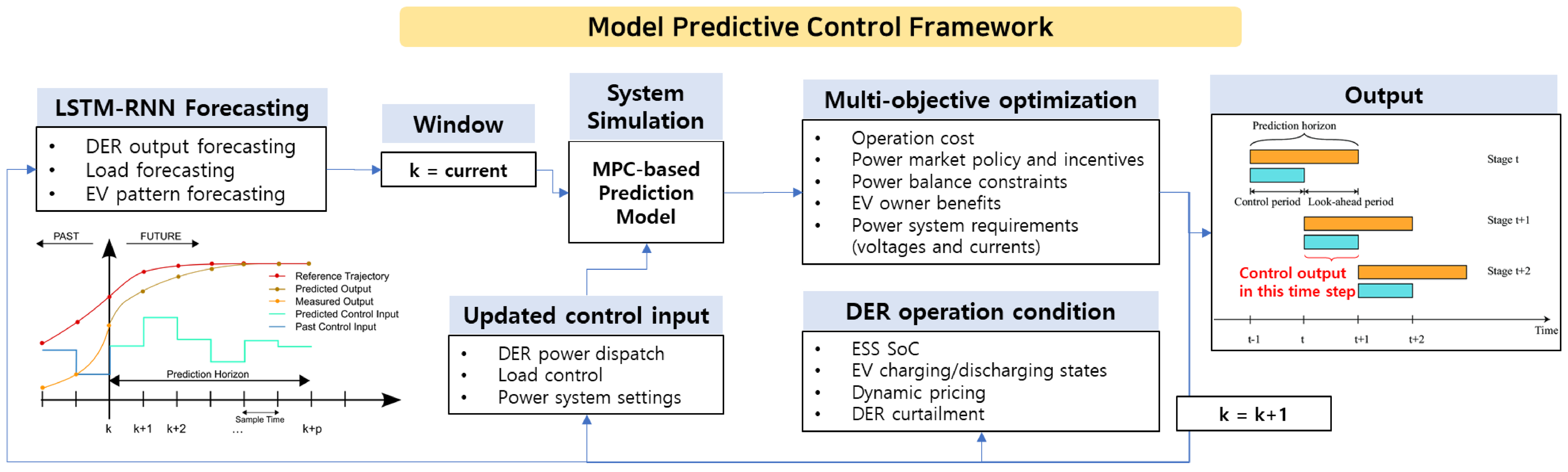
Proposed Control Scheme

- **Two-layer control scheme: Day-ahead forecasting and real-time operation layers**



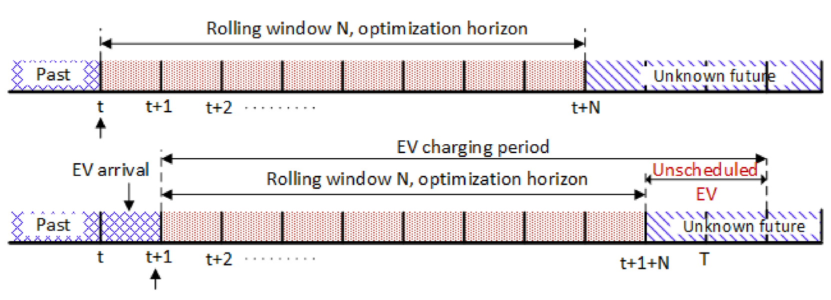
Model Predictive Control

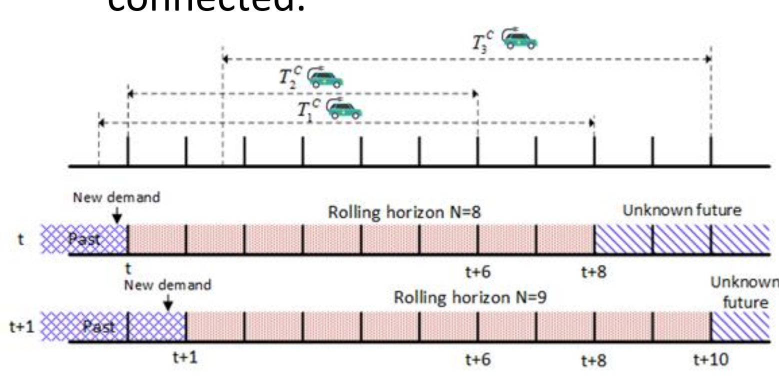
- **Rolling Horizon Control (RHC) as Model Predictive Control (MPC)**
  - MPC: Find the control command that can improve control performance in the future
  - Rolling Horizon Control as MPC framework.



Adaptive Rolling Horizon

- **Randomness of EV Connection**
  - EV arrival time and the initial SOC of the EV are intermittent and random.
  - If there are multiple EVs, the fixed size of rolling horizon has limitation to consider the whole EV connection time.
- **Adaptive Rolling Horizon**
  - When a new EV arrives, extend the rolling horizon up to the new EV connection time.
  - We can fully use V2G capability of all EVs connected.



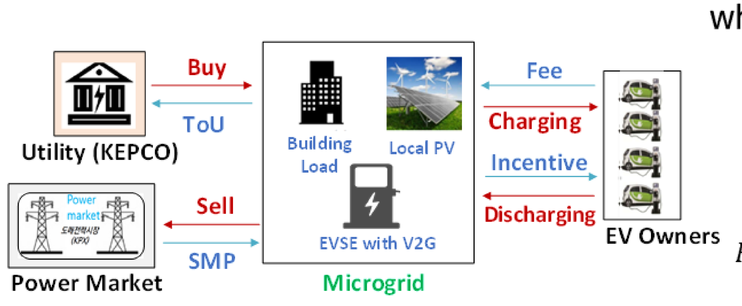


Objective Function

Objective Function: $\min \phi_{obj}^{t} = \min(\phi_{energy}^{t} + \phi_{demand}^{t})$

Energy Charge: $\phi_{energy}^{t} = \sum_{k=t}^{t+W_{RH}^{t}} \left[\sum_{m=1}^{N_{EV}^{t}} \delta^{m,k} \cdot (\varphi_{ch}^{k} s_{ch}^{m,k} P_{ch,max}^{m} - \varphi_{dch}^{k} s_{dch}^{m,k} P_{dch,max}^{m}) + \varphi_{ToU}^{k} P_{grid}^{buy,k} - \varphi_{SMP}^{k} P_{grid}^{sell,k} \right]$

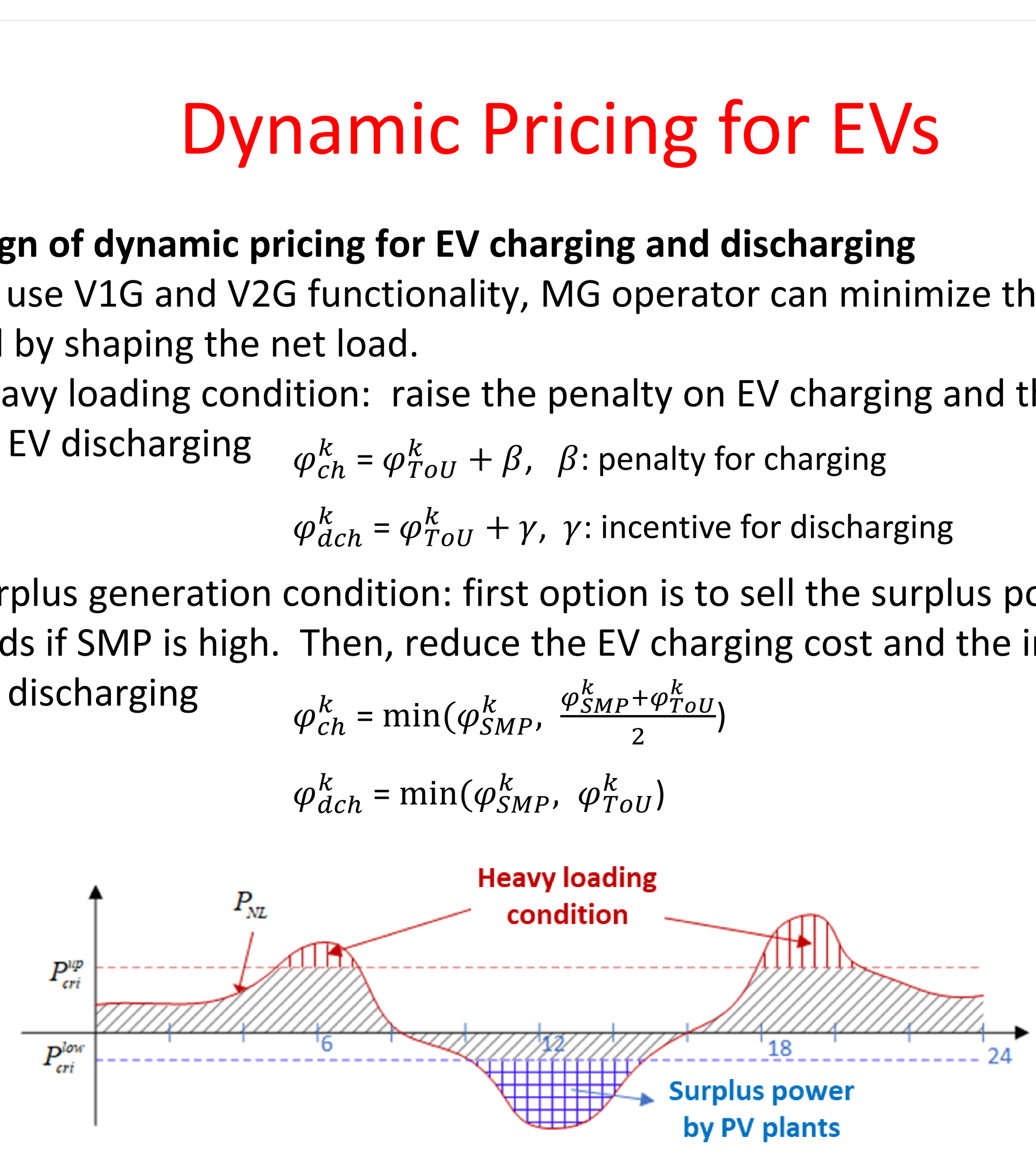
Demand Charge: $\phi_{demand}^{t} = \sum_{k=t}^{t+W_{RH}^{t}} u(P_{netload}^{k} - P_{peak}) \cdot \varphi_{peak} \cdot (P_{netload}^{k} - P_{peak} + s_{ch}^{m,k} P_{ch,max}^{m} - s_{dch}^{m,k} P_{dch,max}^{m})$



where:
- W_{RH}^{t} : Rolling horizon window size for optimization at time t
- N_{EV}^{t} : total number of EV connected at time t
- φ_{ch}^{k}, φ_{dch}^{k} : price for EV charging and discharging at interval k
- $s_{ch}^{m,k}$, $s_{dch}^{m,k}$: state for EV charging/discharging at interval k (real values btw 0 and 1)
- φ_{ToU}^{k}, φ_{SMP}^{k} : electricity tariff for import from and export to the grid (ToU, SMP prices)
- $P_{grid}^{buy,k}$, $P_{grid}^{sell,k}$: electricity purchased and sold at interval k
- $\delta^{m,k}$: connection state of m-th EV at interval k (either 0 or 1)

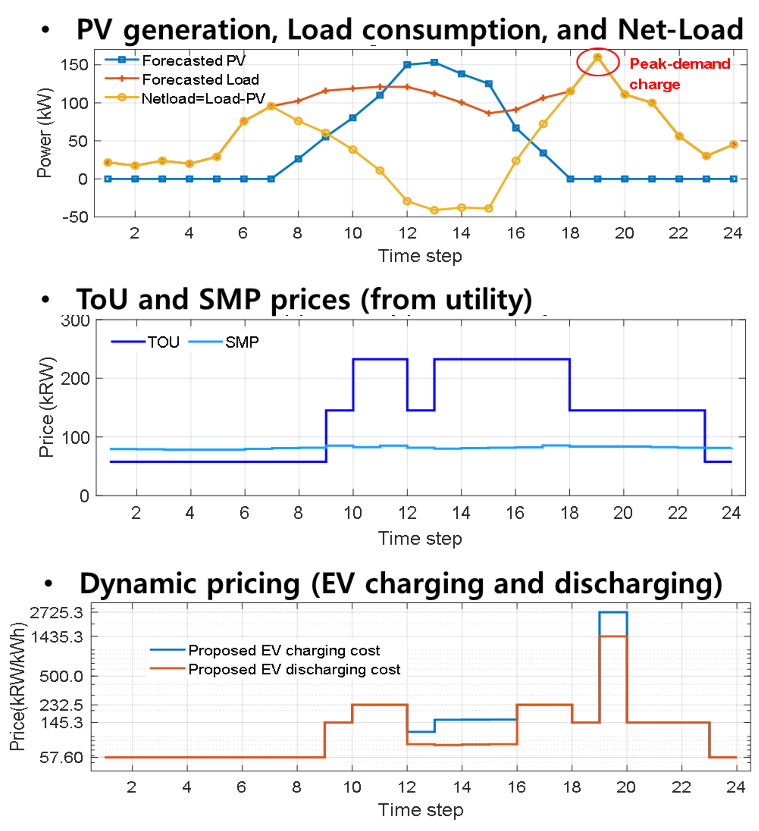
Dynamic Pricing for EVs

- **Design of dynamic pricing for EV charging and discharging**
  - To use V1G and V2G functionality, MG operator can minimize the electricity bill by shaping the net load.
  - Heavy loading condition: raise the penalty on EV charging and the incentive on EV discharging
    $\varphi_{ch}^{k} = \varphi_{ToU}^{k} + \beta$, β: penalty for charging
    $\varphi_{dch}^{k} = \varphi_{ToU}^{k} + \gamma$, γ: incentive for discharging
  - Surplus generation condition: first option is to sell the surplus power to grids if SMP is high. Then, reduce the EV charging cost and the incentive on EV discharging
    $\varphi_{ch}^{k} = \min(\varphi_{SMP}^{k}, \frac{\varphi_{SMP}^{k} + \varphi_{ToU}^{k}}{2})$
    $\varphi_{dch}^{k} = \min(\varphi_{SMP}^{k}, \varphi_{ToU}^{k})$



Case Studies

Simulation Scenario



EVSE#1 & EVSE#2 - Simulation Results