Integrated Optimized Charging and Economic Analysis of V2G Enabled School Bus System

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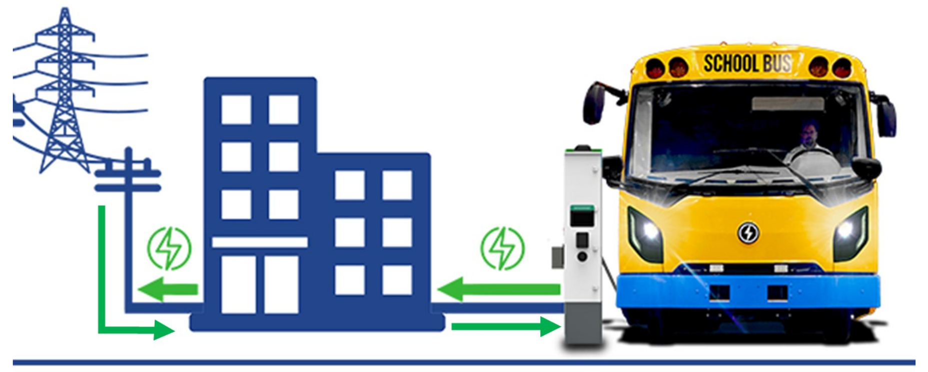

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Background

Scenarios

- Battery Electric School Buses (BESB) are idle for three quarters of the day and 1/3 in year
- School Buses have predictive daily / seasonal schedules and routes
- ESB carries larger batteries
- V2G is challenging because of challenges like unmanaged charging, battery degradation & high demand charges
- No or less explored area: V2G benefits specific to ESB system compared to transit buses

Motivation

- Grid stress mitigation due to growing electrification and peak demand period
- Utilized idle BEBs potential for V2G to create revenue stream
- Develop solutions to manage battery degradation, demand charges and operational costs associated with V2G operation
- Research gaps in BESBs V2G integration

Objectives

- **Develop smart charging schedules considering time of use electricity pricing and demand charges**
- **Formulate a MIP optimization model incorporating battery ageing, demand charges and operational constraints for BESB system**
- **Provide insights into financial benefits and offer guidance on optimal battery sizing in V2G adoption**

Problem Setting

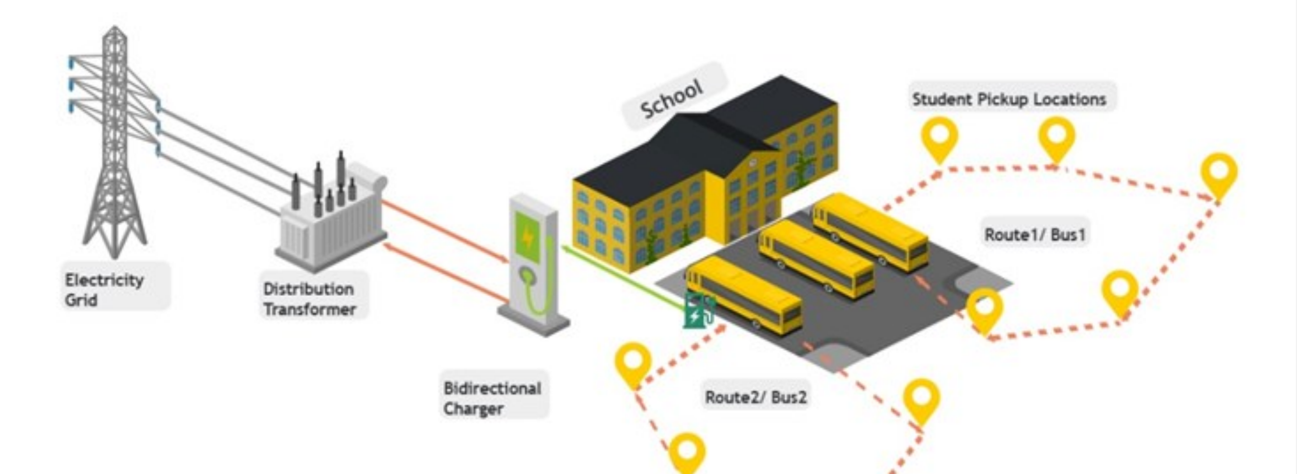


Figure: Typical layout pf school bus operation and grid interaction

This problem description lays the foundation for developing and optimized smart charging and V2G integration considering real-world school bus operation challenges and economic factors.

- Realistic school bus operation system consideration
- Two types of bidirectional V2G chargers are considered
- Charger selection based on the operational needs
- Fixed bus routes and schedules are gathered from schools schedules
- Time of use electricity prices for peak and off-peak periods and same for demand charges
- Optimization of both charging and discharging schedules

Mathematical Model Formulation

Mixed Integer Programming (MIP) model formulation

Min Daily Operation Cost (DoC)

$$\sum_{k} b^k * a^k + \sum_{t\in T} p_t w_t^c - \sum_{t\in T} s_t w_t^d + \sum_{k\in K}\sum_{t\in T} d_{k,t} + \frac{\mu_\lambda}{30}\sum_{k\in K}\sum_{t\in t_{on}/t_{off}} \lambda_t$$

Min Annualized Cost (AC)

$$\sum_{winter} (DOC_{weekday} + DOC_{weekend}) + \sum_{summer} DOC$$

Subject to,

- *Assigned bus route and bus index constraints*
- *Charging discharging constraints*
- *Demand charge constraints*
- *Battery lifecycle and degradation constraints*
- *Battery consumption and battery bounds constraints*

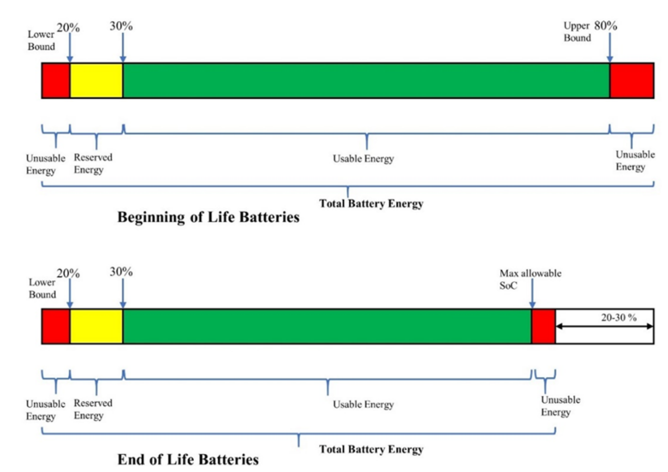


Figure: Battery degradation concept due to charging discharging cycles

Heuristic Implementation

temp(t)=100, cooling_rate=0.98, max_iteration=1000
for iteration in range(max_iteration):
  current_obj $(f(S'))$ *=DOC*
  assign best_schedule = none
  assign best_obj $(f(S_2))$
  calculate $\Delta = \frac{(f(S_2)) - (f(S'))}{(f(S'))}$
  if $\Delta \leq 0$*:*
    current_obj $(f(S'))$ *= best_obj* $(f(S_2))$
    best_schedule = reset_schedule()
  else:
    calculate acceptance probability $(p_r) = e^{\frac{-\Delta}{t}}$
    generate random probability r [0,1]
    if: $r > p_r$ *: break*
    else: current_obj $(f(S'))$ *= best_obj* $(f(S_2))$
  current_obj $(f(S'))$*, best_schedule*
  *calculate t = t * cooling_rate*
  if t < 0.00001
    break

Results: Case 1

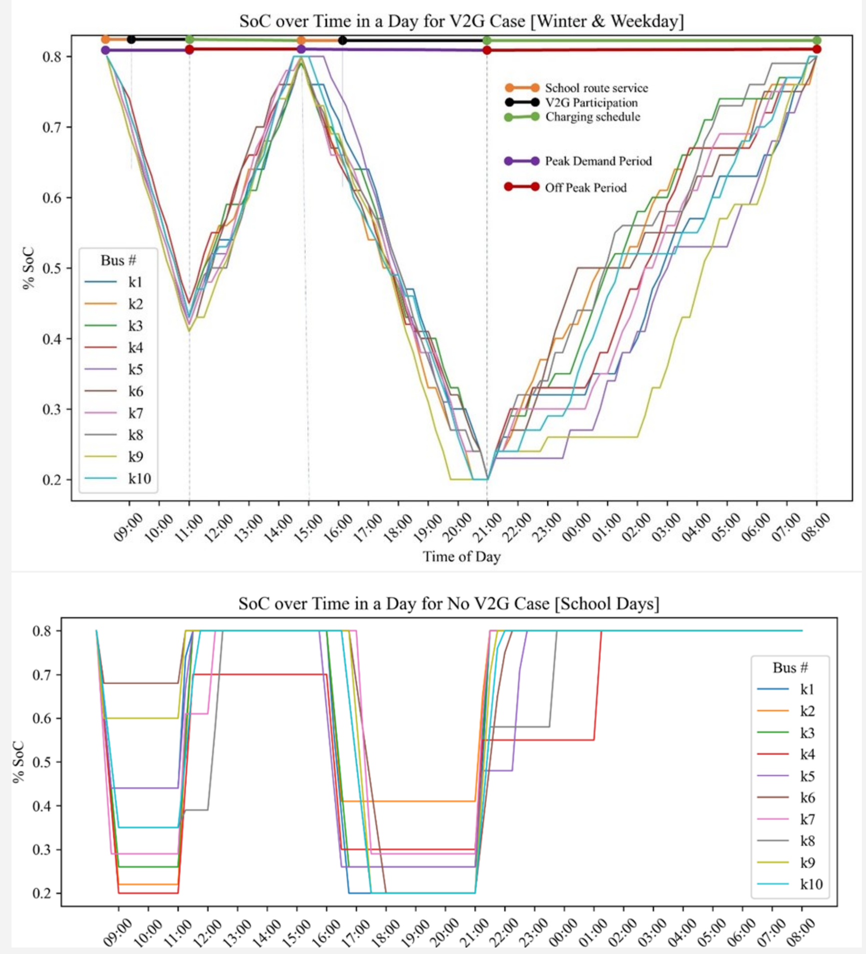


Figure: SoC variation without demand charge for BESB during school days

Test Case Results for Stage1 and Stage 2

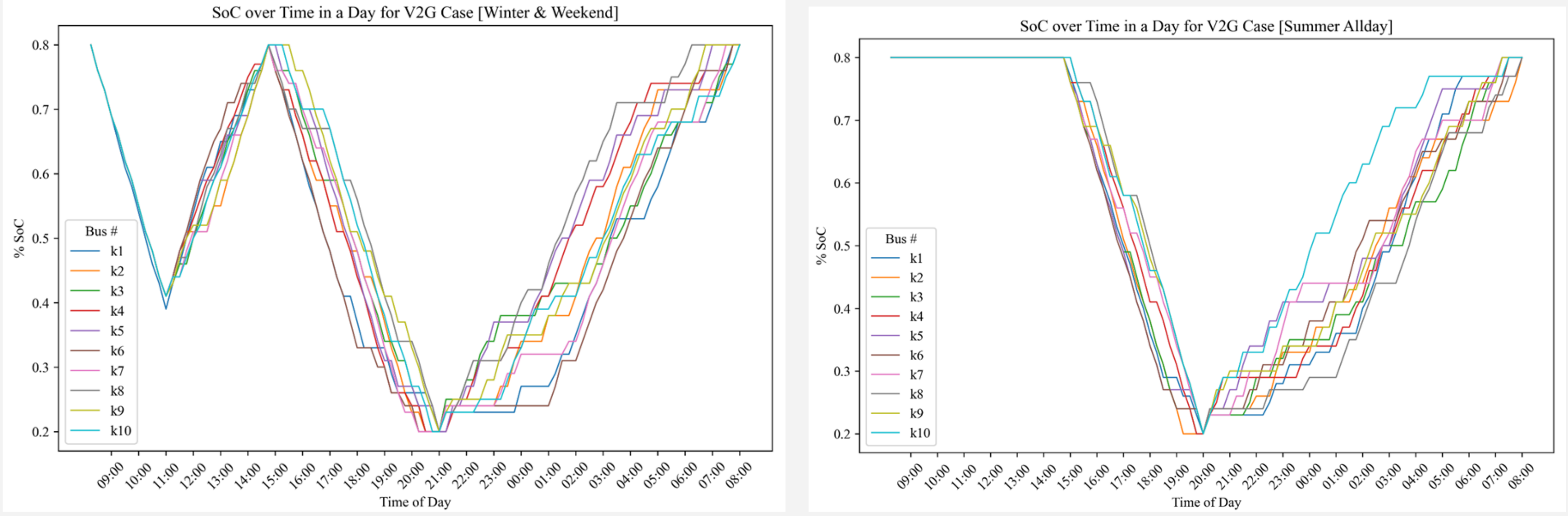
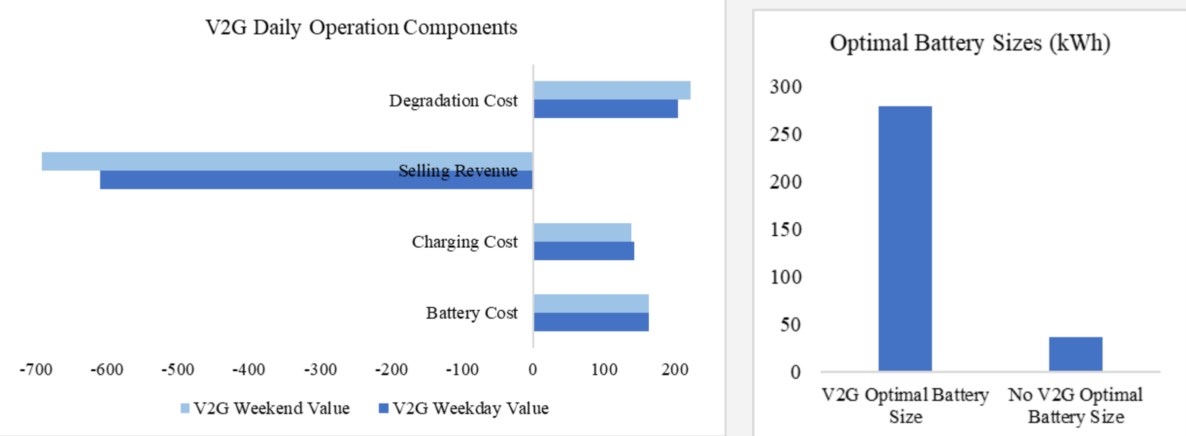


Figure: Smart charging discharging schedules during seasonal and weekend holidays

DOC and Optimal Battery Sizing



Results: Case 2

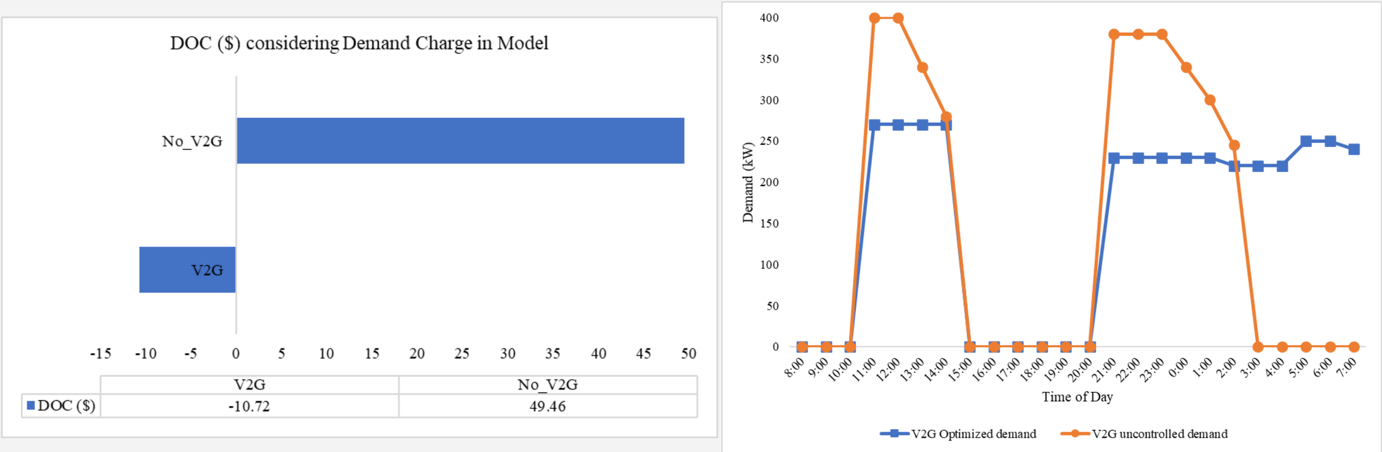


Figure: Demand charge optimization & DOC saving in V2G system

Sensitivity Analysis

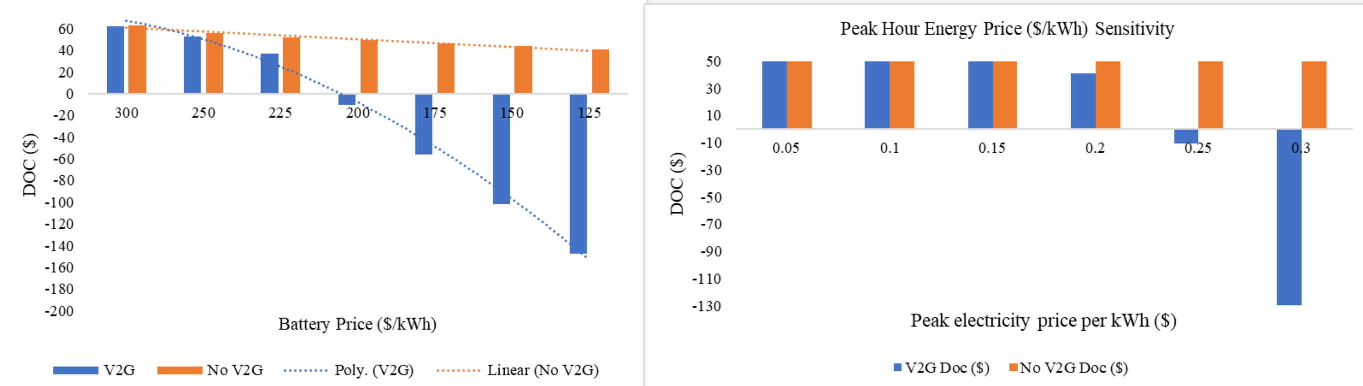


Figure: DOC cost sensitivity for V2G and no-V2G cases

Figure: Selling electricity price sensitivity for V2G and no-V2G cases

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Conclusion & Way Forward

- Significant economic benefits of V2G participation
- Annual profit per bus $5310.40 after accounting battery purchase cost, charging costs, battery degradation and demand charge costs
- The smart charging optimization reduced demand charges by 32.5% demonstrating model efficiency & practicality of BESB V2G participation
- Sensitivity analysis depicted that future reductions in battery prices and increase in energy acquisition further enhances profitability of V2G integration
- Findings have significant policy implications

⇒ We need to address V2G operational challenges like bidirectional charger technology and charger prices

⇒ Exploring BESB as a portable energy storages to enhance grid resiliency during emergency situations/ natural disasters