Optimal Frequency Support by Residential Multi-Port Power Converters

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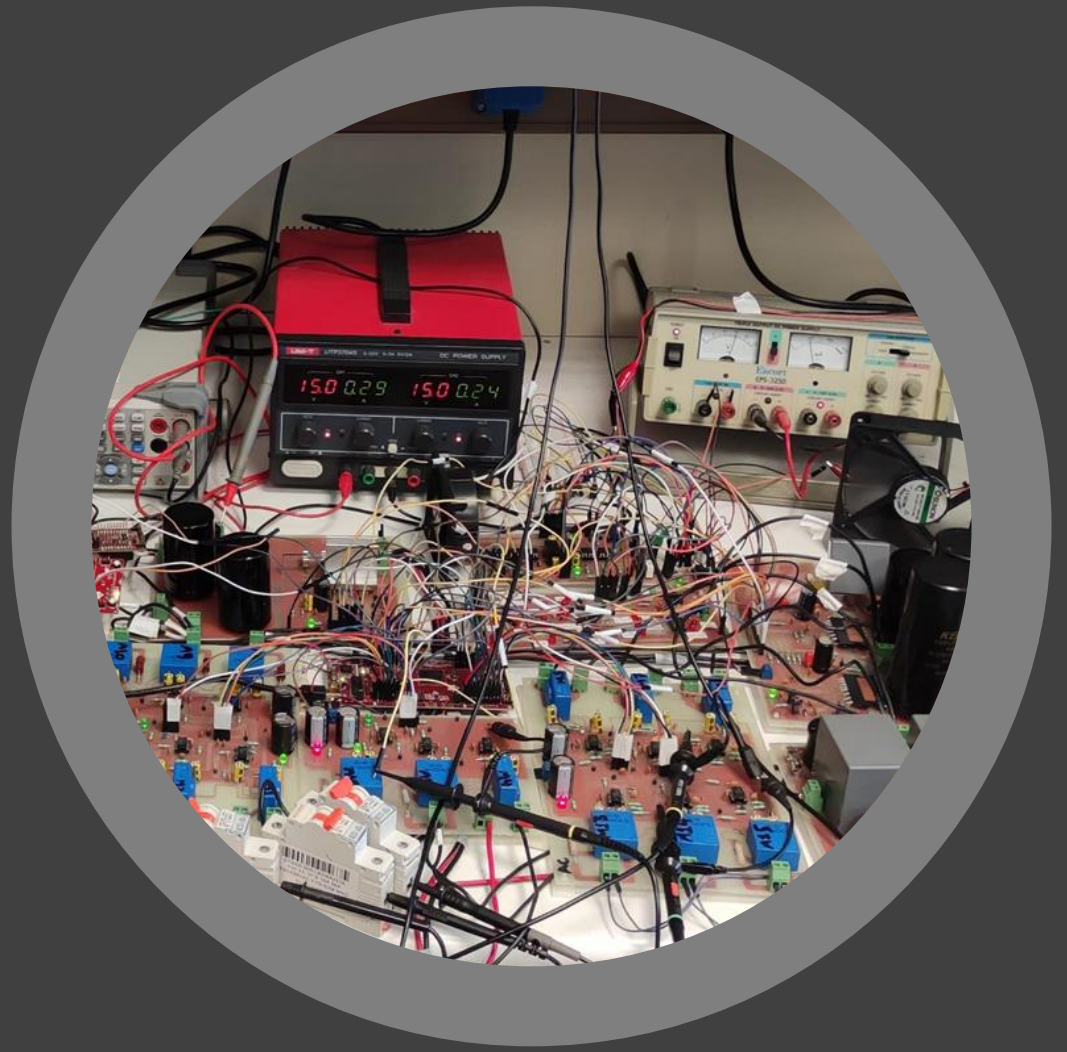

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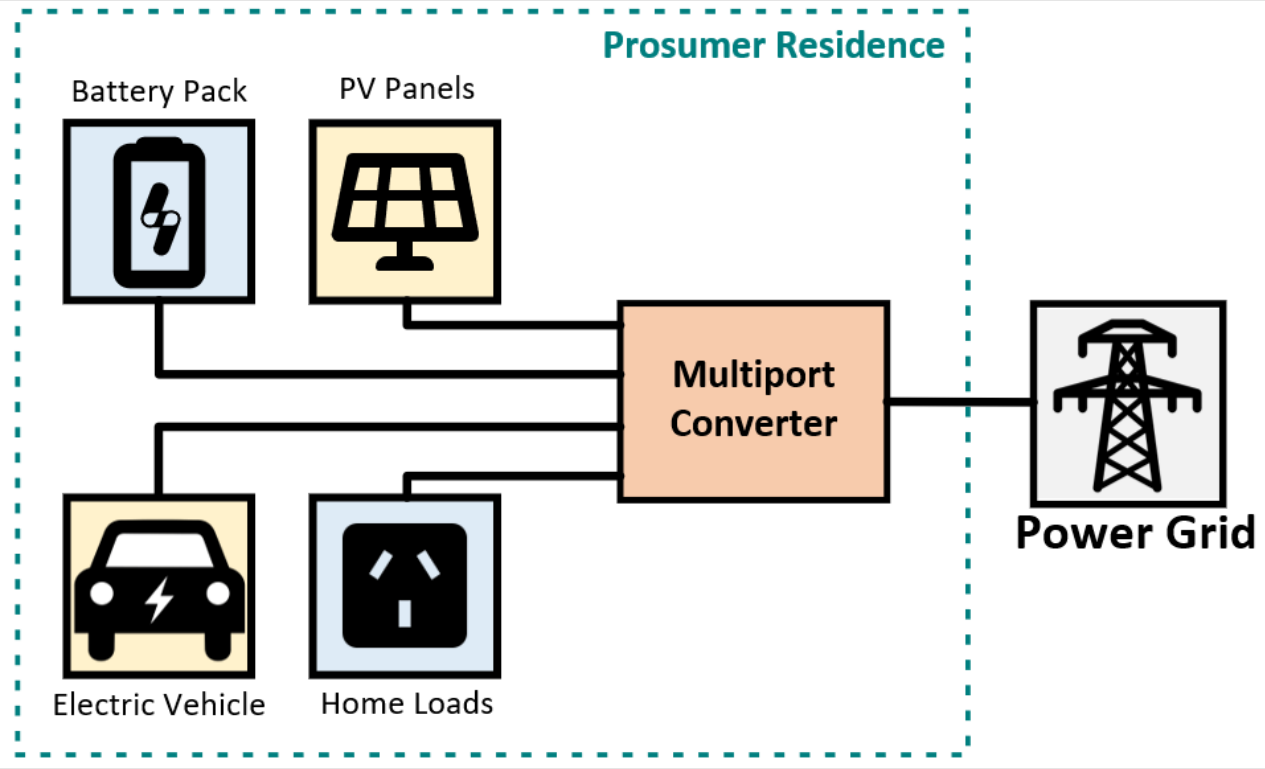
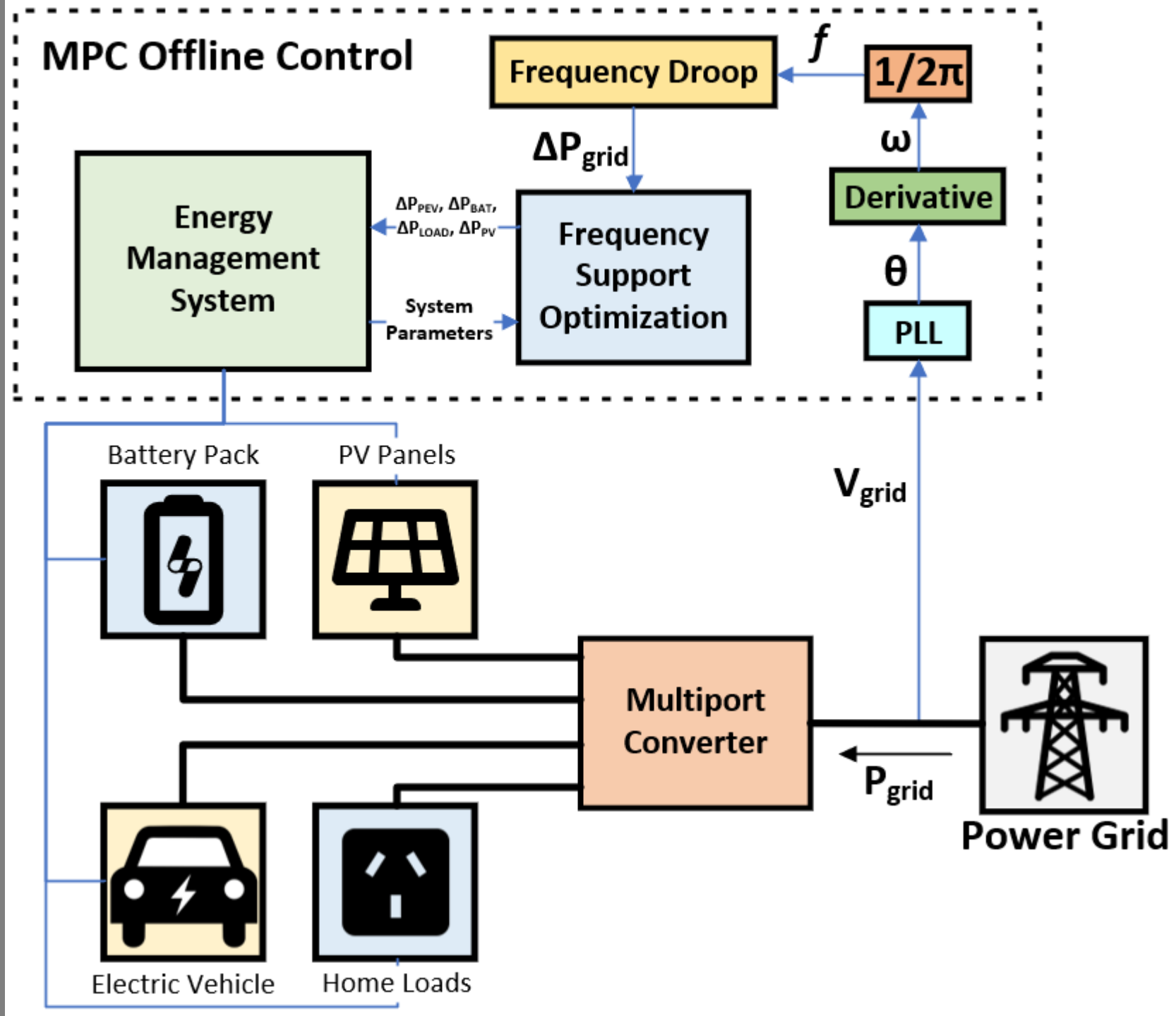
Introduction



Residential Multi-Port Converters

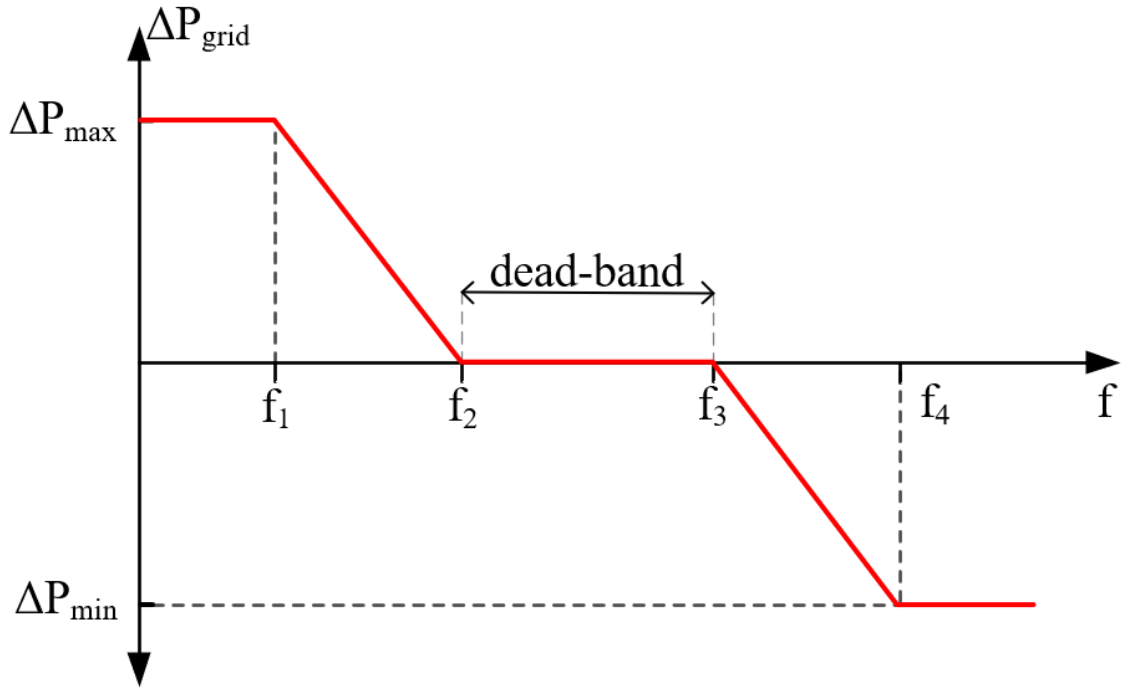
- Electric Vehicles with V2G technology
- Home Battery Packs
- Renewable Energy Sources
- Flexible Home Loads


MPC Offline Control
Frequency Droop
f
1/2π
ΔP grid
ω
Derivative
Energy Management System
ΔP PEV, ΔP BAT, ΔP LOAD, ΔP PV
Frequency Support Optimization
θ
System Parameters
PLL
Battery Pack
PV Panels
V grid
Multiport Converter
P grid
Power Grid
Electric Vehicle
Home Loads

Droop Control characteristic

$$\Delta P_{grid}(f) = \begin{cases} \Delta P_{grid,min} & f < f_1 \\ \Delta P_{grid,min} - \dfrac{\Delta P_{grid,min}}{f_2 - f_1}(f - f_1) & f_1 \le f \le f_2 \\ 0 & f_2 \le f \le f_3 \\ \dfrac{\Delta P_{grid,max}}{f_4 - f_3}(f - f_3) & f_3 \le f \le f_4 \\ \Delta P_{grid,max} & f > f_4 \end{cases}$$

f_1 = 49.2 Hz, f_2 = 49.8 Hz, f_3 = 50.2 Hz, f_4 = 50.8 Hz



Optimization - Objective function

$$\max \sum_i w_i \cdot flex_i(t) = \max \begin{pmatrix} w_{EV} \cdot flex_{EV}(t) + \\ w_{bat} \cdot flex_{bat}(t) + \\ w_{load} \cdot flex_{load}(t) \end{pmatrix}$$

Optimization-Flexibility

$$flex_{bat}(t) = \begin{cases} \dfrac{SoC_{bat,max} - SoC_{bat}(t)}{SoC_{\mathrm{bat},max} - SoC_{\mathrm{bat},min}}, & \Delta P_{grid} > 0 \\ \dfrac{SoC_{bat}(t) - SoC_{\mathrm{bat},min}}{SoC_{bat,max} - SoC_{\mathrm{bat},min}}, & \Delta P_{grid} < 0 \end{cases}$$

$$flex_{load}(t) = \begin{cases} \dfrac{P_{load,max} - P_{load}(t)}{P_{load,max} - P_{load,min}}, & \Delta P_{grid} > 0 \\ \dfrac{P_{load}(t) - P_{load,min}}{P_{load,max} - P_{load,min}}, & \Delta P_{grid} < 0 \end{cases}$$

Optimization-Constraints

$$SoC_{bat}(0) + \sum_{0:dt:t} P_{bat}(t) \cdot dt \leq SoC_{bat,max} \; \forall t$$

$$SoC_{bat}(0) + \sum_{0:dt:t} P_{bat}(t) \cdot dt \geq SoC_{bat,min} \; \forall t$$

$$P_{bat}(t) \leq P_{bat,max} \; \forall t$$

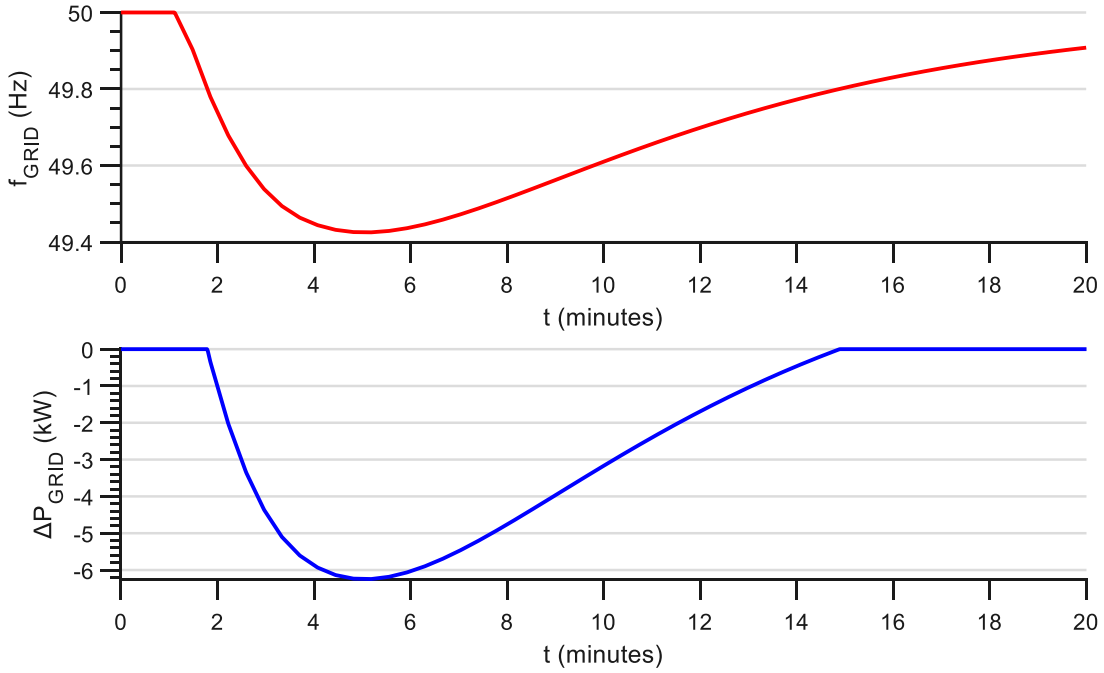
$$P_{bat}(t) \geq P_{bat,min} \; \forall t$$

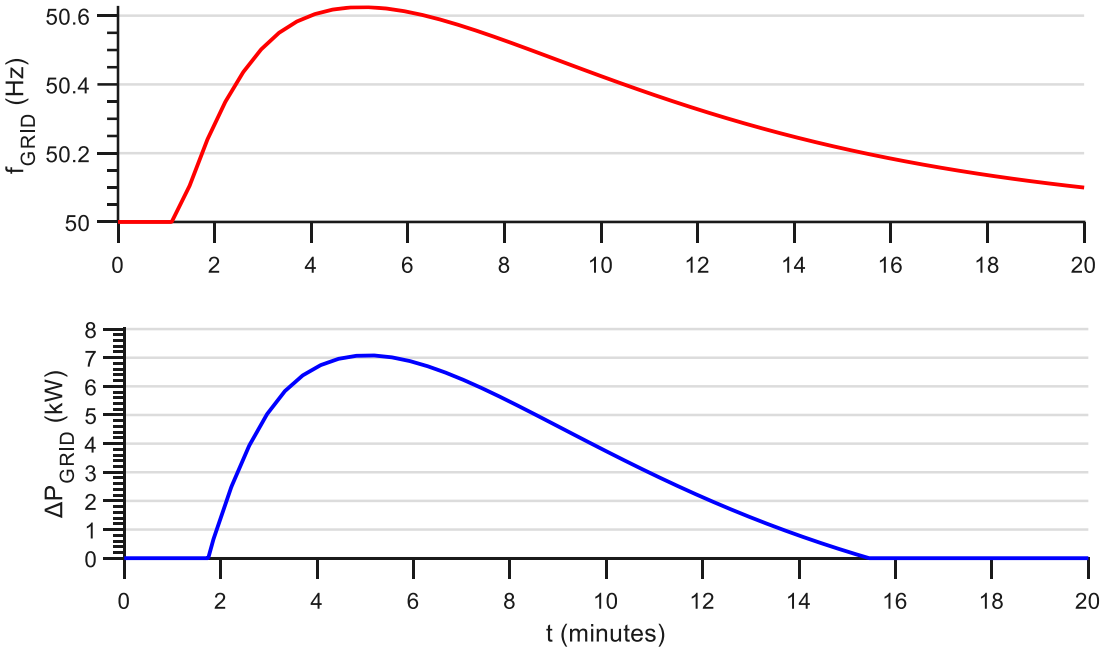
$$P_{load}(t) \leq P_{load,max} \; \forall t$$

$$P_{load}(t) \geq P_{load,min} \; \forall \mathrm{t}$$

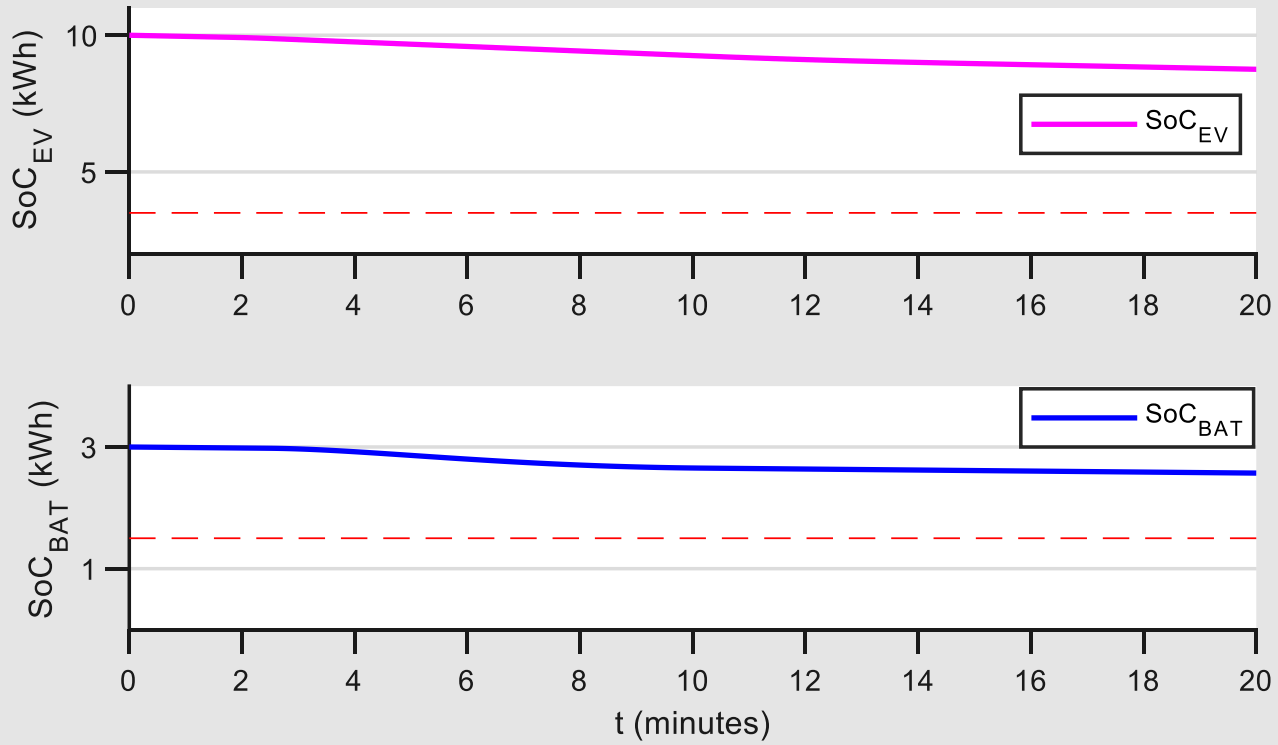
$$\Delta P_{grid}(t) = \Delta P_{EV}(t) + \Delta P_{bat}(t) + \Delta P_{load}(t) + \Delta P_{PV}(t) \quad \forall t$$

Case Study – Grid Fault





Grid under-frequency



- EV battery has more energy stored than the home battery pack

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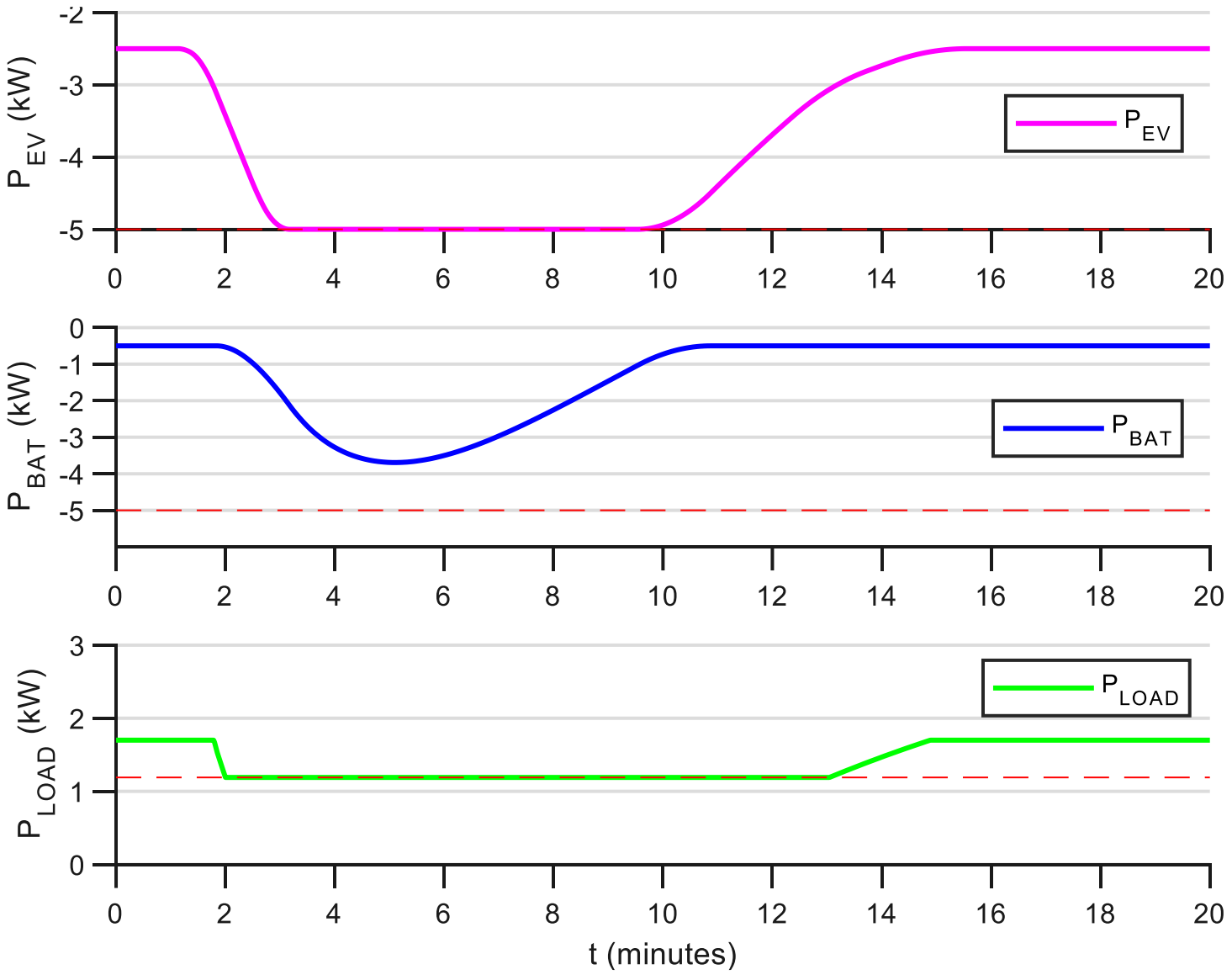
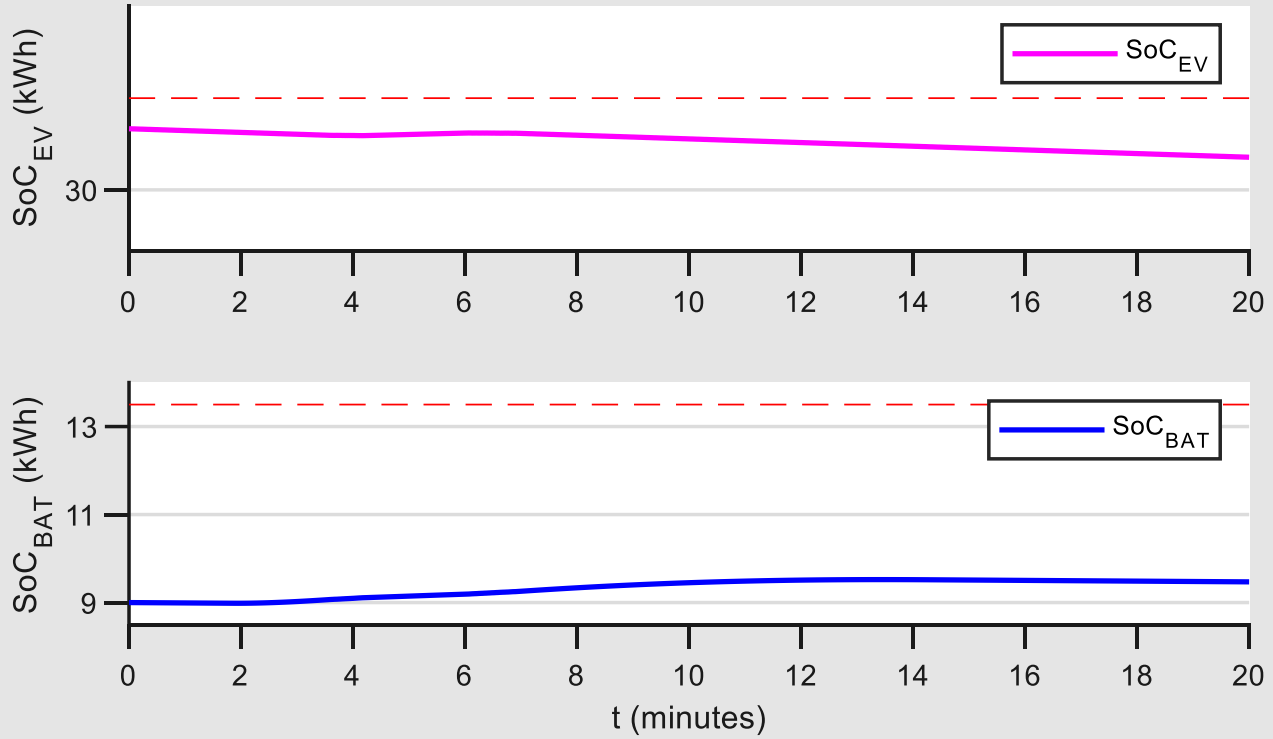
- EV battery has higher flexibility

Grid under-frequency

- Demand response is engaged first
- EV Battery is engaged second
- Home battery pack is engaged last



Grid over-frequency



- EV battery is almost fully charged, while the home battery pack can absorb more energy

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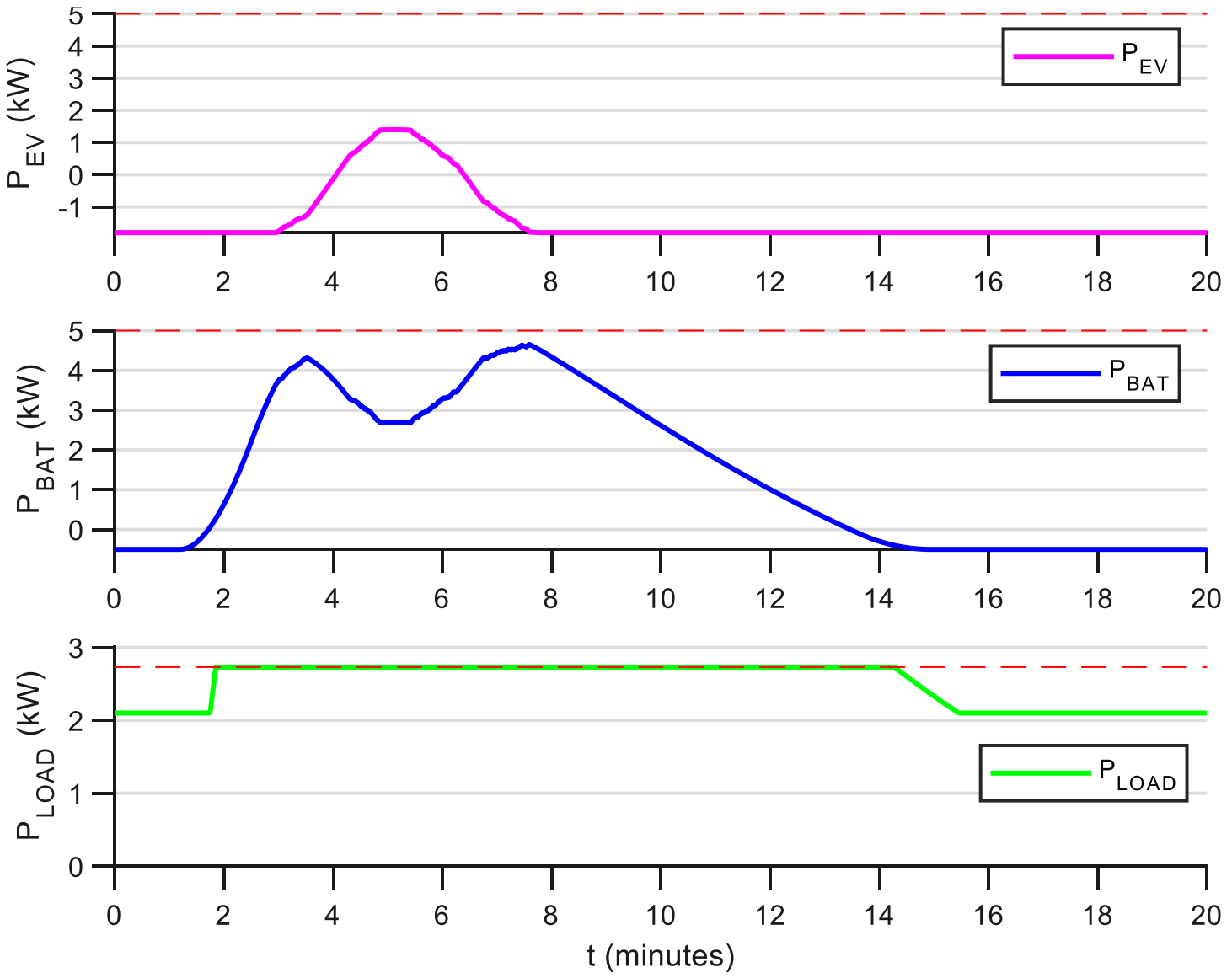
- Home battery pack has higher flexibility

Grid over-frequency

- Demand response is engaged first
- Home battery pack is engaged second
- EV battery is engaged last



Conclusions

Residential Prosumers are able to provide ancillary services to the grid

The proposed algorithm respects the flexibility of each module

Providing frequency support under the proposed algorithm does not deviate the system from its original operation by a significant amount

Acknowledgement

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Thank you for your attention!