Load Demand, Batteries, and Electric Vehicles Modelling to the Energy Management of Microgrids

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Agenda

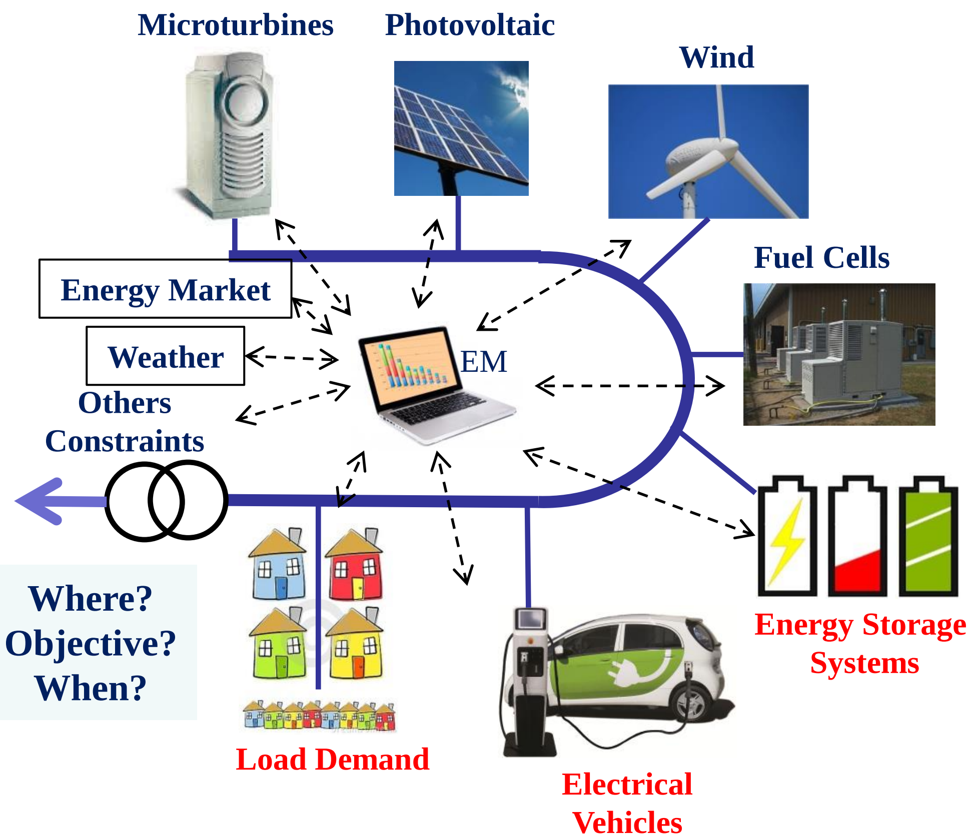
- **Energy Management of Microgrids**
  - Microgrids
  - Energy Management
- **Load Demand**
  - Critical, Curtailable Load Demand, Reschedulable Load Demand
  - Diffuse and Pre-Diffuse Load Demand
- **Batteries**
  - Lithion-ion Batteries
- **Electric Vehicles**
- **Didactical Microgrid and Computational Results**
  - Didactical Microgrid and Input Data
  - Computational Results
- **Conclusions**

Microgrids

Definition

MG consists of a group of Distributions Energy Resources (DERs) and controllable and uncontrollable loads that could operate either synchronised with the main grid or autonomously

Island and Connect Microgrid



Energy Management

- **It has similarities, at least in philosophy, with the classic problem of unit commitment for large power system, but also:**
  - might considers the use of other sources of energy besides electrical energy
  - could consider the load demand control
  - has faster dynamics for the DERs
  - has differences in the planning horizon and the discretization step time
  - has greater presence of intermittent generation

- **State of Art**
  - In most of the time the cost are represented by a linear function
  - The maximum and minimum amount power is set for each step time for the purchase / sale of energy to the main grid
  - In most cases, the horizon is 24 hours and is discretized at intervals of 1h, 30, 15 and 5 minutes
  - Is assumed that the problem have a deterministic approach
  - The size of this problem depends primarily on the following factors
    - Number and type of DERs
    - Number of lines
    - Size of the planning horizon and
    - Number of discretizations used over the horizon

Load Demand Modelling

Concept of Load as a Resource

Load Demand Modelling

Critical Load Demand

- most important load demand;
- impossibility of supplying this type of demand is modelled as a deficit (expensive fictitious generator)

Curtailable Load Demand (CLD, also called shedable)

- load demand for every step time
- cost of discontinuous for the load
- maximum time of discontinuity of each load
- maximum frequencies of discontinuity
- minimum down time after the shed
- minimum up time after turned on

Load Demand Modelling

Equations for the CLD

$$CC_{ct} \cdot pdc_{ct} \quad (1)$$

$$-pdc_{ct} - uc_{ct} \cdot DC_{ct} \leq -DC_{ct} \quad (2)$$

$$pde_{t} + uc_{ct} \cdot (10000) \leq 10000 \quad (3)$$

$$uc_{c,t-1} - uc_{ct} + zc_{ct} \leq 0 \quad (4)$$

$$-uc_{c,t-1} + uc_{ct} + yc_{ct} \leq 0, \quad (5)$$

$$\sum_{t=1}^{ND} zc_{ct} \leq NDC_{c}^{st} \quad (6)$$

$$-\sum_{t=1}^{ND} uc_{ct} \leq -ND + NC_{c}^{\max} \quad (7)$$

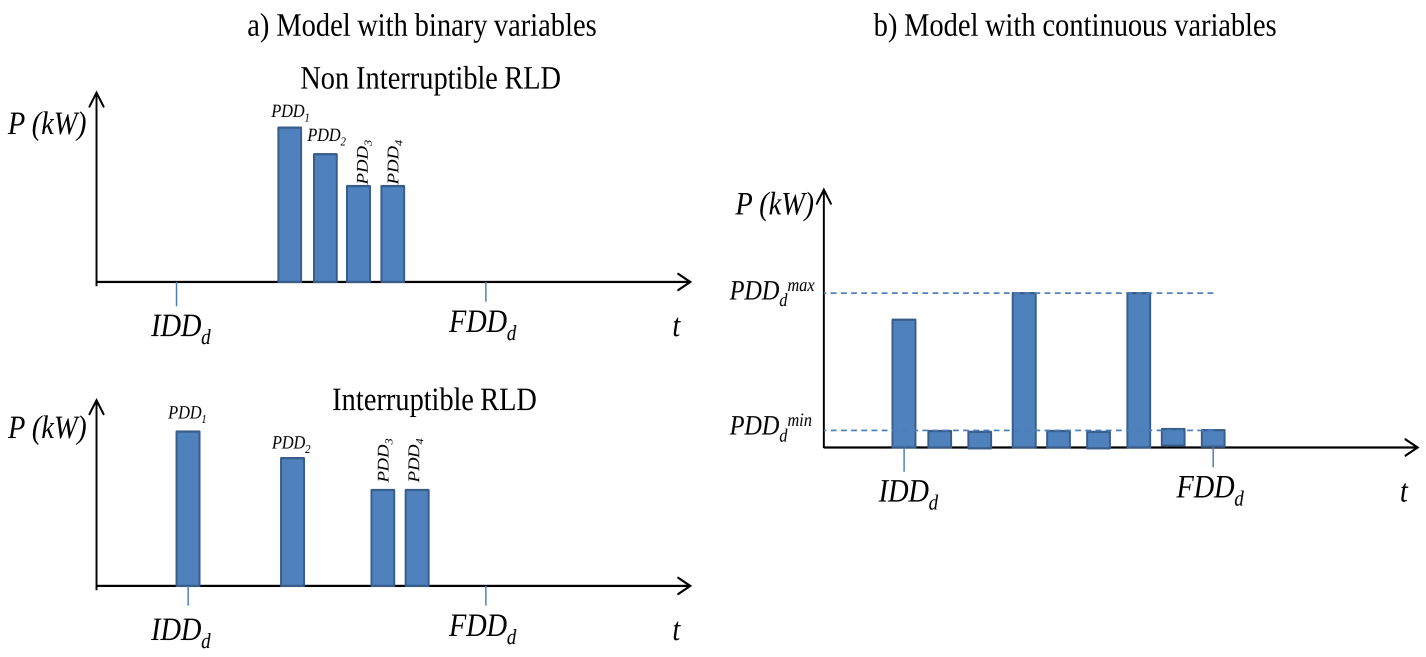
$$yc_{ct} + \sum_{i=1}^{OFF_c} zc_{c,t-1+i} \leq 1 \quad (8)$$

$$zc_{ct} + \sum_{i=1}^{ON_c} yc_{c,t-1+i} \leq 1 \quad (9)$$

$$0 \leq pdc_{ct} \leq DC_{ct} \quad (10)$$

Load Demand Modelling

- **Reschedulable Load Demand (RLD, also called Shiftable)**
  - load demand for every step time
  - maximum acceptable shift time
  - cost of load shifting (not all models consider)
  - planning time required for warning the load reschedule
  - total energy for the continuous variables approach



Load Demand Modelling

RLDB (Binary)

$$\sum_{i=1}^{UDD_{dd}} PDD_{ddi} \cdot ud_{dd,t-i+1} - pdd_{ddt} = 0 \quad \text{for} \quad IDD_{dd} \le t \le FDD_{dd} \qquad (12)$$

$$pdd_{ddt} = 0 \quad \text{for} \quad FDD_{dd} < t < IDD_{dd} \qquad (13)$$

$$\sum_{t=IDD_{dd}}^{FDD_{dd}-UDD_{dd}} ud_{ddt} = 1 \qquad (14)$$

$$ud_{ddt} \in \{0,1\}, \qquad (15)$$

RLDC (Continuous)

$$\sum_{t=IDD_{dc}}^{FDD_{dc}} pdd_{dct} \cdot H / ND = EDD_{dc}^{total} \qquad (16)$$

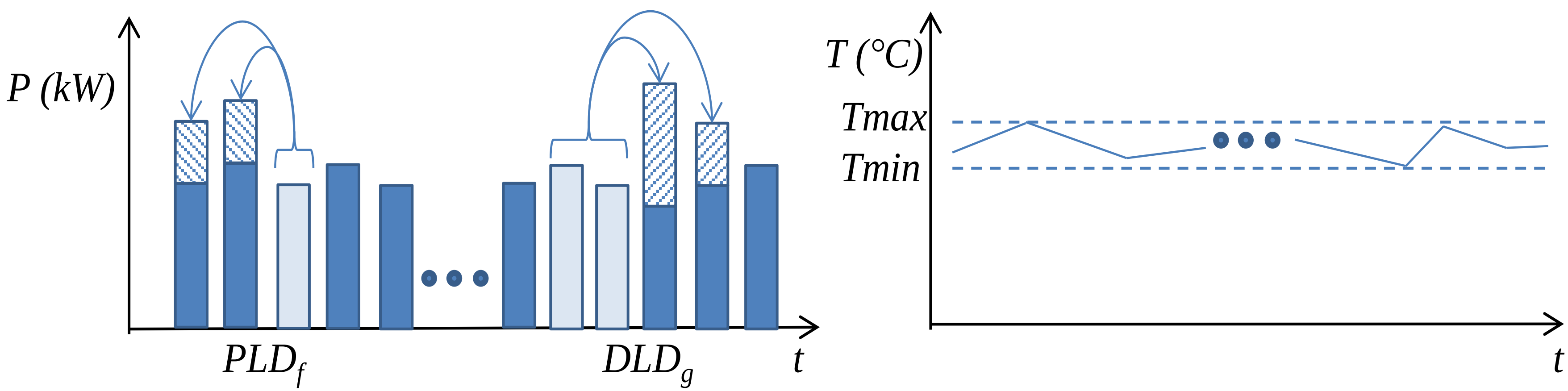
$$pdd_{dct} = 0 \quad \text{for} \quad FDD_{dc} < t < IDD_{dc} \qquad (17)$$

$$PDD_{dc}^{\min} \le pdd_{dct} \le PDD_{dc}^{\max} \quad \text{for} \quad FDD_{dc} > t > IDD_{dc} \qquad (18)$$

Load Demand Modelling

Diffuse and Pre-Diffuse Load Demand

- the electrical load demand is known for each step time
- the load could be turned off for a specific number of step times if a previous/posterior known increment (%) of the load is performed without trespassing the temperature limits



Load Demand Modelling

Equations for the Diffuse Load Demand

$$\sum_{i=1}^{SDL1_g} VDL1_{gi} \cdot DLD_{gi} \cdot udg_{g,t-i+1} + \sum_{j=1+SDL1_g}^{SDL1_g+SDL2_g} VDL2_{gj} \cdot \sum_{i=1}^{SDL1_g} DLD_{gi} \cdot udg_{g,t-j+1} - dld_{gt} = 0, \quad (19)$$

$$\sum_{t=1}^{ND} udg_{gt} \leq DLD_g^{\max}, \quad (20)$$

$$udg_{gt} \cdot 0.01 \leq DLD_{g,t+SDL1_g+SDL2_g}, \quad (21)$$

$$\sum_{i=1}^{IDLD_g^{\max}} udg_{g,t+i-1} \leq 1, \quad (22)$$

$$udg_{gt} \in \{0,1\} \quad (23)$$

Battery Modelling

Lithium-ion Batteries

Battery Modelling

- **ESS are important to Microgrids especially due to:**
  - The intermittent characteristics of wind and solar generation
  - The possibility to supply the rapid changes in demand
  - The possibility of islanded operation of microgrids
- **Regarding the modelling of the costs and constraints for the problem of EM of a microgrid some basic information are needed, such as**
  - cost of use
  - capacity
  - maximum power charge and discharge
  - efficiency
  - self-discharge

Battery Modelling

- **Lithion-Ion Batteries**
  - Cost of use (F. Fortenbacher, J. L. Mathieu, G. Andersson, 2014)

$$J_{\text{bat}} = \underbrace{b(SOC-a)^2}_{} + \underbrace{cu_{\text{gen}}^{\text{bat}}}_{0\ \text{(zero)}} + \underbrace{du_{\text{load}}^{\text{bat}} + e{u_{\text{load}}^{\text{bat}}}^2}_{}$$

  - deviation of the SOC

$$CDB_e \cdot deb_{et}, \quad eb_{et} - deb_{et} \leq EB_e^{st}, \; -eb_{et} - deb_{et} \leq EB_e^{st}$$

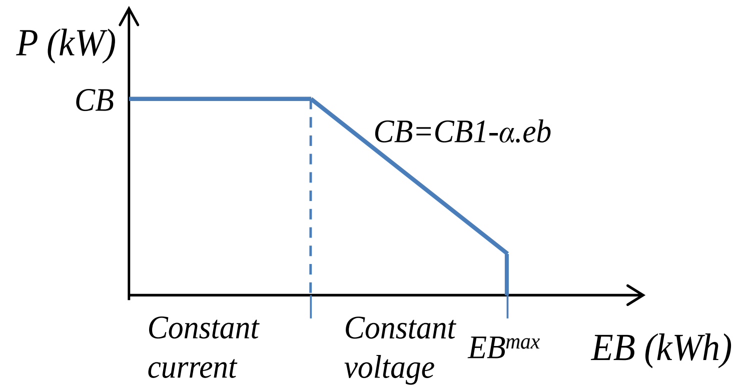
  - cost of charge (approximation by piecewise linearization)

- **Battery discharge characteristics**
  - the performance decreases with cold temperature and increases with heat; heat shortens battery life
  - cannot over-discharging
  - deploy a larger battery if repetitive deep discharge cycles cause stress
  - moderate DC discharge is better for a battery than pulse and aggregated loads

Battery Modelling

Battery charge characteristics

- Li-ion cannot accept overcharge
- the charge is between 0.5 and 1C in stage of constant current
- Li-ion does not need to be fully charged and avoiding it prolongs battery life
- Charge characteristic



Other battery characteristics

- efficiency is very high for the charge and discharge
- self-discharge is very low

Battery Modelling

Li-ion Battery constraints

$$eb_{e,t+1} - eb_{et} + \left(\frac{pbd_{et}}{\eta_e^{bd}} - \eta_e^{bc} \cdot pbc_{et}\right) \cdot \frac{H}{ND} = -PB_e^L \cdot \frac{H}{ND},$$

$$eb_{e2} + \left(\frac{pbd_{e1}}{\eta_e^{bd}} - \eta_e^{bc} \cdot pbc_{e1}\right) \cdot \frac{H}{ND} = -PB_e^L \cdot \frac{H}{ND} + EB_e^I,$$

$$eb_{eND} - \left(\frac{pbd_{eND}}{N_e^{bd}} - N_e^{bc} \cdot pbc_{eND}\right) \cdot \frac{H}{ND} = PB_e^L \cdot \frac{H}{ND} + EB_e^F,$$

$$-eb_{et} + \sum_{i=1}^{RB} \frac{rb_{e,t+i}}{\eta_e^{bd}} \cdot \frac{H}{ND} \leq -EB_e^{\min}, \quad eb_{et} \leq EB_e^{\max},$$

$$0 \leq pbc_{et} \leq CB_e, \; 0 \leq pbc_{et} \leq CB1_e - eb_{et} \cdot \alpha_e$$

$$0 \leq pbd_{et} \leq DB_e, \; 0 \leq rb_{et} \leq DB_e,$$

$$pbc_{et} - ub_{et} \cdot CB_e \leq 0$$

$$ub_{et} \cdot DB_e + pbd_{et} \leq DB_e$$

$$ub_{et} \in \{0,1\}$$

Without controlling the charge

$$-pbc_{et} + ub_{et}^{aux1} \cdot CB_e + ub_{et} \cdot 10000 \leq 10000$$

$$-pbc_{et} - \alpha_e \cdot eb_{et} + ub_{et} \cdot 10000 + ub_{et}^{aux2} \cdot CB1_e \leq 10000$$

$$-ub_{et}^{aux1} \cdot 0.7 \cdot EB_e^{\max} + eb_{et} \leq 0.7 \cdot EB_e^{\max},$$

$$-ub_{et}^{aux2} \cdot 0.7 \cdot EB_e^{\max} - eb_{et} \leq -0.7 \cdot EB_e^{\max},$$

$$ub_{et}^{aux1} + ub_{et}^{aux2} = 1$$

Plug in Electrical Vehicles (PHEV) and Vehicles to Grid (V2G)

PHEV and V2G

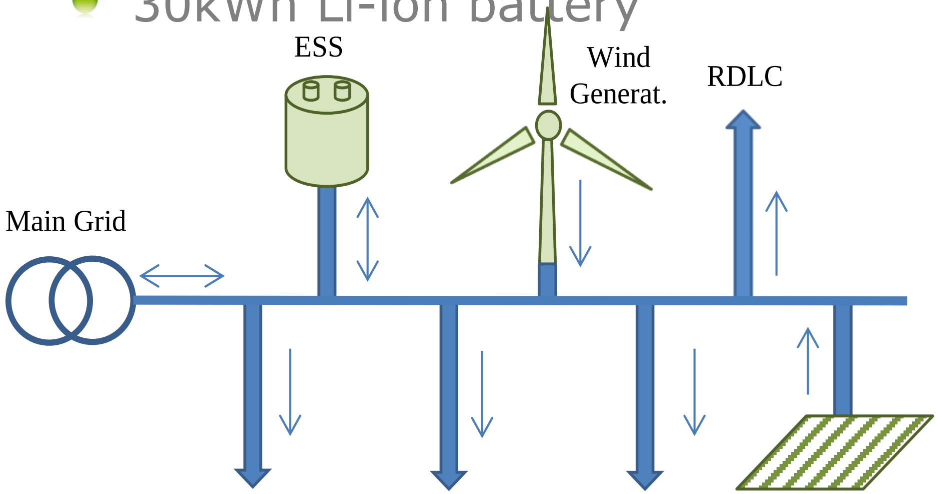
- **Classified by the technology used**
  - the hybrid or the fuel cell technology which could be used as a conventional controllable microgeneration
  - the photovoltaic vehicles which could be connect to the grid and used as a renewable generation
  - and the plug-in hybrid (PHEV) or the battery-powered vehicles which could be used as an ESS or a electric load demand
- **In this paper we proposed the modelling as an electrical load demand or as a battery**

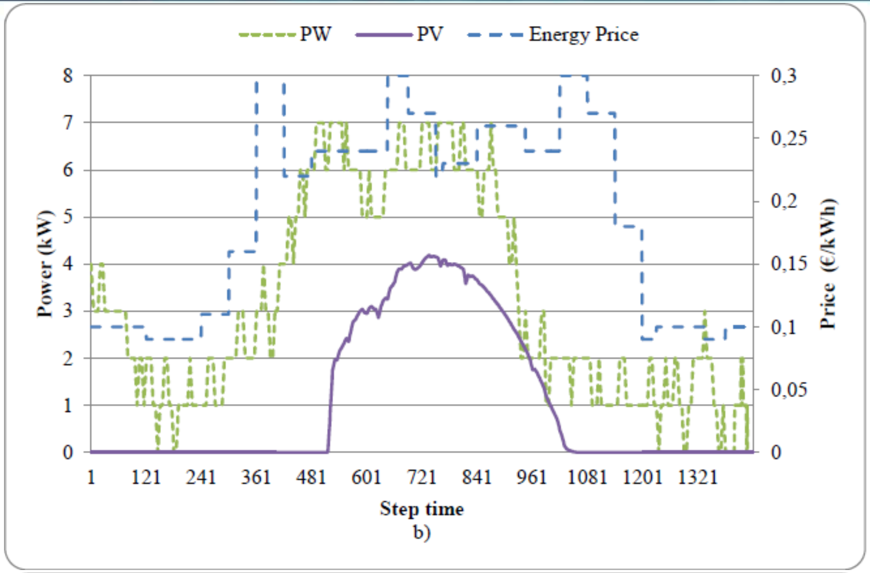
Didactical Microgrid and Computational Results

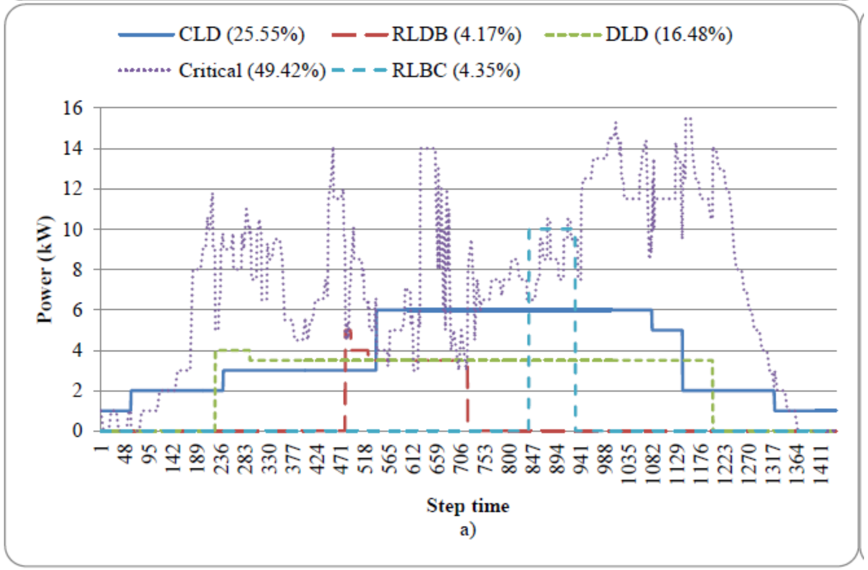
Didactical Microgrid

Didactical Microgrid

- 4 kW photovoltaic panel
- 7 kW wind generator
- possibility of buy/sell energy from/to the grid (20 kW)
- critical load demand; CLD; RLD with Binary approach (RLDB); RLD with the Continuous approach (RLDC); DLD
- 30kWh Li-ion battery







Computational Results

- **Solver and Dimensionality**
  - Matlab 2011b + Gurobi 5.5
  - 20,160 continuous variables
  - 11,520 binary variables
  - 27,547 constraints
- **Optimal Costs and Computational Time**

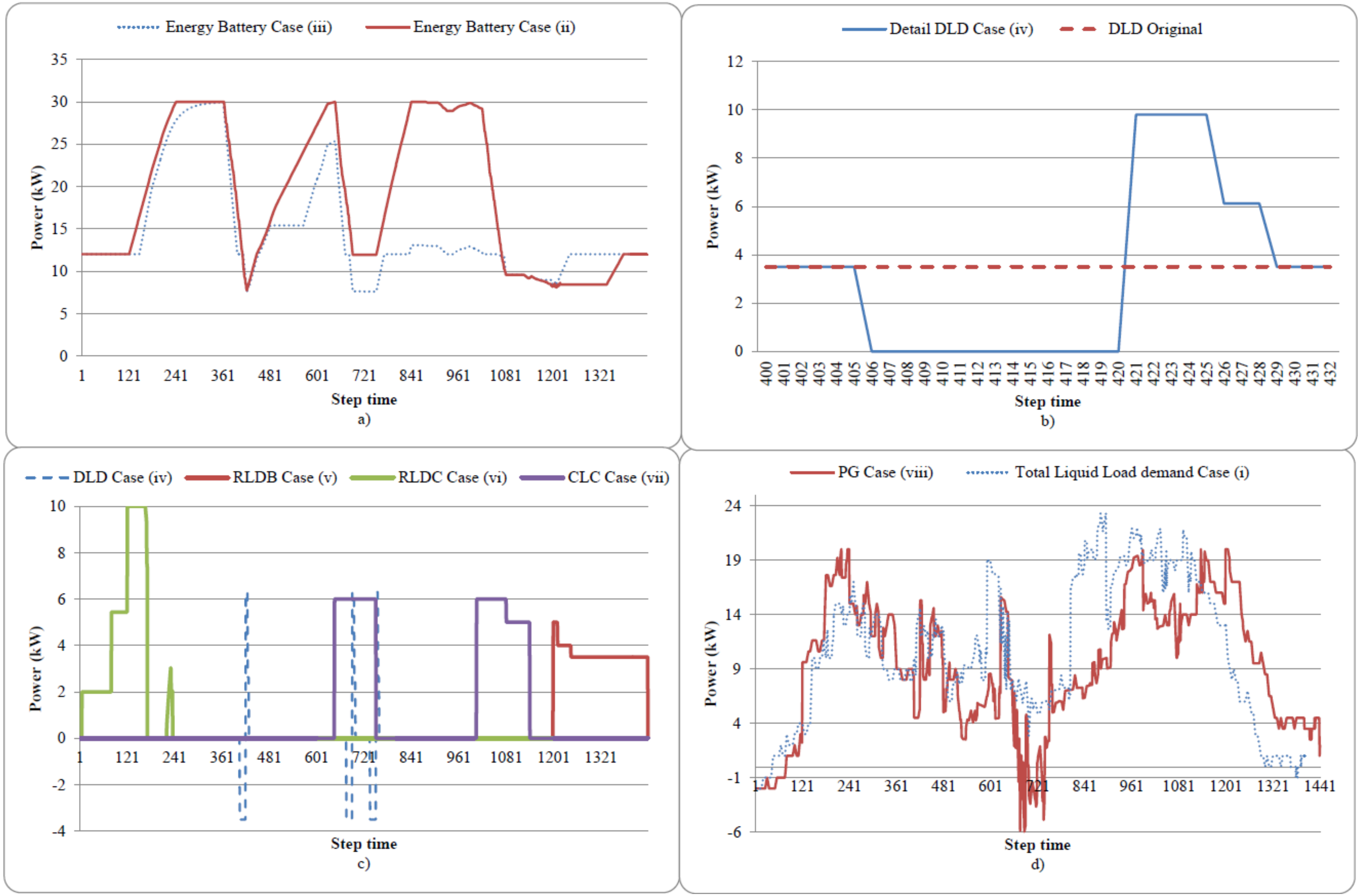
	Classic Battery	Li-ion Battery	DLD	RLDB	RLDC	CLC	Cost Function (€)	Comput. Time (s)	Comp Case (*i*)
Case (*i*)*	N	N	N	N	N	N	54,09	0,00	
Case (*ii*)	Y	N	N	N	N	N	48,68	59,06	-10,00%
Case (*iii*)	N	Y	N	N	N	N	50,17	19,80	-7,25%
Case (*iv*)	N	Y	Y	N	N	N	49,77	35,16	-7,99%
Case (*v*)	N	Y	Y	Y	N	N	47,49	60,08	-12,20%
Case (*vi*)	N	Y	Y	Y	Y	N	44,95	60,08	-16,89%
Case (*vii*)	N	Y	Y	Y	Y	Y	44,10	60,06	-18,47%
Case (*viii*)*	N	N	Y	Y	Y	Y	48,21	24,41	-10,87%

* These cases do not consider the 10min reserve due to the absence of battery

P.s. The results with 60s have the error less than 0.03% from the optimal solution

Computational Results

Cases Results



Main Conclusions / Future Works

- **The proposed models proved feasible to implement**
- **The models could be used to support the system operation, planning, policies and to quantify impacts**
- **The results may not have demonstrated all the potential for EM economy, being necessary tests in other systems**
- **Regarding the modelling of Li-ion batteries, this still needs more research on improving the modelling, especially due to the temperature, since they will be used in electric vehicles which are usually parked outdoors**
- **Future tests with 1/5/15 min for the step time interval and with 5, 10 and 15 % of error considered for the renewable generation**

Thank You!

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