Optimal capacity planning and scheduling of BESS serving communities resilient to regulatory changes

Irina Ciornei*, Mihaela Albu* Mihai Sănduleac **and Lucian Toma**
*MicroDERLab, Department of Electrical Engineering, University Politehnica of Bucharest
**Department of Power Systems, University Politehnica of Bucharest

Abstract & Motivation:

The last decade marked an exponential increase in photovoltaic (PV) systems installed on the rooftop of domestic residences within Europe and in other developed countries around the world. This situation was basically favored by generous financial schemes such as Feed-in-Tariff. However, such governmental incentives drastically reduced recently or they were already replaced with net-metering schemes which favor a different scenario: increase of self-consumption and decrease of grid back injection. This unstable regulatory environment puts both new and old owners of PV systems under a regulatory financial risk. Battery energy storage systems (BESS) are seen as viable options to overcome such barriers as well as increasing the self-consumption from locally produced energy. Furthermore, formation of resilient communities arranged as clusters of residential microgrids within a small territory is also appealing due to the potential of buying and selling locally produced renewable energy (favored by the smoothing effect load aggregation), reduced power losses within the distribution grid where each prosumer within the cluster is connected, and potential of sharing static or mobile electricity storage installed individually or at community level.

We focus this study on the use of storage for increasing self-consumption of PV local production at community level microgrids and develop an optimal scheduling strategy of storage facilities within the cluster over a 24 hour period and one year, respectively. The optimization problem has been framed as a stochastic program with probability weights derived form a k-mean clustering method applied on real PV measured data over one year.

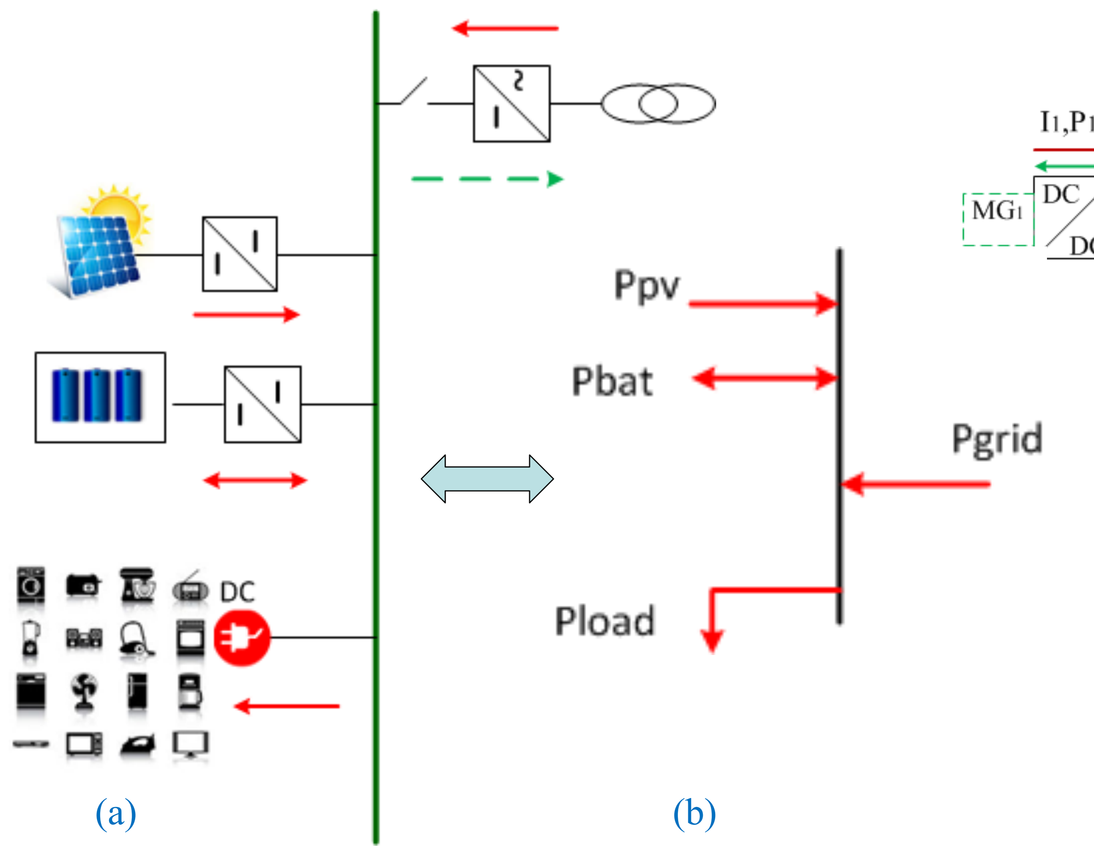


Fig.1. Single-Bus DC resilient MG: (a) optional back to grid injection; (b) main design and operation option with no-back to grid generation

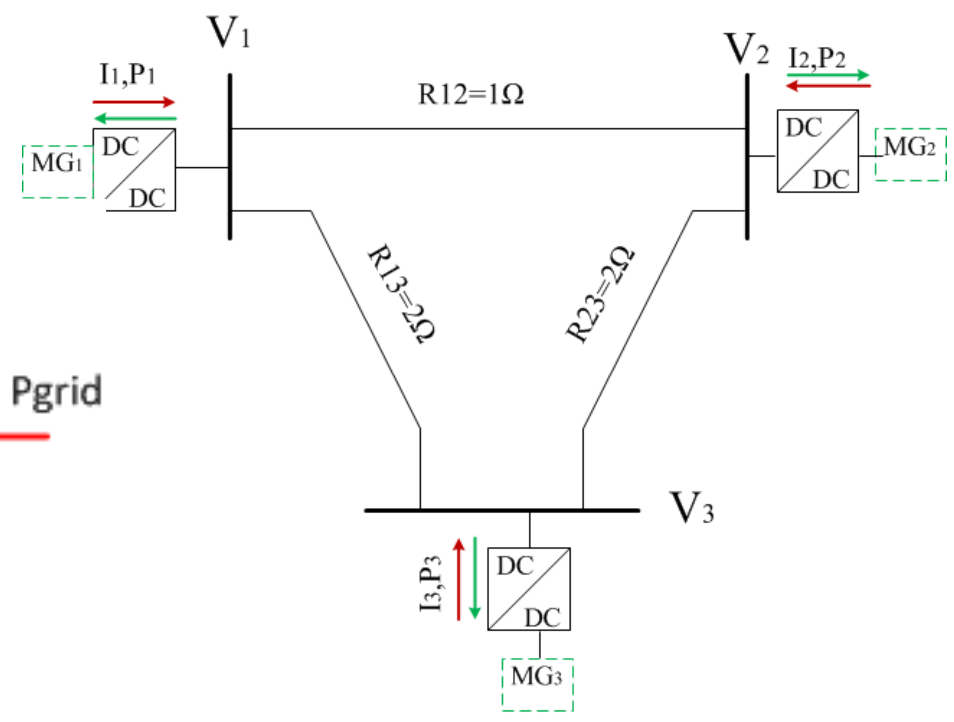


Fig. 2. DC-MG cluster, ring configuration: community MGs

Preliminaries & Assumptions

- Our study is focused on the type of storage that fits into long-term duration (4 to 8 hours) with frequent partial charges and discharges (e.g. one or two full cycles per day, and more than 250 full cycles per year) [1].
- Battery scheduling in a PV-BESS system forms the inner loop of the Energy Management System (EMS) [2] of each resilient MG [3] and it was framed both as a deterministic and as a stochastic optimization model. Each MG has its own agent to carry on its EMS and according to the results it will enter or not into negotiations with the neighbors for selling/buying energy in the next hour.
- All power set-points for selling or buying energy to/from neighbors remain constant over one hour interval, until the next trading. Thus, all deviations from predicted PV-generation and load are either managed through the grid connection point or the local BESS.
- Grid energy tariffs are always higher than purchasing prices from neighbors
- Selling price to neighbors is always >0, while sending the same energy back to the grid receives no payment.
- For exemplification of the methodology we consider 3 DC MGs, each one connected to the grid and furthermore, connected in ring between them (see Fig. 2.)
- We assume a priori sizing of the MGs, as given in Table 1, while adjustments might be performed according to the proposed methodology, to follow.

Table 1: Characteristics of each MG in the cluster

MG1:	MG2:	MG3:
MG1.MaxLoad= 5 kWp	MG2.MaxLoad= 3.5 kWp	MG3.MaxLoad= 7 kWp
MG1.PV=4 kWp	MG2.PV=2 kWp	MG3.PV=5 kWp
MG1.Bat.Cap=7.5 kWh	MG2.Bat.Cap=2 kWh	MG3.Bat.Cap=10 kWh
MG1.Bat.MaxPch=5 kW	MG2.Bat.MaxPch=1 kW	MG3.Bat.MaxPch=5 kW
MG1.Bat.MaxPdch=3 kW	MG2.Bat.MaxPdch=1 kW	MG3.Bat.MaxPdch=5 kW

Methodology

For each cluster we perform an independent estimation of the annual costs for purchasing energy from the grid to cover the load demand using actual load and PV profiles, and the estimated savings possible due to storage, respectively. No back-to-grid injection is assumed for all the calculations. By design, injection back to the grid is possible in scenarios where compensations above the price of selling the same energy within neighborhood appears (opportunistic profit).

The proposed methodology is summarized in the following steps/layers (Fig. 3):

1. *Perform initial sizing of the MGs according to Table 1.*
   - *Given input data: load demand time series with 15 min resolution for one year & PV generation profiles: time series with 10 min resolution for one year*
2. *Apply k-mean clustering to determine daily characteristic load and PV profiles (centroids) and their associated probability weights (e.g. each cluster has no of days per year, ω_i, associated with it)*
3. *Apply EMS for each MG with their associated centroid data (e.g. 3 centroids for MG1 => run EMS 3 times and store results such as: the operation costs, battery utilization (estimated full cycles), expected available energy for export to neighbors)*

www.dcnexteve.microderlab.pub.ro
www.dcnexteve.et.aau.dk
www.openenergyprojects.ro

Github (open source code available to download and test):
https://github.com/openenergyprojects

3. *Estimated total annual costs and battery utilization factors for each MG*
4. *Adjust battery capacity and start from 3*
5. *Stop when the utilization factor for the battery is close to 1.*

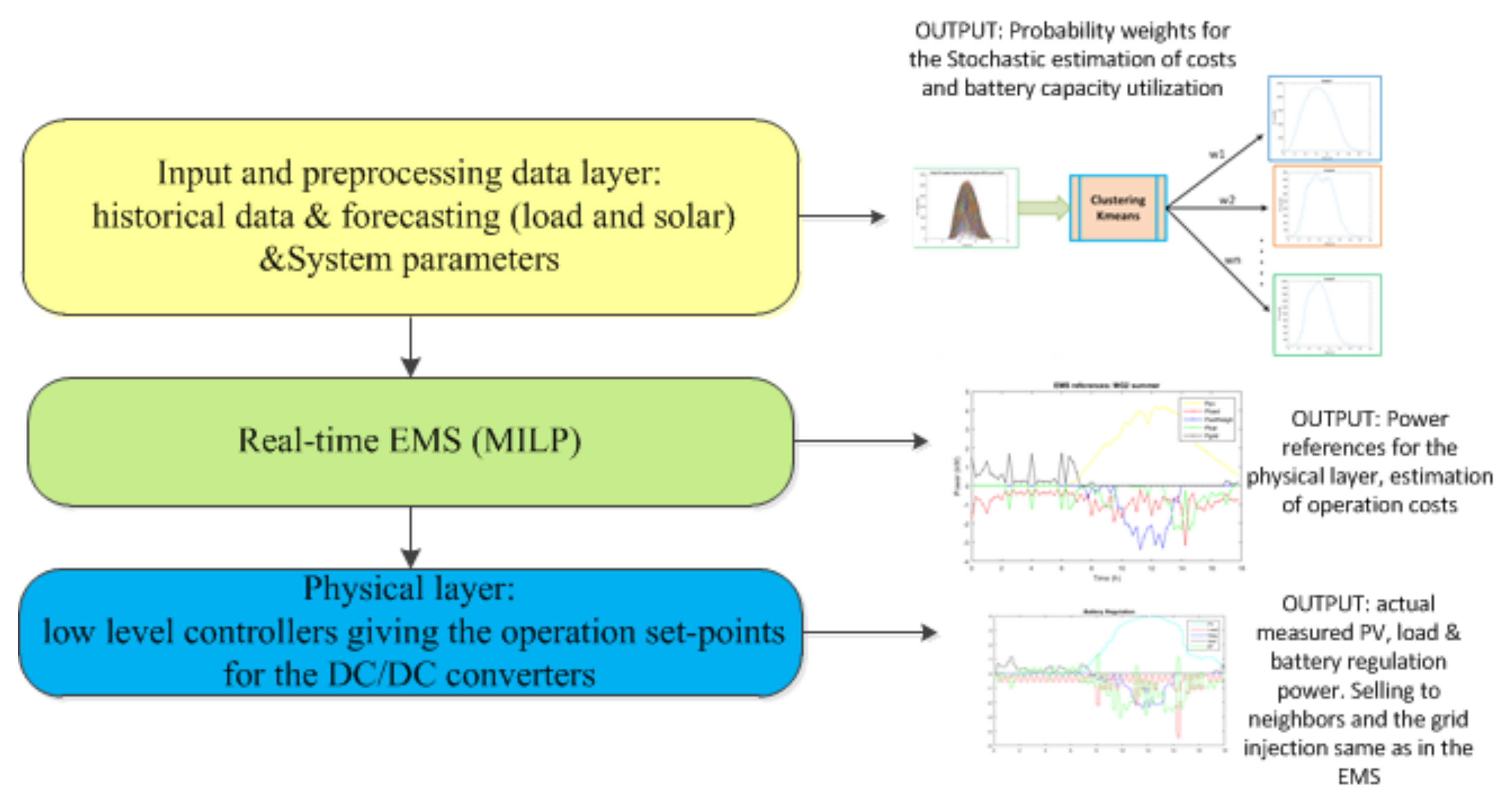


Fig.3. Three layer approach for optimal capacity planning and scheduling of the BESS serving resilient communities to regulatory changes

EMS - submodule

The scheduling is performed every 24h taking into account a deterministic approach for both load demand profile and the PV power production (based on the input centroids coming from the above layer);

Use of a MILP formulation taking into account the linearized form of the converter's efficiency characteristic.

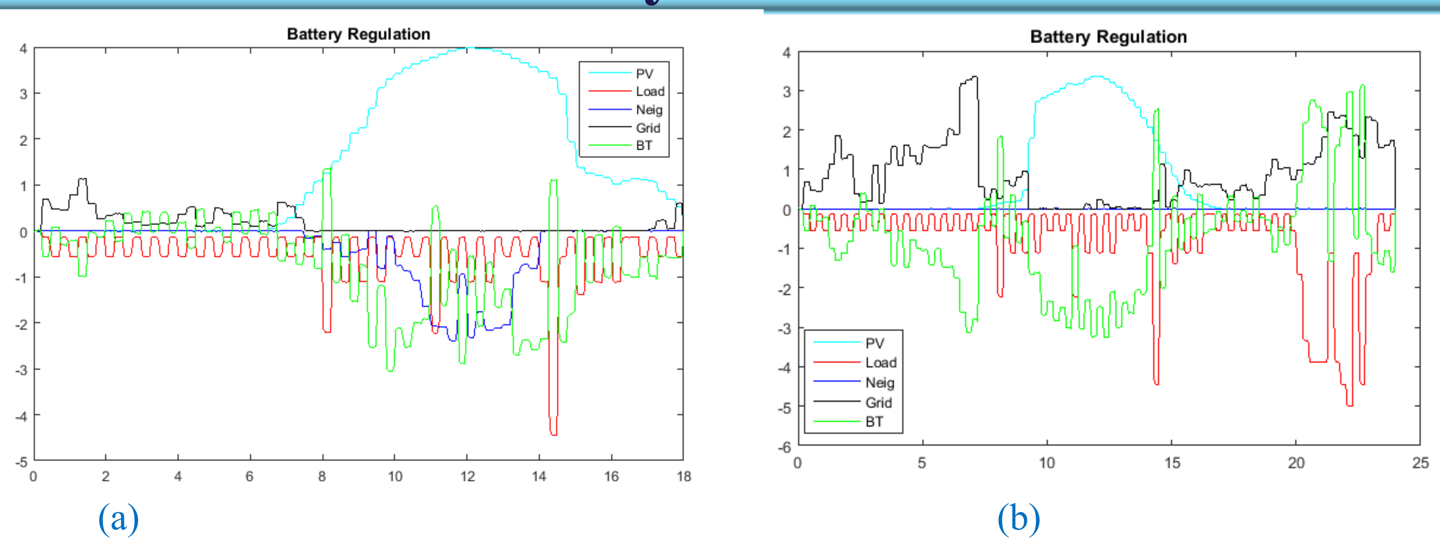
- The optimization problem was formulated as:

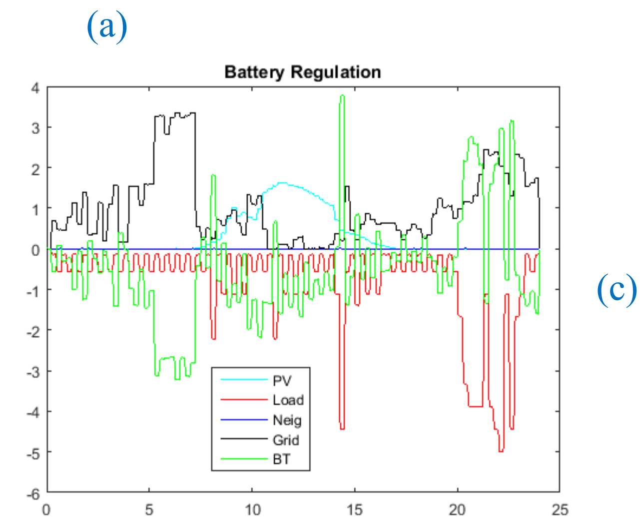
$$Min\ TotalCost = \Sigma_{t=1}^{T} (Tariff_t \cdot P_{grid_t} + P_{bat_t} \cdot f(\Delta SoC,) + P_{neigh_t} \cdot Price_t)$$

subject to:

$$P_{load_t} + P_{bat} \cdot \eta_{bat_t} + P_{neighSell_t} \cdot \eta\left(P_{neigh_t}\right) = P_{pv_t} + P_{grid_t} \cdot \eta(P_{grid_t}) \ldots$$
$$P_{neighBuy_t} \cdot \eta(P_{neigh_t}),\ \forall t \in \{1, 2, .., T\}$$
$$-P_{bat}^{dch\_min} \leq P_{bat_t} \leq P_{bat}^{dch\_max},\ \forall t \in \{1, 2, .., T\}$$
$$SoC_t = SoC_{t-1} + P_{bat_t} \cdot \delta t$$
$$0.15 \cdot MaxBatCap \leq SoC_t \leq MaxBatCap$$

Analysis of results





(c)

Fig.4. MG1 – Cyprus site: (a) summer scheduling ($\omega_1 = 213 \frac{days}{year} = 58.4\%$, 1 cycle/day) (b) winter scheduling ($\omega_2 = 53 \frac{days}{year} = 12.8\%$), 2 cycles/day, (c) spring-autumn scheduling ($\omega_3 = 99 \frac{days}{year} = 28.8\%$, 2.3 cycles/day)

Conclusions and Future work:

This work proposed and tested a methodology for optimal capacity planning and scheduling of BESS in a residential microgrid, grid interconnected and with potential of selling/buying in a locally formed ad-hoc cluster of similar prosumers/microgrids. The methodology used a MILP approach for Real-time EMS of each individual MG, while for the evaluation of the battery capacity a stochastic approach was proposed, making use of clustering techniques such as k-mean to determine the probability weights. The work could be further expanded into a game theoretic approach for evaluating shared BESS at community level, instead of individual MG.

References:

[1] K. Anderson, D. Cutler, et.al, "Optimal Sizing of a Solar-Plus Storage System For Utility Bill Savings and Resiliency Benefits," 7th Int. Conf. on Innovative Smart Grid Technologies (ISGT2016) Minneapolis, Minnesota, September 6–9, 2016.
[2] D. Pozo, J. Contreras, and E. E. Sauma, "Unit commitment with ideal and generic energy storage units," IEEE Transactions on Power Systems, vol. 29, no. 6, pp. 2974–2984, 2014.
[3] M. Sanduleac, M. Albu, L. Toma, J. Martins, A. Gonçalves Pronto, and V. Delgado-Gomes, 'Hybrid AC and DC Smart home resilient architecture: Transforming prosumers in UniRCons', 23rd ICE/IEEE ITMC Conference, pp. 1-6, Madeira Island, 27-29 June 2017.

Acknowlegements:
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 708844.