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

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Abstract & Motivation:
The last decade marked an exponential increase in photovoltaic (PV) systems installed on the rooftop of domestic residences worldwide 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 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 levels.

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.

EMSS - submodule
The scheduling is performed every 24th 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:
$$\text{Min. Total Cost} = \sum_{t=1}^{T} \left( f(t) \cdot P_{\text{load}}(t) + P_{\text{grid}}(t) + f(S_{\text{SoC}}) + \text{Price}_{\text{PV}}(t) \right)$$
subject to:
$$P_{\text{load}}(t) + P_{\text{grid}}(t) + P_{\text{SoC}}(t) \leq P_{\text{max}}(t)$$
$$S_{\text{SoC}}(t) = S_{\text{SoC}}(t-1) + P_{\text{SoC}}(t) - \text{Price}_{\text{PV}}(t)$$

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).

References:

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Fig.1. Single-Bus DC resilient MG: (a) optimal 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

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.

Analysis of results

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.

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

Fig.4. MG1 – Cyprus site: (a) summer scheduling (ano = 213 days/year = 58.4%, 1 cycle/day); (b) winter scheduling (ano = 53 days/year = 12.8%, 2 cycles/day); (c) spring-summer scheduling (ano = 99 days/year = 28.8%, 2.3 cycles/day)

Table 1: Characteristics of each MG in the cluster

<table>
<thead>
<tr>
<th>MG1</th>
<th>MG2</th>
<th>MG3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG1.PV=14kW</td>
<td>MG2.PV=16kW</td>
<td>MG3.PV=18kW</td>
</tr>
<tr>
<td>MG1.Cap=10kWh</td>
<td>MG2.Cap=12kWh</td>
<td>MG3.Cap=15kWh</td>
</tr>
<tr>
<td>MG1.MaxPdch=5 kW</td>
<td>MG2.MaxPdch=6 kW</td>
<td>MG3.MaxPdch=7 kW</td>
</tr>
<tr>
<td>MG1.MaxCap=7.5 kWh</td>
<td>MG2.MaxCap=9 kWh</td>
<td>MG3.MaxCap=11 kWh</td>
</tr>
</tbody>
</table>

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/layer (Fig.3):
1. Perform initial sizing of the MGs according to Table 1.
2. 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
3. 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, ano, associated with it)
4. 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)