MICROGRID AS A TECHNOLOGICAL MEAN TO MULTI-ENERGY COMMUNITIES PENETRATION

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ABSTRACT

Multi-Energy community systems represent a bottom-up answer to the needs to increase the quote of renewable generators installed and the upcoming request from citizens to increase their energy control. Microgrids are sought as the technological mean to implement community of energy. In this paper we propose a model of energy management for a multy-energy community system such that power and thermal consumption requests are satisfied by different technologies and the system flexibility (extra-generation and extra-absorption) is offered as services to the market in order to support the power grid and gain revenue. The paper also shows that these systems are able to save enough margins to guarantee the multy-energy community system reliability.

INTRODUCTION

The installation of renewable non programmable generators is deeply transforming the distribution system. This is driven by targets concerning the greenhouse gas reduction, and in general energy decarbonisation, and increasing energy efficiency (e.g., those imposed by European Union). The widespread installation of renewable sources mainly takes place upon the distribution networks, and fosters the local satisfaction of generation and consumption needs. This is transposing a few transmission system management functions to the distribution system (e.g., planning, operational planning and network control and regulation).

The transformation of energy landscape towards decentralized low-carbon energy systems engages a multitude of actors to deliver new and innovative solutions. Utilities are adapting their business models and new energy services are emerging. In this context, new roles are asked by local communities, requiring the transitioning from passive consumers to active prosumers with local generation, demand response and energy efficiency measures [1]. Demand response refers to programs which provide incentives for consumers to modify their consumption patterns [2] [3]. The shift towards renewable-based production for energy consumption and increasing electrification of different sectors requires local generation to be integrated and coordinated. Such integrated approaches bring energy generation closer to consumers, thereby reducing all the complexity, cost and inefficiencies associated with a centralized energy system. Hence, decentralized co-ordination is required for both engaging customers and integrating sectors.

Multi-energy community systems (MECSs) emerge as a powerful concept to ensure energy sustainability keeping the prices affordable. MECSs are often meant as neutral and inherently positive solutions, their diffusion faces different barriers favouring centralized energy systems. Government agencies, private companies and utilities are sometimes at the top of this list. In essence, MECS (local communities) represent bottom-up solutions to the energy production and RES penetration problems. A growing number of references is concerned with the importance of more deliberative and inclusive participation of consumers in the energy production (and ownership and "maintenance" of generators) process [4]. The penetration of the energy community concept (such as: residential, commercial, industrial, public service health, transport, school, etc.) enabled by the peer-to-peer energy exchanges, can take advantage of microgrids as a technology mean.

The paper is organized as follows: the next section proposes a discussion about multi-energy community systems, then a model of the energy management tailored for energy communities is proposed.

THE MULTI-ENERGY COMMUNITY

The increasing penetration of renewables generators supplied by intermittent sources demands flexibility from all the actors among the electricity stakeholders, and brings in a new relevance the power system customers. Technological and economic progress is shifting the energy production and consumption towards a smart grid paradigm that is increasingly concerned with climate change mitigation. This is forcing to redesigning our energy systems to integrate distributed energy resources. The energy system is transforming to a combination of top-down and bottom-up processes, being incentivized by the vulnerability and insecurities associated with centralized energy infrastructure, depletion of fossil fuels and climate change. This is leading communities to ask for a greater control of energy generation and demand.

Multi-energy community systems (MECSs) are a mean for sustainability, at maintaining energy reliability, and striving for energy independence keeping the prices affordable. MECSs are often meant as neutral and inherently positive solutions, though their diffusion faces different barriers. The biggest barriers of MECSs are institutions favouring centralized energy systems. Government agencies, private companies and utilities are often at the top of this list.

Collective community identity and the aim of management autonomy play a critical role about community engagement in the larger context of energy systems. Energy generation from MECSs is reported to have higher public acceptance compared to private or utility-based generation. Citizen engagement or local support is composed of an attitude towards technologies, inducing changes in energy consumption patterns and investment in MECSs. Community engagement is deemed essential in the transformation from existing centralized energy supply to a more distributed supply system that exploits the full potential of local generation including renewables. Technology progress is essential to linking local energy services and making them accessible and affordable.

Community micro-grids comprise of locally controlled clusters of DERs which are seen as single demand or supply from both electrical and market perspectives. Micro-grids can be operated grid connected to the national grid, or not. They enable higher penetration of DERs such as solar, wind, combined heat and power, demand response as well as storage systems. These local resources can be used to supply local demand, thereby reducing losses and increasing the efficiency of the energy delivery systems. A multi-energy microgrid is a local aggregation of several energetic carriers and technologies. It can supply energy to neighbours in order to exploit local synergies and thus increase the energy system efficiency.

A strong commitment coming from power system concerns the availability of resources for regulation. *Ancillary Services* consist of different procedures to control the stability and balance the power system. These bring in action active power control resources like primary, secondary and tertiary reserve, power balancing and congestion resolution. Microgrids are able to offer AS provision in a flexible way combining generators and loads, and in some cases even storage systems. In this view, services are provided by an aggregation strategy which exploits as far as possible the availability of different resources. A bid to buy or sell ancillary services can be commercially sketched as a hurly quantity of active energy to be bought (*import energy* from the main grid) or sold (*export energy* to the main grid) at a specific price. An accepted bid is provided at the point of common coupling (PCC). During this time period microgrid exploits all the capability (flexibilities) offered by its own equipment, combining extra-availability of *generation* (or *absorption*. *Capability* is the measure to quantify the surplus generation and absorption margins. Quantitatively is the measure of how much an equipment/a system is able to lower or to rise on the current power.

THE LOCAL MULTI-ENERGY MODEL

In this section the model of the energy management system to set the daily plan of a MECS is proposed. This algorithm has been inspired by [5].

Model many types of loads

Demand management can be an effective tool to mitigate a number of drawbacks, like the peak load or peak-to-average ratio. Demand management can increase the reliability of daily planning for the microgrid energy resources, in particular that has been implemented through the categorization of different loads according to their elasticity and controllability degrees. Loads are distinct into *inelastic* loads, those that must be supplied at any rate; and *elastic* loads, those that can be subject to different degree of controllability. All these types of loads allow one to model different needs and at the same time enable the system to provide a level of flexibility, then flexibility.

Inelastic (I). Each load must be supplied for each hour as specified, and for each scenario. Inelastic loads are distinct into fixed (L_f) and auxiliary (L_x) loads. Here follows the definition of the two types, respectively:

$L_I^f(t) = \sum_{w=1}^{L_f} l_{I,f}^{\mathrm{w}}(t),\ t \in T$ and
$L_I^x(t) = \sum_{z=1}^{L_x} l_{I,x}^{\mathrm{z}}(t),\ t \in T$

Elastic (*E*) loads is partitioned into two different types: *adjustable* and *cumulative*.

Adjustable (A): these loads are modulated according to generation availability within the variability range specified, given the set of adjustable loads L_A held in the community:

$$L_{A.MIN}^k(t) \le l_A^{\mathrm{k}}(t) \le L_{A.MAX}^k(t) \;\&$$
$$L_A(t) = \sum_{k=1}^{L_A} l_{E,A}^{\mathrm{k}}(t),\ t \in T$$

Cumulative (*C*): these loads are defined by an energy value and a time interval τ with respect to the energy must be supplied. Given the set of cumulative loads within the energy community L_C, each cumulative load is specified as follows:

$L_C(t) = \sum_{j=1}^{L_C} l_{E,C}^{\mathrm{j}}(t),\ t \in \tau \;\&\; L_C(t) = 0\ t \notin \tau$ and
$L_C^{ENERGY}(\tau) = \sum_{t\in\tau} L_C(\mathrm{t})$ and $\tau \subseteq T$

The total load resulting by the contribution of each load category held in the community for each time instant is computed as follows:

$$\forall t \notin \tau$$
$$L_I^f(t) + L_I^x(t) \le L_{TOT}(t) \le L_I^f(t) + L_I^x(t) + L_A(t)$$
$$\forall t \in \tau$$
$$L_I^f(t) + L_I^v(t) + L_C(t) \le L_{TOT}(t)$$
$$\le L_I^f(t) + L_I^v(t) + L_A(t) + L_C(t)$$

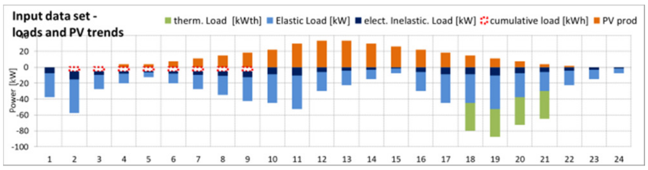

Figure 1 - Typical input to the planning system

Figure 1 shows the forecast of daily trends of a typical input to the planning system: the *photovoltaic production* (orange bars), the *inelastic loads* (dark blue bars), the *elastic loads* (light blue bars), the *cumulative loads* (20 kW to be supplied during hours drawn by dashed red bars) and the *thermal load* (green bars).

The dispatch model of (electric and thermal) generators

The dispatch model of generators mainly consists to fix lower and upper power limits.

$$P_{Gen}\ (t) = 0 \vee (P_{Gen}(t) \geq P_{Gen}^{min}\ \&\ P_{Gen}(t) \leq P_{Gen}^{max}),\quad t \in T$$

It is assumed there exists a linear relationship between power and thermal power generated by the combined heat and power engine. The coefficients of this relationship are α and β, set as follows:

$$P_{Gen}^{TH}(t) = P_{Gen}(t) \cdot \alpha + \beta, t \in T$$

Start-up costs and operation costs of the engine are $C_{Gen}(\mathrm{t})$ and C_{Gen}^{START} respectively.

The model of storage systems

The peak shaving issue can be dealt with using the advancement of energy storage devices. Here follows the model of such a system mainly expressed by the relationship between the energy status of the storage and the discharge (*dch*) and charge (*ch)* power set for each time instant. This relationship strongly depends on the efficiency (η).

$$Soe_{bat}(t+1) = Soe_{bat}(t) - P_{bat}^{dch}(t) \cdot \frac{1}{E_{bat}^{max} \cdot \eta_{dch}} \cdot \sigma + P_{bat}^{ch}(t) \cdot \frac{\eta_{ch}}{E_{bat}^{max}} \cdot \sigma,\quad \mathrm{t} \in \mathrm{T}$$

In order to preserve as much as possible the useful life of the storage system, it is better to confine SOE variability within the range 15%-85%.

$$0.15 \leq Soe_{bat}(t) \leq 0.85$$

The interaction among MECS users

The power balance set by the planning system states the equilibrium between absorption and generation in a MECS. The different types of loads are considered as a whole by the term L_{TOTAL}. For each time instant, this variable ranges from the minimum value, the sum of inelastic and cumulative loads, and the maximum one, the sum of inelastic and elastic loads. In detail, about the generation the equation includes the generators (*Gen – CHP*, controllable combined heat and power, and *pv –* photovoltaic non-programmable generators), the discharging storage systems (*DCH – bat*) and the power import form the grid (*In - GR*). The absorption includes the total load L_{TOTAL}, the charging storage systems (*CH – bat*) and the export (*Out – GR*).

$$P_{GR}^{In}(t) + P_{Gen}(s,t) + P_{bat}^{DCH}(t) + P_{pv}(t) - \left(P_{GR}^{Out}(t) + P_{bat}^{CH}(t)\right) = L_{TOTAL}(t)$$

Thermal loads are satisfied by an inequality constraint: thermal power must be at least equals to the thermal request (if the request is greater than zero). Thus, the power request has to be followed; thermal one must be satisfied accordingly.

$$P_{Gen}^{TH}(t) \geq L_{TH}(\mathrm{t})$$

The interaction between MECS and the power system through PCC

The model of the connection between the MECS and the main grid is represented by a bidirectional power exchange, import and export, respectively $P_{GR}^{In}(t)$ and $P_{GR}^{Out}(t)$. This model allows one to represent grid connected and not-connected modes where in the latter both terms are equal to zero. This model also allows one to represent the participation of MECS to power system ancillary service provision. In this case, energy exchange and service provision are represented by $P_{Grid}^{-}(t)$ and $P_{ASGrid}^{-}\ (t)$, respectively, as follows:

$$P_{GR}^{In}(t) = P_{Grid}^{In}(t) + P_{ASGrid}^{In}\ (t) \qquad \text{and}$$
$$P_{GR}^{Out}\ (t) = P_{Grid}^{Out}(t) + P_{ASGrid}^{Out}\ (t)$$

It is assumed that a bid in the Ancillary Service (AS) market to import energy (buy $P_{Grid,As}^{In}(t) > 0$) is possible during no-export phase of the energy program ($P_{Grid}^{Out}(t) = 0$), and, correspondingly, a bid in the AS market to export energy (sell - $P_{Grid,As}^{Out}(t) > 0$) is possible during no-import energy ($P_{Grid}^{In}(t) = 0$), formally:

$$\begin{pmatrix} P_{AsGrid}^{Out}(t) \geq 0 \Rightarrow (P_{Grid}^{In}(t) = 0\ \&P_{ASGrid}^{In}\ (t) = 0) \\ P_{AsGrid}^{In}(t) \geq 0 \Rightarrow (P_{Grid}^{Out}(t) = 0\&P_{AsGrid}^{Out}(t) = 0) \end{pmatrix}$$

The mode of storage systems

The objective function of the daily planning problem is expressed by a cost minimization problem with respect to the interval *T*, the *planning horizon*. In this problem are taken into account the production costs to supply the loads, and the revenue coming from the energy sell to the grid ($c_{Grid}^{Out}(t)$) and ancillary services provided to the grid ($C_{AsGrid}^{Out}(t)$).

$$\min_P \sum\nolimits_{t\in T}(c_{Grid}^{In}(t)P_{Grid}^{In}(t) + c_{Grid}^{Out}(t)P_{Grid}^{Out}(t) + \\ + P_{Gen}(\mathrm{t}) \cdot C_{Gen}(\mathrm{t}) + uc_{Gen}(\mathrm{t}) \cdot C_{Gen}^{START} - C_{AsGrid}^{Out}(t) \cdot P_{AsGrid}^{Out}(t) + C_{AsGrid}^{In}(t) \cdot P_{AsGrid}^{In}(t) + \delta \cdot L_A(t))$$

The elaboration of the planning program against the input proposed in Figure 1 gives as result the following program where many bids on the AS market are supposed to be proposed and accepted. Among them there are just three sell bids (yellow bars) and many sale bids (light blue bars).

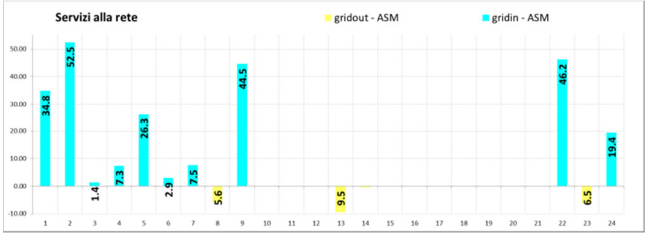

Figure 2 - Bids on the ancillary service market resulted from the daily program elaborated

Capability of a MECS

The capacity of the MECS system is the summation of the capabilities provided by generators, loads and storages, according to the elaborated daily planning.

Generators: generation UP means the ability to grow up power from the current value, and generation DW means the ability to lower down power from the current value.

$$CAP_{Gen}^{GEN.UP}(t) = uc_{Gen}(t) \cdot P_{Gen}^{Max} - P_{Gen}(t)$$

(where uc_{Gen} is the unit commitment of the generator).

$$CAP_{Gen}^{GEN.DW}(t) = P_{Gen}(t) - uc_{Gen}(t) \cdot P_{Gen}^{Min}$$

Loads: load UP means the ability to grow up power from the current value, and load DW means the ability to lower down power from the current value.

$$CAP_{Load}^{ABS.UP}(t) = L_A^{TOT}(t) - L_A(t)$$

(where L_A^{TOT} is the total amount of elastic adjustable load)

$$CAP_{Load}^{ABS.DW}(t) = L_A(t)$$

Storage: storage *UP* means the ability to grow up power from the current value (if storage is discharging power, UP means to increase the current value till the nominal discharging power, otherwise it is charging UP means to decrease charging until power 0 and then increasing power discharging), and load DW means the ability to lower down power from the current value (if storage is charging power, DW means to increase the current value till the charging nominal power, otherwise it is discharging, DW means to decrease discharging power till 0 and then increasing power charging). UP and DW procedures sketched must also take into account the storage state of charge.

The absorption capability of the storage equipment

$$P_{Bat}^{Ch}(t) \leq P_{Bat}^{Ch.UP}(t) \leq uc_{Bat}^{Ch}(t) \cdot P_{Bat}^{MAX.Ch}(t) \&$$

(where uc_{Bat}^{Ch} is the battery unit commitment for the charging phase).

$$CAP_{Bat}^{ABS.UP}(t) = P_{Bat}^{Ch.UP}(t) - P_{Bat}^{Ch}(t)$$

The generation capability of the storage equipment

$$P_{Bat}^{Dch}(t) \leq P_{Bat}^{Dch.UP}(t) \leq uc_{Bat}^{Dch}(t) \cdot P_{Bat}^{MAX.Dch}(t) \&$$

$$CAP_{Bat}^{GEN.UP}(t) = P_{Bat}^{Dch.UP}(t) - P_{Bat}^{Dch}(t)$$

MECS generation and absorption capabilities consist to aggregate the capabilities of the single contributions.

$$CAP_{UP}^{GEN}(t) = CAP_{Gen}^{GEN.UP}(t) + CAP_{Bat}^{GEN.UP}(t) + CAP_{Load}^{ABS.DW}(t)$$

$$CAP_{UP}^{ABS}(t) = CAP_{Gen}^{GEN.DW}(t) + CAP_{Bat}^{ABS.UP}(t) + CAP_{Load}^{ABS.UP}(t)$$

According to the definition of capability given and applied to the elaborated program, it is possible to highlight the extra generation or absorption available and plotted in the next figure.

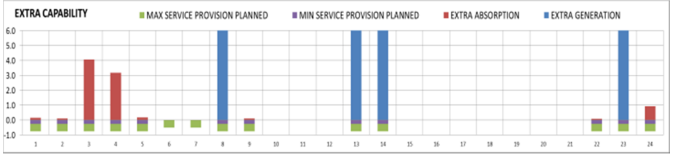

Figure 3 - MECS capability after daily plan elaboration

The capacity of the MECS system is the summation of the capabilities provided by generators, loads and storages, according to the elaborated

AKNOWLEDGEMENT

The work was financed by the Research Fund for the Italian Electrical System under the Cont. Agr. between RSE S.p.A. and the Ministry of Economic Development Gen. Dir. for Nuclear Energy, Renewable Energy and Energy Efficiency - in compliance with the Decree of March 8, 2006

CONCLUSIONS

The paper proposed a discussion about the multy-energy community systems and the role microgrids can play to increase the MECS penetration. To illustrate the point an example of energy management system tailored on the MECS model has been proposed. The example showed the ability of MECS to satisfy internal requests, provide services to the power system and to maintain extra-margin to ensure system reliability. Next this algorithm will be extended in order to manage uncertain input and associated probability.

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