Sustainable Energy Microsystems for a Smart Grid

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Abstract. The paper deals with the proposal of a new architecture, called Sustainable Energy Microsystem (SEM), for a smart grid project in urban context. SEM includes energy sub-systems (SS) currently independent, such as high efficiency buildings, sustainable mobility systems (Electrical Vehicles and metro transit-systems), dispersed generation from renewables and Combined Heat and Power units. The present paper includes the description of the main SEM elements and some results of an energy analysis on each subsystem, showing the effective possibilities of integration, aimed to energy saving and environmental sustainability.

Keywords: energy, environment, mobility, power systems, smart grid, sustainability.

1 Introduction

In national and international context, many research projects are conducted to study the possible evolution of the distribution of electricity to the so-called smart grid. The European Technology Platform defines a Smart Grid as "an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies" [1].

In other words the aims of smart grids implementation are to allow:

- the connection and operation of generation power plants with different primary resources, size and technology;
- the consumers play an active role in the operation of the power systems that supply them (demand response as ancillary service);

with the final task of significantly reducing the environmental impact of the whole energy system, enhancing the level of system reliability and improving security of supply.

The great interest of the international scientific community towards the topic of smart grid is proved by a vast and recent literature [2]-[12].

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The analysis of the scientific literature shows that smart grids are usually investigated from the point of view of distributors, with a top-down approach, that means starting from the evolution of grid control technologies, then focusing on the consequent effects upon active and passive users.

In [13] some of the authors proposed a new architecture, called Sustainable Energy Microsystem (SEM), for a smart grid project, aimed at promoting an aggregation at the customer level, in order to show how several energy sub-systems, presently operated as independent. In particular a SEM includes energy sub-systems currently independent, present in a urban context, such as high efficiency buildings, sustainable mobility systems (Electrical Vehicles and mass transit-systems), dispersed generation from renewables and Combined Heat and Power units.

In the present paper, Section II summarizes the main figures of the proposed architecture of SEM, presented in details in [13]; Section 3 includes the results of a energy analysis, showing the possibilities of integration of the different sub-systems, aimed to energy saving and environmental sustainability; the conclusions are drawn in Section 4.

2 Sustainable Energy Microsystem Proposal

The innovative idea of the authors is to move beyond the current concept of smart grid, including the possibility of an integrated management of energy flows between different sub-systems (SS) currently independent. The global energy system is defined Sustainable Energy Micro-system (SEM).

In SEM, the centrality of customers is proposed not only in economical and commercial terms, but also with functional implications, that means asking the grid customers to be actively involved in the system operation; just as an example, customers could vary their cumulate load profile and/or the power produced locally in the SEM according to the actual hourly cost of energy furnished by the supplier. This enhanced interaction between distributors and customers could help the system operation, with significant enhancements in cost-effectiveness of investments, energy efficiency, optimal use of grid capability and power quality.

The purpose of SEM is to build sustainable micro energy islands connected to the electricity public distribution grid exchange, with the minimization of the energy to the network and the optimization of energy flows in the exchange.

The energy sub-systems (SS) taken into account in the SEM proposed, as shown in Figure 1, are:

- SS for the urban mobility: metro-transit system and trams (SS1);
- SS for the connection to the electric network and the recharging of plug-in electric vehicles (EV) for the surface mobility (SS2);
- SS of final users and high efficiency buildings (SS3);
- SS of dispersed generation from renewable and Combined Heat and Power (CHP) units (SS4).

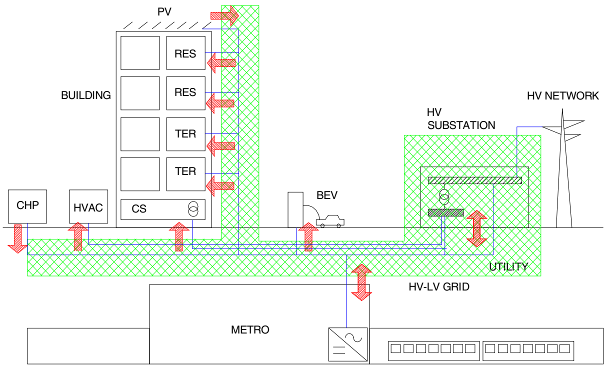

Fig. 1. Energy Subsystems (SS) considered in Sustainable Energy Microsystem (SEM)

In Figure 1 the symbols are:

- RES: residential units,
- TER:tertiary units,
- CS: common service for the building,
- HVAC Heating Ventilation Air Conditioned for the building,
- CHP Combined Heat and Power Generator,
- PV: Photovoltaic generator,
- BEV: Batteries Electric Vehicles System,
- METRO: Metro-transit and tram mobility system;

and the filled area represents the property of the public utility.

The reasons at the basis of the choice of these sub-systems are reported in [16]-[17]. Their integration has been implicitly assigned to the electricity grid to which they are connected, which had to perform the functions of a large flywheel, capable of providing adequate power at any time of integration, as well as to absorb the potential energy of an exuberant sub-system. SS (passive and active users) connected to the network is not sought any form of estimates of their needs or surpluses injected into the network.

Each user is therefore appropriate to a pure traditional limitation of its maximum power of exchange, while maintaining a high degree of autonomy and independence in terms of timing diagram.

The regulatory framework of the major western systems is experiencing a gradual expansion to small users of the logical prediction of timing diagrams of power, so far required only to larger sizes. In an effort to meet the needs of programmable profiles imposed by the new network codes and to observe a behavior perceived as virtuous from the system. So each sub-system is called internally to identify appropriate control variables that allow opportunities for more effective interfacing with the electrical system. But only a single view of the logic design and power management sub-systems neighbors can allow their effective interaction at the local level. The proposed SEM would be able to create a dialogue between the single SS and the electricity network, in terms of energy trade allowing a full integration, where the sub-systems are aggregated as a single functional block.

The main technological difficulty of realization of SEM, is the ability to identify the optimum energy of the micro-system architectures, since the characteristics of the utilities that constitute the micro-system are complex and complicated and their synchronization.

This complexity extends to the ability of management and continuous optimization of the micro-system to be understood as a real self-operated network to maximize performance, energy efficiency, economic competitiveness and minimize environmental impact. The distributor can then interact in a simplified and smart reference that will think to respond to requests from the distributor through the internal management system.

From traditional layout shown in Figure 1, the proposed integration can be accomplished in various ways (Energy; Distribution Grid and Virtual Power Plant) that have being the subject of research and are deeply described in [13]-[14].

In the present paper just the integration in terms of energy is reminded: it means maintaining the actual distribution structure and introducing a model for management and optimization of energy flows exchanged on the network provider, as shown in Figure 2.

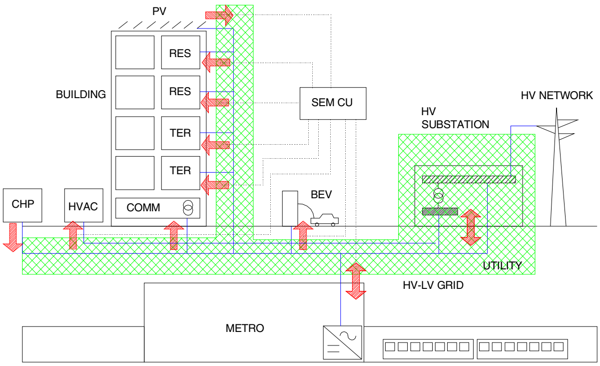

Fig. 2. Architecture for the integration of the SS in terms of energy, with a unique Point of Delivery(POD) by the public utility

The filled area is the same of Figure 1, but a SEM Controller Unit (SEM CU) manages the energetic behaviors of all the SS.

3 Energy Evaluation for the Assessment of Integration Level of SS

In order to understand the potential level of integration among the four SS included in SEM, a preliminary energy analysis on the single SS has been performed.

3.1 Energy Evaluation on a Real SS1

As explained in [15]-[17] a consistent energy saving in metro-transit systems is possible thank to the recovery of the braking energy of the trains.

With the aim of quantifying the amount of recovered energy in a real metro-transit system, a statistical energy analysis has been performed using the data collected by an experimental survey and some simulation studies performed on lines serving the city of Rome. On these metro-lines trains equipped with drives providing both a regenerative braking and a pneumatic braking system (completely substitutive of the regenerative one) are involved.

The details of the above-mentioned metro-transit system and of the wide analyses are included in other papers of some of the authors [17]-[18].

By experimental and simulation studied, it is possible to evaluate, for different time band of the official daily line timetable, the values of the energy saving percentage ($ES_{\%}$), defined for as:

$$ES_{\%} = \frac{E_{ESS}^{W\_REC}}{E_{ESS}^{W/O\_REC}} \times 100 \tag{1}$$

where $E_{ESS}^{W\_REC}$ is the supplied energy by Electrical Sub-Stations (ESS) in case of recovering of the trains braking energy; E_{ESS}^{W/O_REC} is the supplied energy by ESS without the recovering of the trains braking energy.

This parameter allows to get a measure of impact the recovering of the braking trains energy on the performance of the power system.

Another important parameter is the effective recovered braking energy percentage ($ER_{\%}$) in respect of the recoverable braking energy only in case of braking energy recovering, defined as:

$$ER_{\%} = \frac{E_{TR\_REC.ED}}{E_{TR\_REC.BLE}} \times 100 \tag{2}$$

where $E_{TR\_REC.ED}$ is the effective recovered braking energy; $E_{TR\_REC.BLE}$ is the potential recoverable braking energy.

This parameter gives an assessment of the capacity of the line to receive the braking energy by the train: the differential energy is usually dissipated in heat by means of on-board rheostats, but in alternative it could be recovered using storage stationary systems.

ER values assessment is very useful for the energy analysis of SEM: the saved energy in SS1 could be used in SS2 for the recharging of plug-in electric vehicles (EV) for the surface mobility.

ES and ER parameters have to be calculated for different time band, because it is demonstrated that their values are strictly linked to the trains frequency that varies in each time interval. Figure 3 and 4 show this link, and report real values obtained by the simulations of one of Rome metro-line [17].

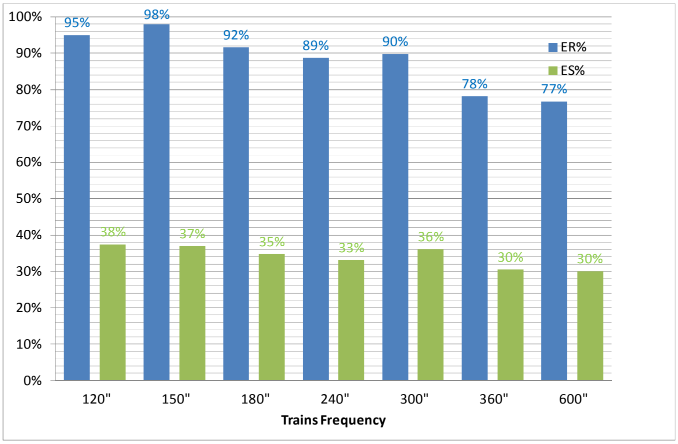

Fig. 3. ES and ER percentage values for different trains frequencies

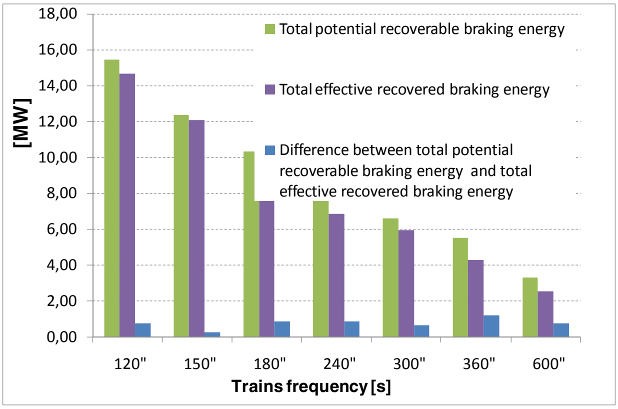

Fig. 4. Comparison between system potential recoverable and effective recovered braking energy for different trains frequency in 1h of simulation

A more detailed calculation of these magnitudes and a complete correlation analysis with traffic and train figures are reported in [19].

A typical timetable of the metro-transit system of Rome city, that corresponds to a real diagram of the trains frequency in 24 hours service, generally includes:

- 6 hours without service and 18 hours with service;
- 4 hours of service with a trains frequency at 150";
- 4 hours of service with a trains frequency at 360";
- 10 hours of service with a trains frequency at 240".

Referring to the this timetable, the daily ES has been estimated around 30%, and daily difference between the potential recoverable braking energy and the effective recovered braking energy is about 14.5 MWh.

This energy could be stored in batteries located along the traction line in each ESS and used for the energy integration with the other SS of SEM, especially the BEV of SS2.

3.2 Energy Evaluation on Real SS2, SS3 and SS4

Relating to the other SS included in SEM, a real case study has been considered including:

- For SS2: 100 battery electric vehicles BEV (60% high capacity and 40% low capacity) with a peak demand of about 200kW;
- For SS3: 2 buildings with 150 residential and tertiary units, 25 small and medium commercial stores and commons services as parks, gardens and halls, with a peak demand of 400 kW and total energy consumption of about 2000 MWh/year;
- SS4: 1 photovoltaic (PV) generator with a peak power of 100 kW and 1 Combined Heat and Power (CHP) with a peak power of 200 kW.

By simulation models, the authors got the value of power and energy demand/production related to those energy SS. The results are summarized in Table 1.

Table 1. Power and energy demand/rpoduction for each SS

<table>
<tr><th colspan="2">SS in SEM</th><th>Power Demand/Production [kW]</th><th>Annual Energy Demand/Production [MWh/year]</th></tr>
<tr><td colspan="2">BEV recharging system (SS2)</td><td>-200</td><td>-800</td></tr>
<tr><td rowspan="3">complex of 2 buildings (SS3)</td><td>common services CS (parks, gardens, elevators, hall, etc), (SS3-a)</td><td>-50</td><td>-400</td></tr>
<tr><td>residential/tertiary/commercial individual units (SS3-b)</td><td>-250</td><td>-1100</td></tr>
<tr><td>heating ventilation air conditioned HVAC common service (SS3-c)</td><td>-100</td><td>-600</td></tr>
<tr><td colspan="2">PV power plan(SS4-a)</td><td>100</td><td>130</td></tr>
<tr><td colspan="2">CHP system (SS4-b)</td><td>200</td><td>900</td></tr>
</table>

Figures 5 and 6 show the load profile (power demand) simulated for the SS2, SS3-a and SS3-c in the winter (Figure 4) and in the summer season (Figure 5). In fact only the aggregation of those SS in SEM, sharing a unique point of delivery (POD) with the electric distribution, it is possible. The reason is that the current regulation in Europe makes not feasible the aggregation of the SS3-b. Therefore SS3-b has a direct supplying by the distribution grid through individual POD.

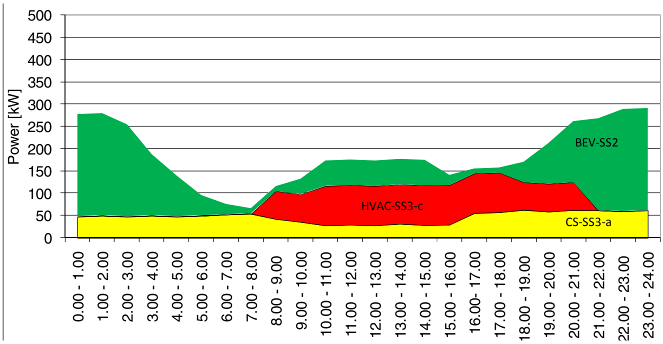

Fig. 5. Load profiles in winter season

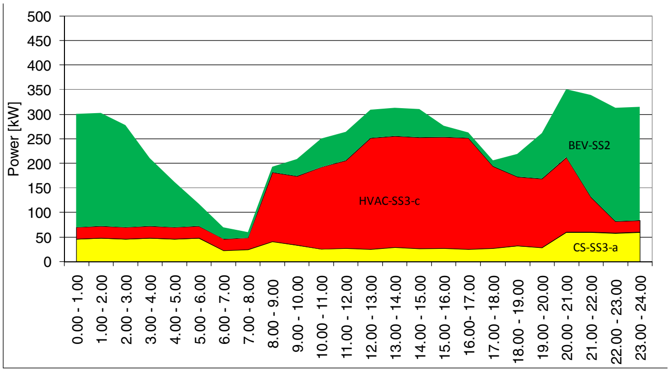

Fig. 6. SS Load profiles in summer season

Figures 7 and 8 show the power generation profile simulated for the SS4-a and SS4-b, in the winter (Figure 6) and in the summer season (Figure 7).

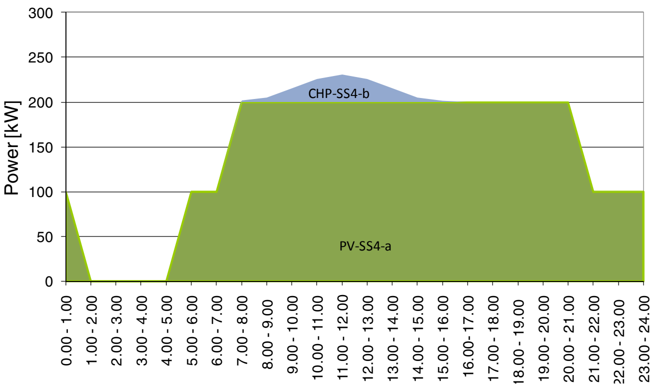

Fig. 7. Power generation profile in winter season

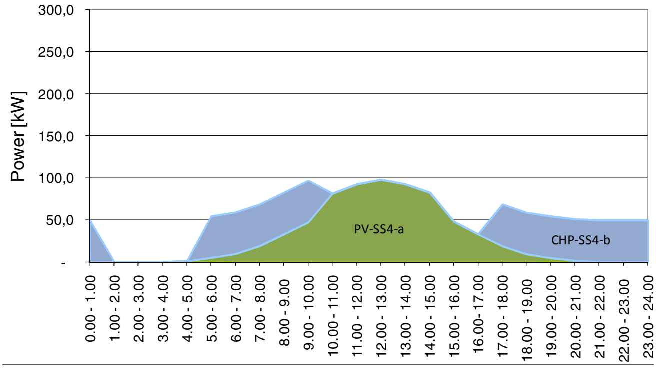

Fig. 8. Power generation profile in summer season

Figures 9 and 10 show the load, the generation and the balance profiles at SEM POD of SS2, 3 and 4 in summer (Figure 9) and winter (Figure 10) season of the case study.

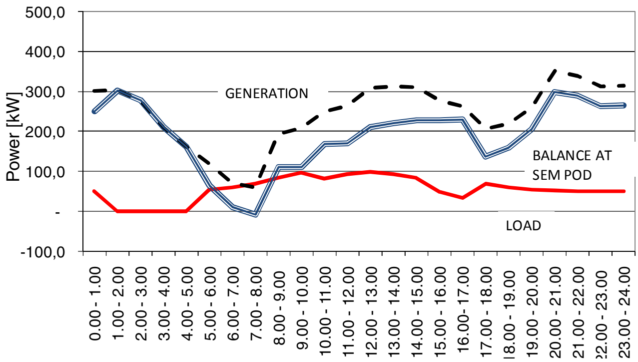

Fig. 9. Load, generation and balance profiles at SEM POD in summer season

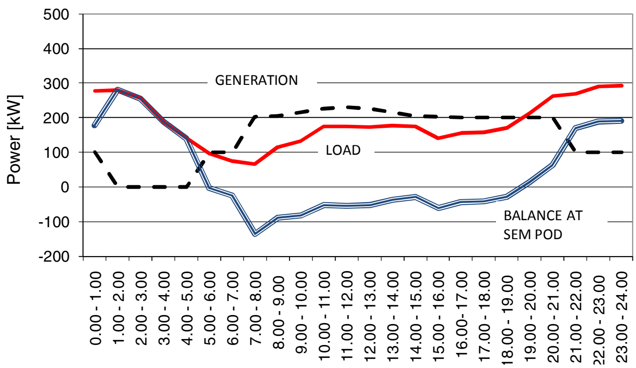

Fig. 10. Load, generation and balance profiles at SEM POD in winter season

The results show that yearly energy balance for the microsystem is acceptable:

- Energy demand: about 1.800 MWh/year;
- Energy generation: about 1.030 MWh/year.

In the summer season the balance of power at SEM POD is acceptable. In the winter season there is an important fraction of power introduced in the distribution network. A portion of this energy could be recovered from SS1.

4 Conclusions

The paper contains a proposal of design of a sustainable energy system (SEM) including the possibility of an integrated management of energy flows among different subsystems (SS) currently independent, such as high efficiency buildings, sustainable urban mobility, dispersed generation from renewable and Combined Heat and Power (CHP) units. This system is defined Sustainable Energy Microsystem (SEM), and could be considered the basis for a smart grid project in a urban context.

The results of an energy analysis on the single SS, referring to real data as case study, are reported and they point out the effective possibilities of energy integration of the different SEM SS and the advantages that the implementation of the proposed architecture potentially presents, according to the worldwide policies of energy savings and environmental sustainability.

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