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Computational framework based on task and resource scheduling for micro grid design

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***Abstract*—Within micro grid scenarios, optimal energy management represents an important paradigm to improve the grid efficiency while lowering its burden. While usually real time energy management is considered, an offline approach can be also adopted to maximize the grid efficiency in certain contexts. Indeed, by evaluating the energy management performance according to the user needs, it is possible to asses which technologies allow the overall system to operate at its best, given the expected load level.**

From this perspective, a computational framework based on the "Mixed-Integer Linear Programming" paradigm has been proposed in this paper as a tool to simulate the micro grid behaviour in terms of energy consumption and in dependence on the technology of choice. By modelling the energy production and storage means, the pool of electricity tasks, and the thermal behaviour of the building, suitable energy management policies for the micro grid scenario under study can be developed and tested in different operating conditions and time horizons. Moreover, the forecasting paradigm has been integrated into the framework to deal with data uncertainty, and a Neural Network approach has been employed on purpose.

Performed computer simulations, related to a six-apartments building scenario, have proven that the suggested framework can fruitfully be adopted to assess the effectiveness of different technical solutions in terms of overall energy cost, thus supporting the decisional process occurring during the micro grid design.

I. Introduction

Smart grid technology has been conceived as the basis for next generation power distribution infrastructures, aiming to overcome the limits of present day power grids [1], [2]. A large scale integration of the required technologies [3] can be overly complex. Because of the utmost importance of electrical energy availability, in fact, a gradual turnover is necessary. In response to this, the small scale of the micro grid paradigm has resulted in a more viable alternative [4]–[6].

Clearly, to integrate energy production and storage in residential environments, an optimization scheme is required [7]. In these regards, diverse Computational Intelligence approaches, such as Particle Swarm Optimization (PSO) [8], Genetic Algorithms (GA) [9], Artificial Neural Networks [10]–[12], Fuzzy Logic [13], Adaptive Dynamic Programming [14]–[16], have proven to be effective in many case studies.

When dealing with highly constrained problems, techniques as Linear Programming [17], Mixed Integer Linear Programming (MILP) [18], [19] and Mixed Integer Non Linear Programming (MINLP) [20] allowed to achieve performing results. With the adoption of these techniques, the attempt to integrate different technologies and energy resource management, taking the data uncertainty into account [21], [22] and the thermal comfort of the users as well, appeared to be feasible and effective.

Moreover, while the micro grid paradigm may provide the means to lower the burden on the main grid [23], [24], it may also support the technology turnover in the next future. Nonetheless, the design of the micro grid still remain an open problem [25]–[27]. A relevant aspect to study is represented by the comparative evaluation of proper technologies for energy generation and storage, taking the user needs and habits into account as well as the adoption of smart energy management policies for optimal usage of available resources.

To face this issue, a computational framework, originally developed to manage the available resources [28] in a residential scenario, has been revised to simulate the environment behaviour at an high abstraction level. As such, it is possible to evaluate the performance of a micro grid, also from a design perspective. In fact, by simulating the task execution, the energy management and the scheduling of either tasks and resources, an highly accurate analysis of the micro grid performance becomes possible, thus revealing the less apparent design flaws, and representing a major asset in the design of Net Zero Energy Buildings [29], [30].

To evaluate the approach presented in this work, a retrofitting problem has been modelled. It consists in the evaluation of different technological solutions, aiming at the improvement of the energy efficiency of an existing building. Differently from the previous work [28], a more articulated micro grid scenario has been considered, and thus a complex of six apartments has been used as target. Micro Combined Heat and Power (micro CHP) generation has also been modelled, and included among the technologies under test. The data uncertainty issue has also been addressed, and a neural networks based data forecaster has been included into the framework: solar irradiation and thermal load profiles are produced as result of the forecasting activity. More complex micro grid topologies will be addressed in future works.

The outline follows. The problem of a simulation based design is presented in Section II, whereas in Section III the data forecast problem is addressed. In Section IV the scheduling algorithm is detailed, whereas in Section V the case study is described and the obtained results discussed. Section VI draws the work conclusions.

II. MICRO GRID ENVIRONMENT: SIMULATION BASED DESIGN

The main strength of a micro grid is the ability to improve the eco-friendliness of the residential environment, leading to a lower energy cost from the user point of view, and to a lower burden from the main power grid point of view. Although different definitions of micro grid seem to coexist nowadays, they share a few common traits that have been addressed in the present work. Micro grids, in fact, are intended as small scale grids, including local energy production and storage, a limited number of building or users, and a semi autonomous energy management system.

At the core of the grid, in fact, a task and energy resource manager, is typically responsible for the management of the task execution and the thermal comfort of the user. For instance, the accurate scheduling of the energy consumption enables the energy demand management. In fact, the adaptation of the load to the availability of renewable energy allows to lower the amount of energy to be purchased or, eventually, the storage discharge. The adaptation, also, could be based on the energy price. A dynamic tariff scheme might lower the cost while leaving the purchased amount of energy unchanged.

Concerning the thermal demand of the building, on the other hand, the thermal task scheduling might present some limitations. In fact, since thermal storage has not been accounted in this case, an actual demand manipulation is not really possible. Nonetheless, depending on the heating technology of choice, thermal production may affect either electrical production or consumption. For instance, micro CHP generation typically provides electrical energy as the resulting by-product of the heat production process. Conversely, an heat pump leads to an additional energy demand contribution.

Although a resource manager may improve the residential environment efficiency, electrical energy production and storage, along with thermal energy production have to be properly balanced and tailored to meet the user needs. Otherwise the improvement margin may be low. In this perspective, whenever an existing building has to be retrofitted with both energy production and storage, eventually paired with a matching thermal production system, both the user needs and the retrofitted building performance are to be accounted, meaning that a thorough analysis might be necessary.

In order to create an automated tool, that simplifies the data computation, and that provides a better insight into energy management for both the electrical and thermal kind, a task energy and resource scheduling framework has been revised. For instance, while the aforementioned framework has been conceived to compute the optimal task execution schedule, it also returns the details concerning the hourly energy demand, management and cost. The revised framework can include an arbitrary task execution schedule, along with the standard inputs, thus simulating the energy management within a micro grid, and providing a detailed summary of the residential environment behaviour.

To verify the tool usefulness, a real life building has been monitored, thus collecting the information concerning electrical and thermal energy demands. With the collected information as a reference, the behaviour of the residential environment has been simulated, and several retrofitting set-ups have been compared. Among the set-up of interest, the presence and absence of electrical energy production and storage have been evaluated. In addition, alternative heating means such as gas boiler, micro CHP and heat pump have been considered. To complete the portrait, even task scheduling and data uncertainty have been included.

It has to be noted that, although in this case an existing building has been monitored, the same process can be applied even if the residential environment of interest has to be constructed yet. As shown in [28], the building thermal losses can modelled quite accurately, by means of the European standards [31]–[33]. A fairly accurate esteem of the user electrical needs may be obtained, on the other hand, by evaluating the energy demand of the household appliances, and modelling the typical daily activity of the user.

III. DATA FORECASTING

The simulation of the residential environment required not only the information concerning the electrical and thermal demand of the building, but also the information concerning the electrical energy production. On purpose, the available dataset has been integrated with the profiles of solar irradiation, and outdoor temperature, retrieved by means of the local meteorological station, which is part of the Regional Meteorological-Hydrological Information System[1].

An additional set of profiles has been obtained through data forecasting based on Neural Networks, and used to evaluate the effect of data uncertainty on system performance. Two Multi Layer Perceptrons (MLPs) yield the day ahead predictions of solar irradiance and thermal demand, respectively. The forecasters share a similar structure. The MLP predicting the solar irradiance has had 73 neurons in the input layer, 36 and 24 in the hidden and output ones, respectively. The MLP predicting the thermal needs has had 73 neurons in the input layer, 45 in the input one, and 24 in the output layer. In both cases, the hyperbolic tangent has been used as activation function in both the hidden and output layers. Since a day ahead prediction approach has been adopted, 24 samples have been generated from the samples of the previous day. All data have been normalized and mapped into the range [-1, 1]. The chosen performance function is the Mean Absolute Error (MAE), whereas the gradient descent with momentum and adaptive learning rate has been used for training. The number of validation checks has been fixed equal to 500, and the number of epochs has been increased accordingly.

The input is made of 3 subsets, of 24 samples each, pertaining outdoor temperature, thermal load and solar irradiance. An index representing the day of the year and coded through the minus cosine function completes the input set. The training has been carried out by means of a dataset that spanning over two years, 2011 and 2012, specifically, whereas the testing set spans over the first ten month of 2013. Since the output data is composed of 24 distinct values, one for each hour of the day, recurring prediction and error propagation have been avoided. The Neural Networks toolbox, part of the MathWorks MatLab[2] 2012a framework, has provided the environment to

[1] http://84.38.48.145/sol/info.php?lang=en

[2] http://www.mathworks.com

create, train and use the aforementioned MLP. Future efforts will be oriented to minimize the network sensitivity to weight initialization and input/output data normalization.

IV. Task and Energy Resource Scheduling

Task and energy scheduling is aimed to select an optimal schedule, and to keep the building overall energy demand to the minimum, while meeting the user needs. The hourly energy demand is expressed in terms of hourly energy cost, to account the pricing scheme applied by the provider.

If the optimal schedule is required, the framework computes energy production, storage, consumption, purchase and sale that correspond to the minimum cost, and then the optimal schedule is returned. Nevertheless, an arbitrary schedule can be also assigned to the framework, along with the input. In this case the algorithm searches for the energy production, storage, consumption, purchase and sale that correspond to the given schedule and input, and returns the subsequent energy cost.

In the first operational mode then, the task and energy scheduling is carried out. In the second operational mode, conversely, the simulation of the task execution and energy management occurs.

Both operational modes have been jointly employed to assess in which way the data uncertainty affects the energy management. In this case, the scheduling process has been carried out first with forecast data as input. The simulation process has been carried out thereafter with historical data as input, along with the schedule obtained in the previous step. The simulated energy allocation and the corresponding energy cost characterize the energy management in sub-optimal conditions.

The monetary balance of the energy demand of the building is expressed as follows:

$$Q = \sum_{t=1}^{slots} \left\{ \left[\sum_{j=1}^{houses} \sum_{i=1}^{tasks} \left(E_{j,i} tb_{j,i,t} \right) + \left(E_t^c - E_t^d \right) + -E_t^{re} - E_t^{gas} + E_t^{so} + E_t^{he} \right] C_t - E_t^{so} S_t^{price} + C_t^{gas} \right\} \quad (1)$$

$tb_{j,i,t}$ is the task binary variable that has defined the activity state (ON/OFF) of the *i*-th task of *j*-th building during the *t*-th time slot. The variable $E_{j,i}$ represents the energy demand of the *i*-th task of *j*-th building in each time slot. The sum over *i* and *j* index return the total energy demand of the assigned tasks at the *t*-th time slot. The amount $\left(E_t^c - E_t^d \right)$ represents the energy transferred to or from the storage at the *t*-th time slot. The amount E_t^{re} is the renewable energy production, whereas E_t^{gas} accounts the micro CHP energy production, if the micro CHP is used. The variable E_t^{so}, accounts the sold energy amount and E_t^{he} denotes the heater electrical energy demand, if the heat pump is used. Thus, the quantity within brackets accounts the net energy demand at each time slot. In conclusion, since C_t represents the energy purchase price, the amount $E_t^{so} S_t^{price}$ represents the sold energy revenue, whereas C_t^{gas} is the cost of non-renewable energy resources, each at the *t*-th time slot. The amount within braces denotes the total energy cost minus the total energy income, at each time slot, that is the energy balance at the *t*-th time slot.

Such a monetary balance is complemented by the constraints binding together the unknowns of the equation. For instance, all the constraints already presented in [28] remains unchanged, with the only exception of the set referred to as "energy constraints", which presents the E_t^{gas} addendum, as follows:

$$0 \leq \sum_{j=1}^{houses} \sum_{i=1}^{tasks} \left(E_{j,i} tb_{j,i,t} \right) + \left(E_t^c - E_t^d \right) + -E_t^{re} - E_t^{gas} + E_t^{so} + E_t^{he} \leq P_t^{MAX} \quad t:\ 1 \leq t \leq slots\,. \quad (2)$$

V. Micro Grid Case Study Evaluation

To evaluate the suggested task scheduling framework as a design and evaluation tool, a real life scenario has been monitored, and modelled, by means of collected data also used as a reference. The aim has been the evaluation of the energy demand of the building, and the assessment of the performance enhancement, over both energy demand and user cost, achieved by different technological configurations.

With respect to the previous work [28], in order to better portrait a micro grid environment, a complex of six apartments has been considered. In addition, micro CHP generation has been also included in the evaluation process. Although the proposed scenario may not be particularly complex, the evaluation process can be easily extended to more variegated micro grid structures.

The simulation has been carried out by means of the MathWorks MatLab 2012a environment. The MILP solver, namely GLPK, has been employed by means of the Opti Toolbox 2.05 interface [34]. The MatLab environment is hosted on a Laptop PC, based on the Intel Core i7 CPU series, with 8GB of RAM, and running on the Microsoft Windows 8 64-bit OS.

A. Operating Assumptions

As mentioned above, the present work is aimed at assessing how, and to what extent, a computational framework for energy management, like the one here described, can contribute to the micro grid design procedure, being aware that other issues play an important role in such a procedure (i.e., the purchase cost of each technological solution, the maintenance cost, the user habits in interacting with them and so on) which are not included within the framework itself.

In this perspective, then, some operating assumptions have been made. Since the selection of a technological set-up depends on subjective needs and tastes, the comparison among different set-ups is not aimed to find an absolute best. Also, the variety of technical means available nowadays is too vast to be covered in the current manuscript in its entirety, thus, without loss of generality, only a restricted pool of technologies has been considered.

On the other hand, it is clear that a comprehensive analysis of simulation results, also from the perspective of data uncertainty impact, should cover an extended time frame. However, if the simulation of the micro grid behaviour is presented over an entire year for instance, the analysis of the results would require a proper statistical characterization. An approach like this, although more appropriate from a theoretical point of view, has been deemed not really useful to the understanding of the suggested evaluation scheme, at this stage of development. Thus in order to ease the reader comprehension of the different aspects of the proposed methods, without loss of generality, the simulation has been intentionally restricted to a single day.

B. Simulation Scenario set-up

The actual building is located in Montecarotto, near Jesi (AN). As said, the structure hosts six apartments that share a centralized heating system. The monitoring system records several parameters concerning the building. Among the collected data, the pieces of information of interest are mainly the electrical energy demand of the apartments, and the thermal production of the entire building.

The energy consumption, at each hour, is presented in Fig. 1, for each of the six apartments. In each plot, each stem with a dot on top has been used to represent the actual consumption, whereas the stems with a circle on top have been used to represent the model counterpart.

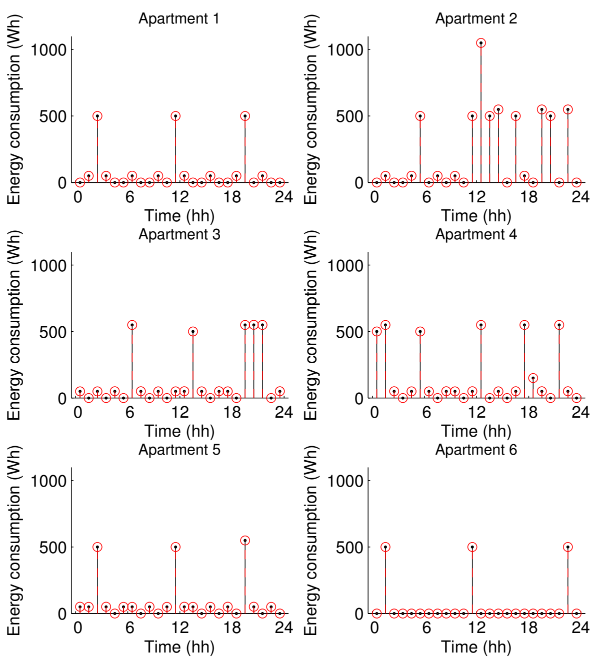

Fig. 1. Electrical needs: real and model profiles

The thermal demand is presented in Fig. 2, to report the entire requirement of the building, at each hour, assuming that a single thermal generator has been used.

To satisfy the thermal demand different configurations have been evaluated:

- a gas heater: electrical neutrality case,
- a micro CHP generator: additional electrical production,

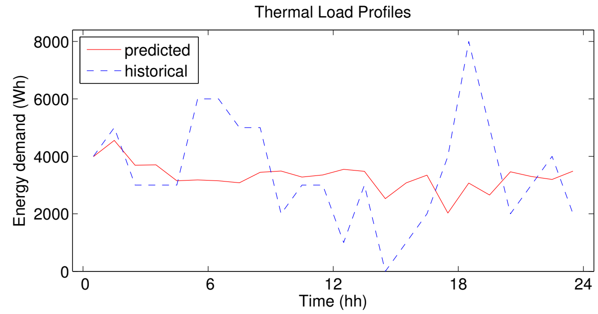

Fig. 2. Thermal needs: historical and forecast profiles

- a heat pump: additional electrical consumption.

Concerning the gas heater, a 90% efficiency has been considered. Regarding the micro CHP, the thermal efficiency is assumed to be 50%, whereas the electrical efficiency amounts to 35%. Concerning the heat pump, a coefficient of performance (COP) equal to 3.4 has been considered, while its input power amounts to 4kW.

A photovoltaic plant is also included, and related solar irradiation data, for one single day, are presented in Fig. 3.

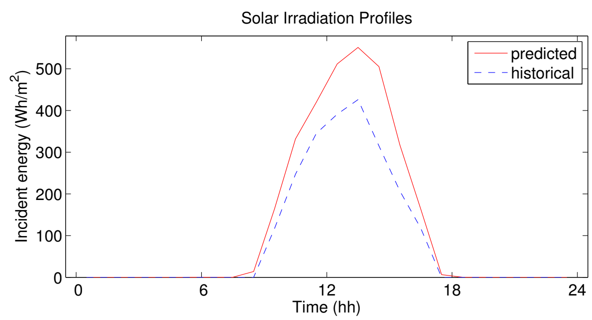

Fig. 3. Solar irradiation: historical and forecast profiles

In the current scenario, a photovoltaic panel of 20 square meters and 20% efficiency, has been deemed sufficient to satisfy the electrical needs of the building. Also, a storage system with 5kWh capacity and 2kW power has been assumed sufficient to cover most of the system needs.

Concerning the electrical energy rates, being the current model based on an Italian scenario, a two-tiered energy tariff scheme has been used. During the peak hours, from 8am to 7pm a gross unitary price of 0.21€ per kWh has been assumed. During the off-peak hours a gross unitary price rated 0.15€ per kWh has been used. The gross selling price, on the other hand, has been rated 0.095€ per kWh.

Concerning the gas rate, a tariff of about 0.62€ per standard cube meter has been assumed. Also the conversion factor from standard cube meter to kWh has been assumed equal to 10.7. The data have been provided by the Regulatory Authority for Electricity and Gas (Aeeg) [3].

Notably, for the sake of simplicity, a yearly average has been used to define the actual energy rates, and the corresponding values have been reported.

[3] Aeeg homesite: http://www.autorita.energia.it/it/inglese/index.htm

C. Results evaluation

By means of the proposed computational framework, on the other hand, it is possible to esteem, not only the actual demand peak, but also its occurrence within the day, as presented in Fig. 4, and even to evaluate the number of occurrences for different demand levels, as suggested by the histogram in Fig.5.

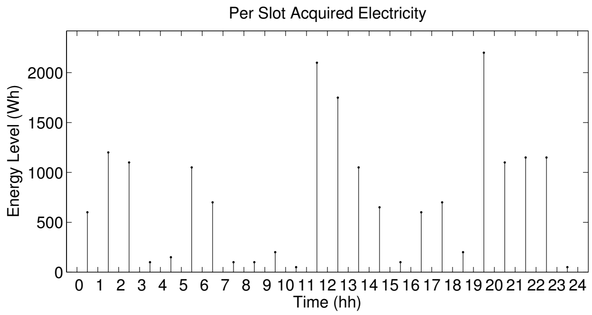

Fig. 4. Task load: hourly purchase

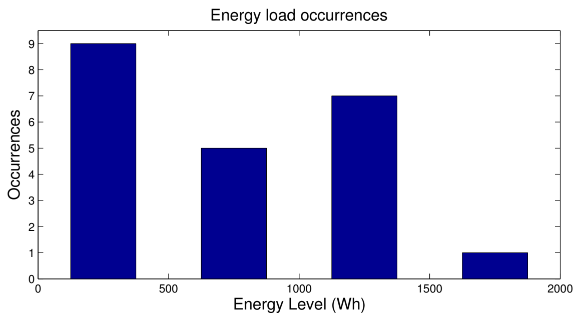

Fig. 5. Task load: demand level occurrences

The occurrences of each consumption levels, in particular, may be used, to size the nominal power of the solar energy plant and storage.

Also, by simulating the task execution, the expected energy cost has been computed. The cost of the energy required to execute only the tasks has amounted to 3.30€. Conversely, when a gas boiler is also included, the total cost rise to 8.60€.

When a micro CHP generator is used, in place of a simple boiler, the additional electrical energy sustains the internal demand, thus reducing the amount of energy acquired from the grid (Fig. 6). In addition the electricity surplus is sold to the grid (Fig. 7), reducing the overall cost to the user while providing the required heat. For instance, in this case, the total cost to the user amounts to 6.00€.

As a mean of comparison, when an heat pump is used instead, the energy demand of the building has been aggravated. Nonetheless, since the energy cost amounts to 6.50€, cost wise the performance of the heat pump is close to the one of a micro CHP.

The next evaluation phase has been carried out by including the energy local production and storage in the system.

In this case, the energy cost required by the task execution, without thermal demand, drops to 1.74€ whereas, when a gas boiler is also included, the total cost has amounted to 7.08€. In fact, the joint benefit of local energy production and storage

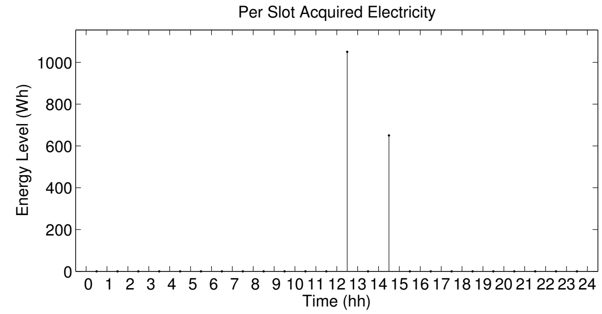

Fig. 6. Task load with chp: hourly purchase

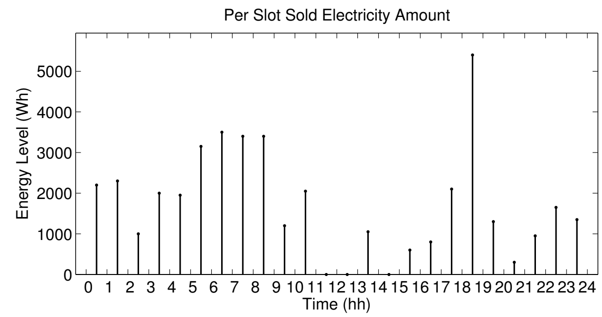

Fig. 7. Task load with chp: sold energy

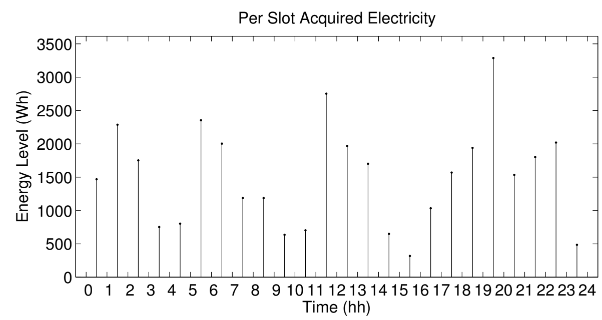

Fig. 8. Task load with hp: hourly purchase

is able to lower the purchased amount of energy, as revealed in Figs. 9 and 10. As a result, the cost shows little to no increase during peak hours, when the energy price is high (Fig. 11).

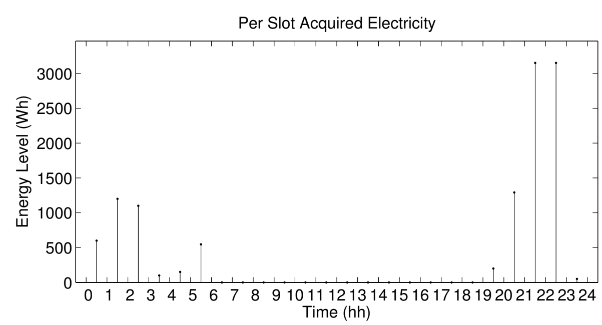

Fig. 9. Task load with solar production and storage: hourly purchase

When a micro CHP generator is included, the system becomes much independent from the grid. In this case the combined production of the solar plant and the micro CHP, has been enough to cover the entire electrical demand, at the point

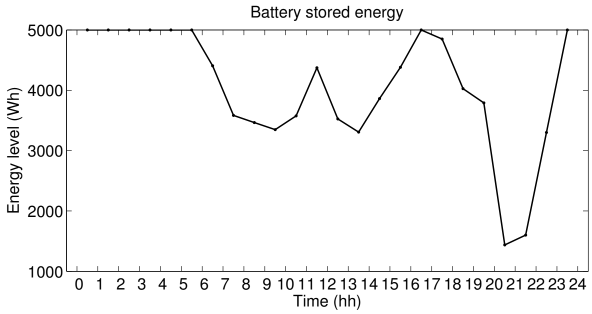

Fig. 10. Task load with solar production and storage: hourly storage level

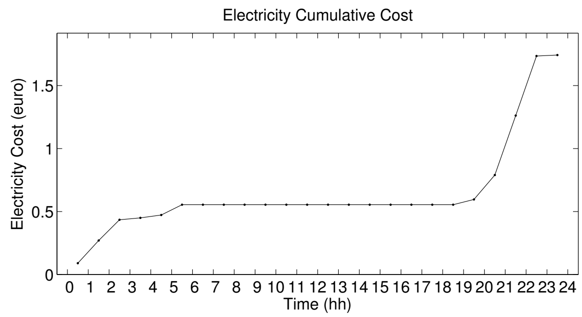

Fig. 11. Task load with solar production and storage: hourly cost expressed in euro (€)

that energy sales occurred at almost every hour, as presented in Fig. 12. No energy is acquired from the grid, nor the storage is discharged. Thus, the total cost of the energy resources, which amounts to 5.00€ , is entirely due to the fuel.

This specific configuration also exemplifies a case of design with unexpected dynamics. Although the electrical energy storage, the solar power plant and the micro CHP have been tailored to satisfy the user needs, thus accounting the maximum demand of the user, their interaction has resulted in energy over production. As a consequence, the energy storage has become unnecessary, meaning that, in a real life environment, there will be no additional benefit to compensate for the extra costs and the extra energy consumption. In addition, the over reliance on micro CHP fuel, with a fixed price, has limited the benefits of energy consumption management.

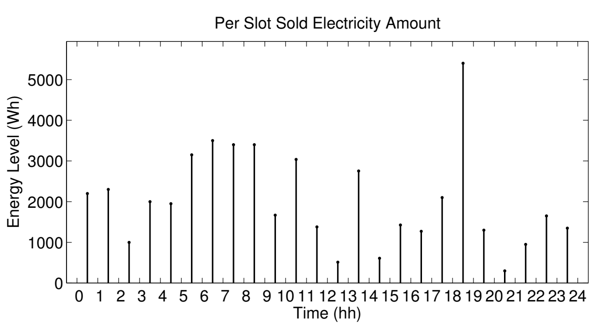

Fig. 12. Task load with solar production, storage and micro CHP: hourly energy sale

Conversely, when a heat pump is used, independence from the grid cannot be achieved, as revealed in Fig. 13. In this case, nonetheless, the energy storage proves to be particularly effective (Fig. 14). Although no energy is sold to the grid, the cost of the energy acquired from the grid has amounted to 4.74€, thus further improving the saving, even with respect to the micro CHP case.

The comparison of the micro CHP case and the heat pump case, therefore, suggests that resource neutrality guarantees enhanced efficiency and savings. If the energy surplus is used locally, the purchase of unnecessary resource is avoided. From a budgetary perspective, since energy resources have an high purchase price and a low selling price, better saving can be achieved. Also, from the efficiency point of view, since the less energy is transferred through the grid in both direction, there are lower transportation losses and costs.

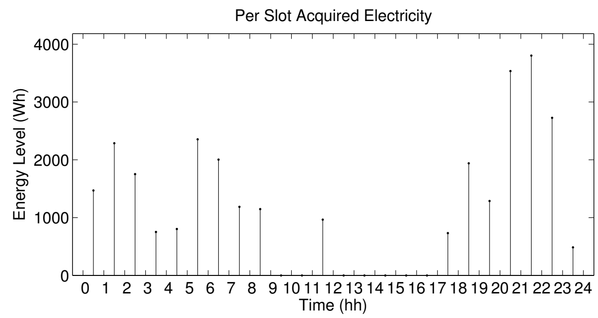

Fig. 13. Task load with solar production, storage and heat pump: hourly energy purchase

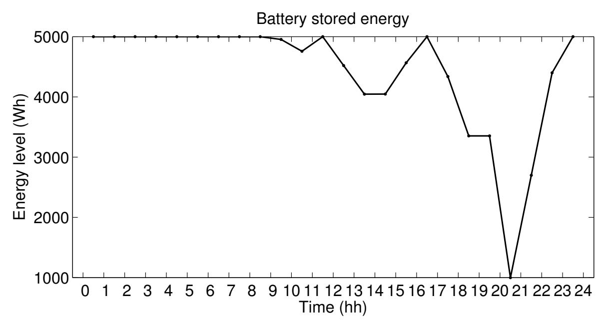

Fig. 14. Task load with solar production, storage and heat pump: hourly storage level

Although the benefit provided by energy production from renewable energy sources is greatly improved by the presence of energy storage, additional improvement can be achieved, by means of a proper task scheduling, which can be considered complementary to the energy storage. The selection of the execution time is left to the scheduler in this case. In particular, for the execution time of each task, a time shift equal to ± 1 hour, with respect to original schedule, is allowed.

The energy demand of the execution of the tasks, without thermal demand satisfaction, is further lowered to 1.51€ from 1.74. A similar improvement is achieved when a gas boiler is used to satisfy the thermal demand, with a cost of 6.86€ while originally equal to 7.08€ . Not surprisingly, when the micro CHP is used, no further improvement is achieved, given the energy surplus, thus proving the design limits of this specific configuration. On the other hand, when an heat pump is used, a further reduction is obtained in the electricity cost, leading to 4.52€ bill.

Certainly, in the current scenario, pertaining the task scheduling, the improvement margin is limited by the reduced shift allowed to the execution time. Also, the effect of an almost fixed price, which is based on a two tiered tariff, is evident. By comparing Figs. 14 and 15, it is possible to observe that the improvement has been achieved by delaying the energy purchase till off peak hour. The purchase delay, clearly, is affected by the storage capacity and, also, by the entity of the allowed time shift.

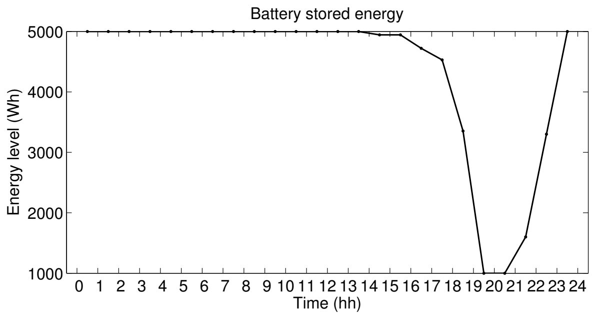

Fig. 15. Task load with task scheduling, solar production, storage and heat pump: hourly storage level

Indeed, when the task scheduling is accounted, it allows the inspection of either the energy tariff, the user habits or both over the performance of the resource management. A less apparent contribution, that affects the scheduling performance, appears when data forecasting is included. Since actual scheduling requires information concerning future, and thus forecast data is used, the scheduler robustness to prediction error has been evaluated.

By submitting the forecasted data as an input to the scheduler, the task agenda is computed by the framework. The obtained schedule, paired with historical data to compose the input data set, has been then submitted to carry out a simulation of the task execution and energy management and evaluate the actual energy management performance.

In this case, the first test has been carried out ignoring the thermal energy management problem. Thus, only the electrical energy management required by the tasks has been evaluated. During the scheduling phase, the expected cost based on forecasted data amounts to 1.14€. When the resulting agenda is used to execute the assigned task, the actual energy cost has risen to 1.53€ . The difference is due to the prediction error. In comparison, when the scheduling is carried out by providing historical data as input, thus obtaining the theoretical optimum, the computed cost amounts to 1.51€.

In the second test, a gas boiler is included to account the thermal energy, the expected cost has been equal to 6.24€ , the actual cost being 6.88€ and the optimum result being 6.86€. In this case, in particular, since the thermal demand does not affect the electrical energy management, the absolute error matches the previous result.

Concerning both the micro CHP set-up, and the heat pump set-up, albeit the absolute error is different, the same trend has been obtained. The corresponding cost values is reported in Table I in order to provide the means to directly compare the different inspected cases.

TABLE I. MONETARY BALANCE FOR THE DIFFERENT THERMAL PRODUCTION TECHNOLOGIES IN PRESENCE OF DIVERSE ENERGY MANAGEMENT STRATEGIES

		Thermal Production Technologies			
		Heat production absent	Boiler (Fuel)	Micro chp (Fuel)	Heat pump (Electricity)
No optimization applied		3.30€	8.60€	6.00€	6.50€
Energy production and storage		1.74€	7.08€	5.00€	4.74€
Energy production, storage and task scheduling		1.51€	6.86€	5.00€	4.52€
Energy production, storage and task scheduling w/ forecasting	expected:	1.14€	6.24€	4.50€	3.73€
	real:	1.53€	6.88€	5.03€	4.53€
	optimal:	1.51€	6.86€	5.00€	4.53€

The comparative analysis of results above, suggests which technology can be most efficiently used in the building scenario under test, taking the energy and task management into account, and in presence of historical or forecasted data. This proves the effectiveness of the adopted methodology for micro grid design purposes, being aware of the limitations already explained above, which will be likely addressed in future developments.

VI. CONCLUSION

Although energy efficiency has been improved by means of an optimal resources management, in a proper design of the residential environment is also paramount to tailor the system features, in order to meet the user needs and habits, and thus to increase the margin of efficiency improvements.

With this in mind, a task and energy resource scheduling algorithm, already proven to be effective in smart home energy cost reduction, has been revised in order to obtain a more comprehensive computational framework for micro grid design purposes. By simulating the environmental scenario evolution over time, and by monitoring energy production, consumption and management, it has been possible to assess the efficiency of the micro grid environment under study, determined in terms of energy cost resulting from the task execution and building thermal regulation.

On purpose, rather than modelling a single apartment, as done in previous works, a reference dataset has been collected by monitoring a real life building made of six apartments. Thus, modelling the task schedule for each apartment in the building, and the total thermal demand, different retrofitting scenarios have been evaluated and compared with the performance of the overall energy system not supported by any optimization solution.

The analysis of the performed results revealed that both the energy storage and the task scheduling share the ability to manipulate the electrical energy demand profile. As such, not only they complement different energy production technologies within the overall energy system, but also they are able to jointly concur to the improvement of the overall energy management, and thus to the micro grid efficiency.

Moreover, the application of the suggested simulation framework resulted in a major asset in the design of a micro grid environment. The simulation framework allowed the punctual investigation of the different energy management aspects in a simulated environment. The uncovered aspects may reveal hidden dynamics and problems, such as in the micro CHP case, that might have remained undetected otherwise. At the same time, they may support a punctual comparison of different micro grid designs, for a given environmental scenario.

While the results appear to be more than promising, it is also clear that several aspects require further efforts and development. As future work, additional technologies shall be included in the evaluation pool, and their performance evaluated. Moreover, in order to support the analysis of the results of multiple simulations, a set of statistical indices shall be defined and assessed. Thereafter, the extension of the evaluation over a long term period shall be carried out.

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