Coordinated micro-generation and load management for energy saving policies


Abstract— The paper describes a joint university-industry project aimed at defining hardware and software requirements for the development of a prototypical microgrid platform on existing sites able to manage generation resources and load. The paper describes an architecture developed for integrating existing software tools for on-line load monitoring and control and for management of in-site generation. The system acquires data from field and stores information on a server, from which an optimization tool gets data in order to perform its calculations and give the optimal set points to the programmable generation resources.

Results are reported about experimentation at test sites with different generating units, such as cogeneration of heat and power (CHP) and/or renewable power generating units equipped with a real-time monitoring tool.


I. INTRODUCTION

The significant changes introduced by the deregulation of electricity markets, by the need for a sustainable development and by the consequent use of less polluting fuels, the development of a technology for small and medium size generations and the investments in the renewable source sector are addressing the development of electric power systems towards the concept of active electric distribution grids against the old passive paradigm.

With "active networks", one means electric distribution networks with a significant presence of distributed generators of small and medium size, often with randomly variable production profiles typical of renewable sources (wind, solar, etc.). In this kind networks, generators and loads can participate to electricity market as main actors and a System Operator may dispatch individual components as well as an aggregation of them.

Future developments for electric distribution networks are well identified by a qualified document of European Community related to the Technological Platform SmartGrids [1] which addresses and encourages the concept of microgrids and related control and management.

The paper describes a joint university-industry project aimed at defining hardware and software requirements for the development of a prototypical microgrid platform on existing sites able to manage the generation resources. An architecture has been developed for the integration of existing software tools for on-line load monitoring and control and for management of in-site generation. The system acquires data from field and stores information on a server, from which an optimization tool gets data in order to perform its calculations and to give the optimal set points to the programmable generation resources.

II. TECHNICAL ASPECTS CONCERNING DISTRIBUTED GENERATION (DG)

In order to realize an adequate development of DG compatible with the present status of power systems, it will be necessary to develop two typologies of structures: microgrids and Virtual Power Plants.

A microgrid is a low voltage grid with distributed sources, with the presence of storage and load control devices [2]. It is a controlled entity which can be managed as an aggregate of generators and/or loads as a response to technical and economic perspectives. A microgrid can contribute to optimize the management of the electric power system thanks to a hierarchical control architecture made up of three levels: (a) Control at the distribution grid level; (b) Microgrid control; (c) Local control of generators

Virtual Power Utilities or Virtual Power Plants (VPP) are a set of conventional and/or renewable generators, distributed resources, on wider geographical areas, which are able to participate to the electricity market by means of intensive use of information and communication technologies.

III. THE PROJECT

A. Project description

The goal of the project was the study and the formulation of guidelines for energy management and saving by means of intelligent management of in-site available sources and of loads.

In the previously mentioned context, for which both generators and loads (either individually or as an aggregate) can be considered by the grid as suppliers of main services
(energy and capability) and auxiliary services (regulation, reserve, etc.), the investigated problem is the optimal programming and generation and load management, performed by means of integrated intelligent devices for the real-time measurement of energy consumptions and production. Such a structure may thus be able to manage the bidirectional energy flow with adequate optimization and control algorithms, by means of a supervisor which proposes the optimal strategy.

A prototype platform has been realized by integrating existing hardware and software tools. The result is a structure which is able to manage different sources in a microgrid and to communicate among different sites.

In particular, the proposed system acquires all the signals from field and stores the information on a server and on a database, which is queried by an optimization program which produces the set-points of the power production for the programmable generators.

Figure 1 shows a conceptual scheme of the proposed architecture.

![Figure 1 – Overview of Data acquisition system from field](image)

The system integrates the load monitoring module with the microgeneration programming. A decision support system allows to obtain an integrated system for the intelligent monitoring and control of electric consumptions for decentralized medium-large size structures.

The proposed platform operates in a microgrid hierarchical structure. A central controller operates both a medium-long term management (intended as the day-ahead optimization of the subsequent 24 hours) and a short term optimization (with a time horizon up to 15 minutes), providing the set-points of local generators [3],[4].

IV. PROJECT IMPLEMENTATION

The project has been developed by integrating two different tools for the real-time monitoring of Distributed Energy Resources (DER) i.e. electrical loads and small/medium size generating units [5],[6]. The tools are named Nextep and ECOMP.

The overall architecture is presented below. Some results from the experimental activities are reported in the next section.

A. Platform Nextep for the monitoring of DER

The monitoring tool Nextep allows the continuous control and management of energy consumptions in the examined sites, by collecting measurement data on a central server, in order to allow the treatment and the diffusion of information to the users through Internet. This solution does not disturb the existing installations and it assures the interoperability and the evolution capacity of the system.

The technical architecture of the platform is structured on three functional levels: (1) sensors; (2) data transmission network; (3) information architecture.

The activity related to sensors has performed the definition of the needs in terms of measurements, wiring points and the identification of the type of signals provided by each different sensors. For this energy management application, the sensors are usually integral energy meters. The most common solution for the acquisition of these data is based on impulsive outputs which are proportional to consumption. Fiscal counters are normally equipped with this type of signal. The real-time monitoring system architecture is represented in Figure 2.

The network architecture is realized so that it presents a good usability in measurement collection and it does not disturb the existing installations. Moreover it uses a “non-proprietary bus” with transportation of accessible data, thus assuring a good interoperability and evolution capacity of the system.

![Figure 2 – Architecture of the real-time monitoring system](image)
(electric energy, gas, water, heat), Multi-platform (Windows, Linux). It allows multi-site and aggregated calculations.

B. Day-ahead Load Forecasting

A Neural network load forecasting tool to be integrated in the prototype has been developed. The obtained results report the ability to forecast energy consumption of a site with a good degree of confidence.

The set of available data of energy consumption (15 minutes samples) was divided into an 'training set' to train a neural network and 'test set'. In particular the 'training set' was made from the consumption data of year 2006 (from 01/01/2006 to 31/12/2006), instead the 'test set' was built with the consumption of 2007 (data from 1/1/2007 to 31/10/2007).

Three types of input with which to train the networks were tested. The input vector therefore has a different structure depending on the type considered. In the first case it contains 96 (24x4) values of the day before power consumption, minimum and maximum temperatures of the previous day. The information is provided on the date on the day of the week (the holiday is treated as if it was Sunday) and this information is represented with a 3-digit binary number (i.e. 001 = Sunday, Monday = 010; 011 = Tuesday, Wednesday = 100; 101 = Thursday, Friday = 110; 111 = Saturday). In the second case the input vector consists of the 96 values of electricity consumption of the day of the previous week, the maximum and minimum temperatures of previous day. The third case represents a union of the two types discussed above, in the sense that the input vector contains both the set. The vector also contains the minimum and maximum temperatures the day before.

From the mathematical point of view simple differences are made between each predicted value from the network and the value of real consumption forecasted. In particular, the difference between predicted consumption and the actual consumption is further divided by the latter so as to obtain a relative error. Then mean and standard deviation errors are calculated. Errors are represented graphically by a histogram which indicates the probability of the error to fall in one of the selected bands. The neural networks considered in the analysis are composed exclusively of one hidden layer. The neurons of output layer are obviously ninety-six, that as many as the power values to be predicted for a given day. One of the differences that exist between the networks created is instead the number of neurons in the hidden layer that has been varied from 20 to 60.

For these types of neurons belonging to the hidden layer a sigmoidal transfer function 'tansig' were chosen to force the output to take values within the range [-1, +1]. It was instead simulated different transfer functions of the output layer and in particular ‘pureline’, ‘logsig’ and ‘tansig’. Furthermore, the analysis was also performed by varying the training algorithm: backpropagation, Conjugate gradient, Gradient descent, Conjugate gradient with Polak-Ribiere updates, Conjugate gradient with Fletcher-Reeves updates and Scaled conjugate gradient algorithms. It important to emphasize that the results achieved by different algorithms are fully comparable as the same networks were always used to perform the workout, thus eliminating the factor of uncertainty due to setting of the weights. Each network was trained for a number of times equal to 20000 and the function chosen to evaluate performance during training was the mean square error. The error on the desired outputs (goal) was set at 10^-4.

Fig. 3 shows that approximately 46% of the errors fall within the percentage ranges 0-5% and about 25% error rate in the range 5-10%.

Moreover, these errors show an average of 9.72% and a standard deviation of 13.35%.

Fig. 4 illustrates the comparison between the prediction made by the neural network described above (in blue) and real consumption (in red) in February.

Forecasting electricity consumption using neural networks has provided quite different results depending on the type of training used. The best results were obtained in the case of the “Resilient backpropagation”.

The prediction of power consumption made during the summer months does not offer as it can be seen from Fig. 5 satisfactory results as those obtained in the case of forecasting the winter months.
This different behavior in the forecast performance is due to the fact that summer time presents a rather different shape due to holidays and due to the presence of air conditioning.

C. Sensors and communication architecture

A specific datalogger (see Fig. 6) has been built in order to monitor energy consumption and Photovoltaic production of one site.

Further in the project and extensive activity on communication solutions between sensors, site and remote server have been done, studying network security and adequacy.

D. Platform ECOMP for energy system planning and management

ECOMP is a modular and semi-empirical calculation code devoted to the evaluation of energy systems and applications in distributed cogeneration and trigeneration sectors, in order to verify the adequacy of the operated choices and to guide the optimization of different constructive parameters. The factors which influence the method, aimed at determining the configuration, the component sizing and the operation strategy and based on an energy saving criterion, are various:

- Energy inputs, formed by fuel costs and purchased electric energy cost and by the related contractual costs for distribution and supply;
- Cogeneration system, defined by plant configuration, single component propriety and the relationships with the external grids which supply electric energy and fuel;
- Energy management, which is influenced by the different load levels at which a component can operate (component off-design);
- The environmental conditions where the cogeneration system operates;
- Energy outputs, formed by electric and thermal users

The code refers to three different libraries. In the first one data are loaded from the input file and are associated with a matrix which stores their values. In the second library it is possible to evaluate the fixed costs of components and to associate them with the goal function. In the third library the machine performances are calculated in design and off-design conditions, thus it is possible to calculate the related variable costs for each significant period, measured in seconds. The code structure is reported in Fig. 7.

ECOMP is divided into two levels (an upper and a lower level).

At the lower level the optimization is carried out by minimizing the variable costs by means of a genetic optimizer, which varies the exploitation percentage of the nominal power of the prime mover. The optimal management condition over the year will be represented by the set of optimal managements in the individual periods. After carrying out the calculation in each period, the goal is achieved.

At the upper level a non linear optimizer varies the rating of the desired component at each iteration. The goal function is the sum of variable and capital (fixed) costs.

The minimization of the goal function is carried out over defined time horizons. The number of significant periods is
variable and it is chosen by the user. Some distinctive days are typically chosen as representative (e.g. summer or winter day, week or week-end day). The request value for each hour in the examined day is also characterized by the number which represents how often this situation occurs over the year. The ECOMP code has been created with a modular structure so that its development is as simple as possible. There is a library with built-in components; each of them presents some gates through which information is exchanged.

V. TEST SITE CONSIDERED

The experimental activities of the project are oriented to the analysis of the technologies and the solutions proposed by the market of intelligent systems for energy management and savings for civil and industrial plants, especially with reference to cogeneration technology represented by microturbines, with economic indications of the main typologies of conventional and renewable generation. In particular, six test sites with different (existing and future) generating plant solutions, have been examined.

For each site the existing and the future plant solutions have been examined by evaluating their advantages and disadvantages in terms of appropriateness to the experimental phase of the present study.

Fig. 8 – One of the test sites considered for experimentation

Evaluation criteria have been set-up based on proposed parameters for the comparison of the different solutions. The results have been reported in an evaluation matrix aimed at outputting the best solution(s) which are achievable for the experimental monitoring.

At the end of this process, three sites have been chosen for the experimental phase:

1. ACAM trigeneration plant in La Spezia. The site was made up of a conventional engine (190 kW) in cogeneration asset with an absorption chiller and a PV plant (35 kWp).
2. RGM photovoltaic plant in Genova. The experimentation was focused on load monitoring and PV characterization (see Fig. 8).
3. University of Genova (Unige) load management. The experimentation was focused on load management and optimization. The site is made up of 19 MV/LV substations.

A. Example of user intervention and optimization of a site

The consumption of the Faculty of Economics was characterized by night hourly average consumption of 100kWh against day average of about 400 kWh. This 1:4 ratio was immediately detected, even by a comparison with other studied cases, as unusual and therefore requiring an intervention.

Furthermore, there was a peak at about 6 am immediately followed by a significant drop in consumption. This behavior appeared to be disadvantageous in terms of power and not coordinated with the public opening of the building.

In general, the overall trend of consumption presented a series of periodic peaks probably related to switching of large loads not coordinated in their operation.

An analysis and a measurement campaign were made on different switchboards to identify the behavior of individual loads and tried to reconstruct a 15 minutes power curve to see if the monitoring system was consistent with the measures made the field in order to clarify the repetitiveness of the pattern of recorded consumption. Figure 9 shows a representation of consumption measured for the Faculty of Economics.

As it can be seen in Fig. 9, saw tooth night consumption detected by the system is associated to air conditioning that are activated for 15 minutes and then switched off for the rest of the hour.

In general the overall trend of consumption presented a series of periodic spikes related to large appliances not coordinated in their operation.

Fig. 9 – Overall and single load shape

Fig. 10 – Overall optimized load shape
Following the analysis and the relative countermeasures regulating power circuits clocks the absorption lines of the main distribution were optimized. Fig. 10 presents the new shape of the building power curve. The black line represents the pattern of consumption before intervention. Table 1 summarizes the detected anomalies and the actions undertaken to achieve the new consumption pattern.

<table>
<thead>
<tr>
<th>Anomaly</th>
<th>Action</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Withdrawals periodic sawtooth peaks</td>
<td>clock setting of the groups of Air handling units (AHU)</td>
<td>Flattening of the curve and reducing overall consumption in 24h. Synchronizing the operation of facilities with the operating hours of the building</td>
</tr>
<tr>
<td>High consumption ratio night / day</td>
<td>Installation of new clocks for AHU</td>
<td>Decreased night of energy usage by approximately 50%</td>
</tr>
<tr>
<td>Operation of air conditioning in rooms not used temporarily (for example classrooms during vacation)</td>
<td>Better room occupancy planning</td>
<td>Drastic reduction in consumption</td>
</tr>
<tr>
<td>Consumption at night due to electrical circuits and non-automated</td>
<td>Performed feasibility analysis and identification of the work required for better management</td>
<td>Further reduction of consumption by about 30% Night. Contemporary optimization of operating and maintenance costs of the lamps</td>
</tr>
</tbody>
</table>

In Fig. 11 the daily energy costs of the building are represented. It can be noticed that the action performed have led to a significant saving (see point (a) with respect to point (b) in Fig. 10). Moreover night and holidays cost (see point (c)) have been reduced.

These savings in energy consumption during the not-working hours can be estimated to be about approximately 6-7 €/h, summing up to the considerable figure of 40 k€ per year.

VI. CONCLUSIONS AND PERSPECTIVES

The paper has presented some of the present problems related to the penetration of DG into power systems. The transformation of electric distribution networks from relatively simple and mainly radial structures towards more complex structures with a strong presence of active components, like distributed generators, implies the need to develop studies for the integration of distributed resources with complex and uncertain characteristics, to identify or adapt control and monitoring methodologies, the design and the realization of adequate communication and protection structures.

The great interest in the control of electric load – intended as a true distributed resource – is located in this line. The availability of adequate tools for (even real-time) monitoring of electric loads could pave the way to the systematic use of system architectures and devices for the coordinated control of generated power and of load which realize the widespread interest among medium-small users in real applications for the optimization of consumptions coordinated with the installation of distributed generators.

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REFERENCES


VII. BIOGRAPHIES

Simona Bertolini was born in 1984. She received the degree in biomedical engineering in 2009. She developed her degree thesis at Department of Communication, Computer and System Sciences (DIST), Genoa, Italy. She actually attend the Ph. D. course in bioengineering at DIST. Her main research interests include medical informatics, machine learning, neural networks and data-mining.
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