# EXPERIENCE ON ENERGY MANAGEMENT IN AN INDUSTRIAL DISTRICT

Stefano BARSALI
University of Pisa – Italy
barsali@dsea.unipi.it

Giovandomenico CARIDI
Navicelli di Pisa – Italy
presidente@navicelli.it

Marcello DE CHIRICO
SDI SpA - Italy
m.dechirico@sdiautomazione.it

Lorenzo FERRARI
CNR – Italy
lorenzo.ferrari@iccom.cnr.it

Romano GIGLIOLI
University of Pisa – Italy
giglioli@dsea.unipi.it

Marco GIUNTOLI
University of Pisa – Italy
giuntoli@dsea.unipi.it

Sandro MAGNANI
University of Florence - Italy
magnani@vega.de.unifi.it

Massimo PENTOLINI
SDI SpA - Italy
m.pentolini@sdiautomazione.it

Giacomo PETRETTO
Enel Ingegneria e Ricerca – Italy
giacomo.petretto@enel.com

Davide POLI
University of Pisa – Italy
poli@dsea.unipi.it

Sandra SCALARI
Enel Ingegneria e Ricerca – Italy
sandra.scalari@enel.com

## *ABSTRACT*

*The paper briefly presents the solutions adopted inside the Smart Grid Navicelli Project for demonstrating the feasibility of optimized management and planning tools and methods to an industrial district. The project involves both a LV Virtual Power Plant and a MV storage compensation system performing several functions for easing the integration of large share of renewables and supplying services to the grid.*

## INTRODUCTION

An increasing amount of different kinds of distributed sources is continuously being installed in both residential and industrial areas throughout the world. In many cases, these systems are operated without considering their interaction with the rest of the system and even with the other sources and loads connected to the same local network. An integrated and optimized management is able to strongly improve the operation of the system from the technical, economical and environmental point of view:

- technical constraints due to line capability, voltage regulation issues, as well as flicker and other dynamical issues might be faced and solved through a proper control of sources and loads in the area;
- the overall economical profit can be maximized by choosing an optimal dispatching of the sources and a proper management of both thermal and electric load;
- the amount of energy generated by the renewable sources can be maximized and their tripping due to grid constraints can be strongly reduced or even avoided.

All these benefits can even be better achieved if some kind of both thermal and electric storages are included.

During the last two years a partnership of universities and industrial operators has developed a research project funded by the Tuscany region authority, focused on applying optimized management tools to an industrial district with different kind of generators (wind, PV, cogeneration) jointly with the installation of electrical and thermal storages.

## THE SMART GRID NAVICELLI PROJECT

The area of the Navicelli canal is located near the town of Pisa and hosts several shipyards, commercial and office buildings. The area was chosen to show the feasibility and applicability of planning and operation tools and methods for the optimisation of the use of energy.

The area includes two large PV plants (3.7MW and 1.0MW) connected to the MV distribution network as well as two small PV plants (summing 25kW) connected at LV. At the time of the project, the large buildings hosting the shipyards needed low amounts of thermal energy, while the building hosting the headquarters of Navicelli S.p.A. needed both thermal and electric energy. For this reason, the project was organised in two demonstrators: the first one relates to the MV network and mainly involves a large (1MW) electric storage system to ease the integration of the large PV plant; the second one regards the Navicelli building where a 19kW cogeneration plant, a 6kW wind turbine and a 15kW electric storage system as well as a thermal storage were added to the existing PV generator to demonstrate the operation of innovative methods and tools for energy management optimisation.

## STORAGE ON THE MEDIUM VOLTAGE

On medium voltage, the storage system was installed with the aim to improve the integration of the large 3.7MW PV plant and to provide regulation services to the grid. Lithium batteries have been adopted for being able to deliver large amount of power with relatively small energy storage.

The system has been designed and built for a converter rated power of 1MVA (made of three 250kVA modules, peaking at 350kVA). The storage is able to deliver 1MW

for 8 seconds. Lower amounts of real power can be supplied for longer periods. Reactive power can be always delivered up to the maximum rating of the converter and depending on the real power demand. The batteries have been made available for free by the converter manufacturer for the duration of the project (EEI srl, Vecenza, Italy).
The system also performs the active filtering function up to the 11th order harmonic, although the PV system does not generates such harmonics.
To make it capable of operating both in parallel to the grid and on a stand alone system supplied by the local sources, a real power vs frequency and reactive power vs voltage droop control has been designed and implemented, as hypothesised in [1] and reported in the figure below. The system has been designed to be installed inside two standard containers for easing the installation procedure.
The storage system can perform several services [2] depending on the control signals it receives. Properly defined real and reactive power set-points can be given through an external controller for optimizing the PV system generation profile according to the schedule contracted on the market or to maximize the profit from selling energy during price peak hours. But even without any external reference signal, the droop control concept makes the converter supply a proper amount of power depending on the grid condition thus contributing to the grid frequency and voltage control.
It can even support the islanding of the PV system on a local load, by supplying the needed voltage and frequency references to the PV converters for the time needed to change the balance between generation and load [1].
The figures below show the result of some preliminary operating tests on one of the 250kVA modules. Figure 3 shows a ramp from no load to the maximum power on a

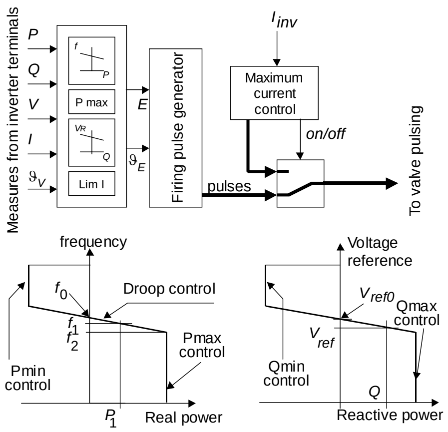


**Figure 1.** Principle scheme of droop control

**Figure 2.** Picture of the inverter and storage containers

resistive load. Figure 4 clearly shows the operation of the droop control during the fluctuations of the grid frequency.

## THE VIRTUAL POWER PLANT ON LV

The second important demonstrator is the Virtual Power Plant (VPP) at the headquarters of Navicelli SpA.
It includes a 25kW PV generator, a 6kW vertical axis wind turbine, a $19kW_e/40kW_t$ gas cogeneration unit, a 15kW/8kWh electric storage, a $5m^3$ heat storage (Figure 5). These systems are monitored and controlled by a centralised supervision system which optimises the operation of the sources accounting for energy prices (known from the day-ahead market), weather and demand forecasts.

### VPP concept

With their innovative bottom-up approach, VPPs are very promising instruments for promoting an effective integration of Distributed Generation (DG) and energy storage devices as well as valid means for enabling consumers to respond to load management signals, when operated under the supervision of a Scheduling Coordinator (SC). These aggregation factors can be very profitable for the Distributed Energy Resources (DERs) economy and for the energy network itself.
Definitely new is the concept of Large Scale VPP (LSVPP), where the production and storage resources under investigation, electrically speaking, are relatively close each other, but they do not share the same Point of Common Coupling (PCC) with the public network. The commercial and technical operation of an aggregate of small-scale producers, consumers, prosumers and energy storages, dispersed on the public network and each having his own PCC, constitutes the most recent research frontier for VPPs. The Energy Management Systems (EMS) of a SC are the

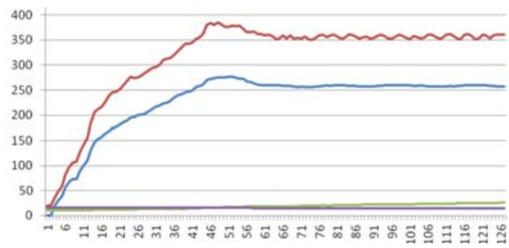


**Figure 3.** Current (upper red curve [Amps]) and power (lower blue curve [kW]) during a test for checking the maximum power of one inverter module (time in s)

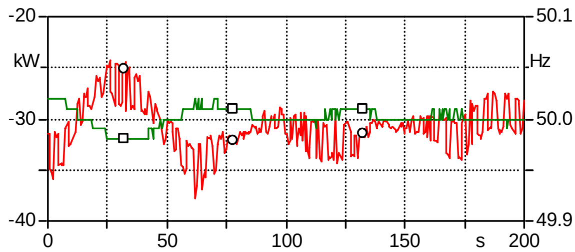


**Figure 4.** Grid frequency (green, square marks) and real power (red, circle marks) during operation at 2% frequency droop and power setpoint at -30kW (battery charging)

core of a VPP. Using a communication infrastructure for data exchange [3], the SC receives signals from the field and market and consequently schedules (ex-ante) and operates (quasi real-time) the energy production of each cluster resource, according to market price signals, to energy demand, to wind and sun availability. It also takes into account the current storage device's energy level [4].
In the area of Navicelli a completely new algorithm for the day-ahead scheduling of a Large Scale Virtual Power Plant has been developed and is now being tested. Some basic features are discussed in the following paragraphs [5].

## The new scheduling algorithm

In the afternoon of the day before the physical delivery, the prices for the following day (set by electricity spot markets) are already known, as well as a quite accurate weather and load forecast. Thus the SC can manage its DERs in order to maximize the cluster daily profit (i.e. considering the sale and purchase prices), but also taking into account the physical position of different resources on the grid, as well as the structural or temporary transport bottlenecks made known by the Distribution System Operator.
Going beyond the traditional dichotomy between Technical VPP (TVPP) and Commercial VPP (CVPP), this approach suggests that the SC manages its DERs in order to maximize the cluster daily profit (i.e. considering the sale and purchase prices like a CVPP does), but also taking into account the physical position of different resources on the grid, as well as the structural or temporary transport bottlenecks made known by the Distribution System Operator (like a TVPP).

## VPP and model of each plant

The considered VPP is a set of plants, individually connected to a public radial network, which is fed by an electrical substation (Figure 6).
The possible presence, inside the network, of loads or producers not included in the VPP, and therefore not subject to optimization, can be easily simulated by simply modeling them as plants with an independent load (positive or negative). The network should not be dissipative thus only the active power is taken into account.
Each VPP plant is modelled as shown in Figure 7. The formal structure of each plant is deliberately over-complex, in order to be customized for including any realistic combination of energy components. This model is very flexible i.e. if a certain component is not present in a given facility, the formal structure of the plant remains unaltered, having simply set to zero the capability of the component.
It's important to underline that one of the main novelties of this approach with respect to previous literature, e.g. [4, 6, 7 and 8], is that the previous picture does not represent the entire VPP, but only a single plant of the aggregation: it is only one element of the cluster, whose components are distributed and embedded in the distribution network, only sharing the HV/MV substation. The focus of the work is therefore a LSVPP, which means taking into account the actual location of individual DERs in the network.
The thermal part of the model, connected to the lower busbar, is basically composed of a) a known load, that can be fed by a CHP plant and b) a boiler and/or a thermal storage device (TS). If the thermal production of a CHP, which exceeds the load, cannot be absorbed by the storage (due to power or energy limitations), then the thermal energy surplus $P_{sur}$ is released into the atmosphere by means of a heat exchanger. Both CHP and boiler are gas-fired.
The electrical part is divided into two sections. The first section is called "internal" and is a conventional auto-producer, whose border with the distribution grid is the internal Point of Common Coupling ($PCC_i$). This part of the model, which is connected to the central busbar, is mainly composed of an electrical load, that can be fed by the CHP,

**Figure 5.** Wind turbine, cogenerator and thermal storage, electric storage inverter and PV plant

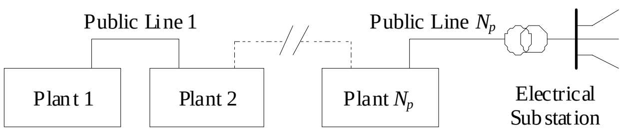


**Figure 6.** Structure hypothesized for the public network where the Large Scale VPP is dispersed

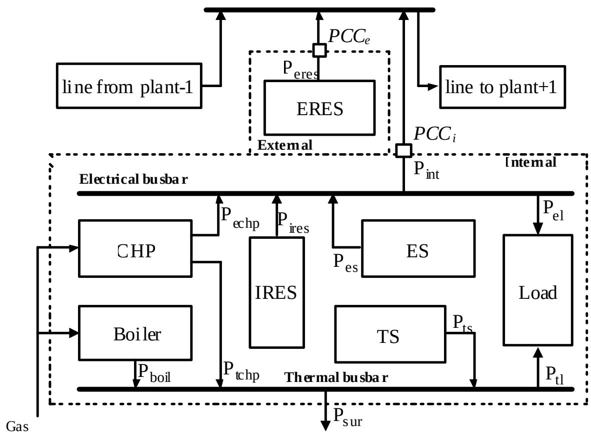


**Figure 7.** Structure of a single plant of the VPP

of an "internal" renewable energy source (IRES) and/or of an energy storage device (ES).
Many feed-in tariffs applied worldwide do not reward the overall energy produced by particular kinds of RES (like very small wind farms), but only the energy amount injected to the grid. In this case, installing such plants inside the VPP internal part would restrict the feed-in tariff only to the production exceeding the local load, if there is any; thus the producer will optimize his investment installing such plants in the surroundings- not internally-, using another PCC; hence the terminology "External Renewable Energy Source (ERES)" and "external PCC – ($PCC_e$)".

## Optimization algorithm

The algorithm implemented on the VPP at Navicelli building assumes as an input:

- the expected power pattern of the electrical and thermal load, at each plant;
- the expected power pattern of RES, at each plant.

With time steps of 15' or 1 hour, the algorithm calculates the daily optimal operation of:

- energy storage devices;
- dispatchable generation (CPPs, CHPs, boilers)

In order to meet the electrical and thermal load and maximize the VPP net daily profit, the tool can also propose load shedding, or RES curtailing, if required in case of a severe shortage of transport capacity (like in islanding).
The net profit takes into account:

- costs for buying electricity and fuel;
- revenues for selling the electricity to the market;
- subsidies for RES, which can be applied to the energy produced or to the energy injected to the grid, depending on the current tariff mechanism.

The technical constraints to be respected are:

- power capabilities of generators, CHPs and boilers;
- energy and power capabilities of energy storages;
- capabilities of public distribution lines.

The algorithm is able to simulate different kinds of operational procedures. In the first mode, called free, the VPP is freely allowed to exchange electricity with the network, simply respecting the mentioned constraints. In the second mode, which simulates an islanded operation, the cumulative flow to and from the electrical substation (i.e. across the line $N_p$) is strictly compelled to be null. In the last configuration, called balanced operation, the VPP receives an additional profit if the power flow exchanged with the substation (that is the VPCC) matches an hourly pattern, within a given tolerance.

## VPP control system implementation

The optimized control system is made of a SCADA system integrated with advanced optimized management functions, implemented on the monitoring and control software eXPert by SDI SpA. The overall system includes:

- the base supervisory and control level of the Smart Grid area,
- the upper level implementing the functions defined by the optimization algorithm

The function of the base level is to measure and store the main energy variables available in the VPP and make them available to the operators. It also enables the upper level to send the needed set-points to the devices for achieving the desired optimized operation.
The upper level uses the measures coming from the base level together with other information to define the set-points needed according to the optimization algorithm.

## CONCLUSIONS

Despite several difficulties due to a slower than expected development of the industrial activities in the area of the project, the two demonstrators installed are starting to show how new management concepts can be applied to an industrial district. A control and management system has been developed using commercial components to apply innovative concepts to a VPP, thus demonstrating the feasibility at a large scale level.
The first results showing the effect of a large storage system connected at MV level promise that very interesting performances and services can be achieved, for both the grid and the renewable plant owners.

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