OPERATION OF DECENTRALIZED ELECTRICITY MARKETS IN MICROGRIDS

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ABSTRACT
A microgrid is a MV/LV grid with embedded distributed generation unit, mainly based on renewable sources, interconnected with the upstream grid to exchange the surplus or deficit of electrical power locally produced respect to the load. An actual research theme in microgrid is to propose rules to implement market competition also inside the microgrid. On this subject, the paper proposes a scheme to implement a local microgrid market linked to main grid market. From the results reported in the paper will be clear the effectiveness of such proposed approach and the economic advantage for local producers and loads.

INTRODUCTION
The penetration of distributed generation (DG) at medium and low voltages (MV and LV), both in utility networks and downstream of the meter, is increasing in developed countries worldwide. One key economic potential of DG application at customer premises lies in the opportunity to locally utilize the waste heat from conversion of primary fuel to electricity by reciprocating engine generators (gensets), gas turbines, microturbines (MTs), or fuel cells (FCs) using small-scale combined heat and power (CHP) equipment. Small (kW-scale) CHP systems, together with solar photovoltaic (PV) modules, small wind turbines (WTs), other small renewables (such as biogas digestors), heat and electricity storage (HES), and controllable loads (CL) are expected to play a significant role in future electricity supply. This new asset is called microgrid (μGrid) [1].

The μGrid architecture is the one depicted in Fig. 1 [1], where the point of common coupling (POCC) is the connection node to the Grid and the Centralized Energy manager (CEM) coordinates the μGrid activity to reach adequate level of economy, power and security of the system.

One of the main topic in μGrid research and development programs is the technical and commercial integration of multiple microgrids, including interface of several microgrids with upstream distribution management systems, plus operation of decentralized markets for energy and ancillary services [1].

For these reason research activities arises in order to propose the implementation of μGrid local markets [2,3] able to involve both DG and LC in local market process with the obvious advantage coming from an economic competition.

In the paper a procedure to implement local μGrid market simultaneous with the day ahead electricity market (DAEM) will be suggested and some preliminary results on a small μGrid will be reported.

RULES OF μGRID MARKET
There are three important pricing rules for electricity auction, but only two of them are generally used in electricity markets:
(1) uniform or single price market clearing rules;
(2) discriminatory or pay-as-bid market clearing rules.
First one is the most common. In this process, sellers would receive the market-clearing price (MCP) for their electricity, even if they bid less than that price and all consumers would pay the MCP, even if they bid more than that price. The theory behind such a bidding system is that all bids to sell electricity would be priced at the marginal cost of that electricity. The implementation of the uniform pricing system came as a natural choice, since it is believed to offer to the bidders the incentives to reveal their true cost.

For this reason in the paper a local μGrid market based on uniform price market clearing rules in the day ahead energy market is assumed.

A hierarchical scheme to perform decentralized energy market will be provided: first the CEM estimates the power required by the load in μGrid (Q*) and submit an offer in the market, grid energy market will be cleared determining the zonal or nodal price (P*) for Q*; simultaneously, a local market in the μGrid take place in which DG can submit bid, consumer including LC can submit offers and HES can submit bid or offer. The CEM will build the aggregate bid and offer curves and will clear the market, considering as bid the couple (P*,Q*). P* represent a price cap for local producer, if there is an excess of local generated power or a...
reduction of consumption the cleared price for the μGrid (P*[^μGrid^]) will be lower than P*. If there is a lack of production or increased load power P*[^μGrid^] will be equal to P*. In practice the POOC will be a slack node, the POCC load power resulting from the local market (Q[^μGrid^]) will be lower than Q*. The difference between Q^m and Q[^μGrid^] will be sold in the ancillary market by the CEM and the gains can be shared between the market participant.

The proposed framework offers a lot of advantages related to the implementation of a local market. In particular demand response program through LC in the small scale market can take full advantage of the effects that an elastic demand can obtain in lower energy prices; HES can take advantage of local extra power availability by renewable sources buying electricity selling when there is a lack of generation power with higher price contributing to reduce P*[^μGrid^].

SIMULATIONS RESULTS

The μGrid reported in fig 3 is used to test the proposed scheme. Only a 6 kWp PV generator (PV) and 6 kW wind generator (WG) are considered to simplify in a first instance the problem. Real data of the Italian Electricity market and weather data of the south of Italy have been used for the simulation performed for a typical working day in two different month of the year January and July.

GD bids

In case of renewable sources, the current cost of producing energy is relatively lower, no fuel and operational cost are involved, compared to the capital cost of buying a wind turbine or PV module.

Therefore producer marginal cost can not be determined as for DG that use fuel to produce electricity.

Economic analyses in these cases are performed using simple payback period. Moreover CO2 emission is absent and incentive due to ‘no carbon emission’ is added advantage to reduce the cost to produce a kWh from renewable sources. In particular for PV plant a feed in tariff of 0,48 €/kWh is assumed while for wind energy an incentive of 0,15 €/kWh in Italian scenario.

From these considerations the price bid are constant values for each hour for all the year and the used values are reported in Tab 1.

The electricity quantity to be bid are the day ahead estimated energy using weather forecast

<table>
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<th>Tab 1 GD prices bid</th>
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<tr>
<td>Ppv</td>
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<td>Pwg</td>
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January

In fig 3 are reported the bid submitted by the generators and the 24 hours P* of a typical day of January of Italian market.

As it can be seen in Fig 4, in consequence of irradiance and wind speed a variable quantity of energy is available over the 24 hours. From the market clearing process a P*[^μGrid^] is determined, less than or equal to P*, and, consequently, the accepted bids. In fig 5 how the load is satisfied by local producer (Q[^μGrid^]) or by the grid is reported. It can be seen that the in most of the hours the local production is selected by the clearing process. In some hours is the local production to determine the P*[^μGrid^]. In Fig 6 the difference between P*[^μGrid^] and P* for each hour is reported.

In consequence of limited availability of renewable sources in the peak hours P*[^μGrid^] < P* so local consumers have no economic benefit in such hours by local competition while an higher price then the bid one is obtained by the local producers (PV and WG). On the hand in off peak hours P* is lower than P*[^μGrid^] with a gain, in term of lower purchasing price, for the load. In the 24 hours the savings for the consumer is € 0,8.

As mentioned above, another benefit of the local market is to sell in the ancillary service market of the upstream grid the difference between Q* and Q[^μGrid^]; in Fig 7 such a difference in each hour is reported.

July

Another 24 hours simulation has been performed for a typical working day of July. The basic aim is to see as the weather conditions, so the availability of renewable sources, impact on the local market solution.

In Fig 8 the price bid in the 24 hours is reported. One can observe easily that P* is higher than January so we expect in summer more savings than the winter ones. Moreover, looking at Fig 9, the expected quantity of electricity produced by renewable sources is, also, higher than the one available in January in consequence of an higher value of photovoltaic production.

After clearing the market on the 24 hours the results are reported in Figs 10 and 11. In Fig 10, the cleared quantities of market participant is depicted while in Fig 11 the difference between P* and P*[^μGrid^] is reported. Fig 11 show that in this case in consequence of the higher value of P* respect to winter period, the savings are in the peak hours in consequence of PV electricity. In consequence of this fact in the typical summer day the consumer savings arise to € 1,3.
Fig 3 January producers bid price

Fig 4 January producers bid quantities

Fig 5 January cleared quantities

Fig 8 July producers bid quantities

Fig 9 July producers bid price

Fig 10 July cleared quantities
Fig 6 January difference between $P^*$ and $P^*_\text{mGrid}$

Fig 7 January quantity of electricity to sell in ancillary market

Fig 11 July difference between $P^*$ and $P^*_\text{mGrid}$

Fig 12 July quantity of electricity to sell in ancillary market

Fig 12 show the difference between $Q^*$ and $Q^*_\text{mGrid}$ which represent the load available to be sold in the ancillary market. The comparison between Figs 7 and 12 show that the quantities of load to be managed in the ancillary market increase in the summer period when problem of system overload exist.

CONCLUSION
In the paper a scheme to implement local μGrid market is proposed. From this preliminary results appears clear that the local market can determine lower price for final customer assuring adequate level of payback period for renewable sources investors.

Several questions are open in such a scenario. First of all the price bid of renewable sources based DG, in the paper they are assumed constant but in a competitive scenario the producers will react reducing the bid price in some hours of the day and arising in other ones. To simulate such behaviour a multi agent system can be implemented.

Other questions are related to the implementation of storage device bidding strategies, that will be able to work as consumer or producers. Such questions are in the research agenda of the authors.

REFERENCE