A MILP ALGORITHM TO SET BIDS FOR ANCILLARY SERVICES IN THE NEXT ITALIAN MARKET FOR DISTRIBUTE GENERATION

Edoardo CORSETTI
RSE – Italy
corsetti@rse-web.it

Antonio G. GUAGLIARDI
RSE – Italy
guagliardi@rse-web.it

Carlo SANDRONI
RSE - Italy
sandroni@rse-web.it

ABSTRACT

Markets for Ancillary Services (ASM) have become more and more interesting because of extra potential profits and power system reliability. The very high penetration of renewable generators on the distribution networks is leading to extend the provision of Ancillary Services (AS) even to wind and photovoltaic plants. This has a twofold perspective. The first one is to progressively shift as far as needed power system from huge thermoelectric centralized plants to decentralized and localized medium/small renewable sources. The second is due to the economic convenience of renewable operators that participating to these markets can receive an economic benefit. In this paper we show the economic convenience and the increase in electrical reliability of ancillary services provided by distribute generation and in particular by microgrids. The different types of sources and loads enclosed in a microgrid provide much more revenue to microgrid operators and a greater flexibility to offer the services. The RSE microgrid use case proposed in the paper demonstrates the thesis in a general sense: for different yearly seasons (with different energy contribution of renewables) for different types of energetic loads (coming from residential, commercial and industrial) and for different levels of flexibility (non-interruptible, cumulative- as electric vehicles rechargers- and interruptible).

INTRODUCTION

The wide and spread installation of renewables sources is leading to transform the shape and the management of the power system. In this sense, renewables are becoming relevant not only as energy sources but also as power system service provider (Ancillary Services – AS). Ancillary Services [1] consist to a number of different procedures to control the stability and balancing the power system. These bring in action methods for active power control like secondary and tertiary, if any, active power reserve; balancing and congestion resolution. The provision of AS from renewable and non-programmable sources, like wind and photovoltaic generators, can accelerate the transition of power system towards renewables. In this paper we are interested to investigate ancillary services provided by aggregate of equipment like microgrid.

A microgrid [2] is a set of equipment connected by one or more energy carrier, with different types of equipment: generators, loads, storage and so on; and connected to the electric grid by a single point. Microgrid can operate electrically connected or not to the main grid. Microgrids are able to integrate local renewable energy generators, as well as improve the power quality and reliability for the local network. On the economic side, power generation cost could be reduced; even environment, greenhouse gases (GHG) and particulate emissions could be mitigated. Microgrid operating in grid mode connected can also supports the grid operation by providing (some of the) ancillary services. Ancillary services can be provided as long as the technical requirements are met. There is a general consensus about the role of ancillary services provision as one of the most promising sources of benefits for microgrids. Even in those cases where the capacity of a single microgrid might be too small for providing ancillary services it is possible to think to the institution of a network aggregator. Such an entity offers an interface with the distribution network to coordinate many different microgrids connected to. In this way, an aggregator acts as a partial sub-centralized control of decentralized organizations ([3]).

The generating capacity of distributed generators allows microgrids to profit from both energy generation and active power reserve. To maximize profits, the optimization of a bidding strategy for participation concurrently in both energy market and ancillary service market is required. Besides DGs, PV systems, load and energy storage systems (ESS) are also good candidates for frequency control services. Loads participating to frequency control service ([4]) must be dispatchable and interruptible; in addition, loads would be preferably used as contingency reserve (e.g. *spinning reserve*) which is not frequently used. Also the deployment of energy storage systems (ESS) is rising on in power systems for many purposes among which ancillary service provision is one of the most important. ESS has a better performance in terms of the response speed. Battery-based energy storage systems are usually expensive, so their inclusion in AS programs is rare, but it is expected a cost reduction and then a wider usage even for small applications.

In this paper we propose an algorithm to optimize the microgrid energy resource planning in order to participate in the day-ahead program and ancillary services provision. The designed algorithm has been tested against the RSE microgrid test facility. The test results show how the participation to the service market is remunerative for the small plants, and microgrid involvement increases the system flexibility, and then its reliability, providing an high capability.

The paper organization consists of a first chapter where the problem of microgrid ancillary services provision is dealt with, next the mathematical formulation as mathematical programming with integer variables is defined, as last chapter the experimentation conducted with respect to the RSE microgrid case study is proposed and conclusions suggests future lines of development.

THE PROBLEM DEALTH WITH

Microgrids, in general, adopt equipment like renewable generators, flexible consumption and sometimes storage devices, to produce/consume power energy, and more and more cases heat. Microgrids provide a single connection point to the main grid (point of common coupling - PCC), and range from small domestic to bigger residential, industrial or commercial systems, acting as prosumers.

The microgrid case study to test the developed algorithm we are proposing is tailored on the RSE microgrid test facility (TF). This microgrid mainly includes a photovoltaic field with 35 kWp, one storage system with lithium technologies with 30 kW charge/discharge power and 32 kWh energy, a mini-wind turbine 3kW peak (*de facto* rarely operating and not considered in the study), a co-generative engine with operating electrical range 25-50 kW, and a controllable load. Controllable load has a nominal power of 90 kW and its set point is the sum of different types of loads considered: *fixed*, non-interruptible, *variable load*, load devoted to supply equipment of the microgrid when operated, *interruptible*, load which can be supplied or not, and as last type *cumulative*, represents one load for which is specified the total energy and the maximum recharge period. Microgrid normally operates connected to the main grid, but it can also be disconnected.

The microgrid PCC is modelled by import and export energy for the day-ahead market (DAM), and by import and export energy for a the day-ahead phase of the AS market (ASM). AS market takes place immediately after the DSM. As in both markets energy is exchanged in hourly time slots, the dynamic of the set of equipment, that is start up - shut down as well as power modulation has been neglected.

Ancillary Services consist of a number of different procedures to control the stability and balancing the power system. These bring in action methods for active power control like secondary and tertiary, if any, active power reserve, balancing and congestion resolution. Micrograds are able to offer AS provision as an integrated contribution exploiting the different types of sources possibly combined with storages. In this view the service is offered by an integration strategy which exploits as far as possible the different equipment available with their specific characteristics. Restricting to the main ancillary services, a bid can be commercially sketched as a quantity of active power to be grow up or lower down, to be sell or buy, respectively at a specific cost or revenue in one hour of a day. An accepted bid is implemented by the microgrid energy management setting the right active power value to the PCC with the main grid at the specific time reference.

THE MATHEMATICAL MODEL

Many models of loads

Demand control can be an effective tool to mitigate a number of drawbacks, like the *peak load* or *peak-to-average* ratio. Demand control in the day-ahead programming for the microgrid model considered consists to set loads according to their elasticity. Load cathgories are distinct in *inelastic* loads, that must be supplied as specified; and *elastic* loads, that can be subject to different degree of controllability.

Inelastic (*I*). Each load must be supplied for each hour planned. Inelastic loads can be:

fixed, when their value are known in advance:

$$load_I^f(t) \;\; t \in 1 \ldots T \tag{1}$$

and

variable, when their values are not known in advance, typically represent the electrical consumption of energy resources (equipment) during operation:

$$load_I^v(t) \;\; t \in 1 \ldots T \tag{2}$$

Elastic loads, two different types of elastic loads are proposed. Elastic loads are distinguished into:

Adjustable (*A*): loads that can be supplied, but if not constraints is satisfied as well (also referred by *interruptible* in the paper):

$$load_E^A(t) \;\; t \in T \tag{3}$$

Cumulative (*C*): the value expresses an energy to be supplied in a maximum time interval, instead of to a time instant. The load is satsfied within the interval according to the optimizer needs while pursuing its objective. This is the case of charging an electric storage.

$$load_E^C(\tau) = \sum_{t \in \tau, \tau \subseteq T} load_E^C(\mathrm{t}) \tag{4}$$

For clarity, time intervals defining the cumulable load term are all disjoint.

$$TOT_{load}(T) = \sum_{t \in T} load_I^f(t) + load_I^v(t) + load_E^A(t) + load_E^C(t) \tag{5}$$

Combine Heat and Power Generator model

The dispatch or generation levels are treated as the *wait-and-see decisions*. Their function is mainly reflected in the generation lower and upper limit constraint (6) the spinning reserve provision (7) and (8). The provision of thermal power by *chp*-engine depends on the electrical power set. It is supposed there exists an affine relationship between them expressed in (9). The constraints are shown as follows.

$$P_{Gen}(t) = 0 \vee (P_{Gen}(t) \geq P_{Gen}^{min} \& P_{Gen}(t) + P_{G,SR}(t) \leq P_{Gen}^{max}), t \in T \quad (6)$$

(Active power for spinning reserve SR shuold be enough to support at time t the specific bus node where the microgrid is connected to).

$$\sum_{g \in Gen} P_{G,SR}(t) \geq P_{RS}^{i}(t), \qquad t \in T \quad (7)$$

The *SR* limits:

$$0 \leq P_{G,SR}(t) \leq P_{G,SR}^{max} \; t \in T \quad (8)$$

The engine thermal production is modeled with an affine linear function:

$$P_{Gen}^{TH}(t) = P_{Gen}(t) * \alpha + \beta, \qquad t \in T \quad (9)$$

The linear approximation between power and thermal is valid for a great number of cases, and coefficients α and β are specific for each equipment.

Electrical energy storage model

In the current electrical power systems, electricity has to be used immediately according to the physical law on power circuits. With the advancement of energy storage devices, the issue called *peak shaving* can be exploit using these devices in the power systems. We formulate a set of energy storage (ES) constraints to address the status of accumulators, power saving and dispatch at each time instant. Constraint (10) indicates energy balance for each accumulator; the other constraints (11), (12) and (13) indicate the available dispatch level and power storage capacity, respectively.

$$Soc_{bat}(t+1) = Soc_{bat}(t) - P_{bat}^{dch}(t) * \frac{1}{\eta_{dch}} * \tau + P_{bat}^{ch}(t) * \eta_{ch} * \tau \quad (10)$$

$$P_{bat}^{Min.dch} \leq P_{bat}^{dch}(t) + P_{bat}^{SR}(t) \leq P_{bat}^{Max.dch} \quad (11)$$

where $P_{bat}^{SR}(t)$ is the spinning reserve for storage microgrid at some time t.

$$P_{bat}^{Min.ch} \leq P_{bat}^{ch}(t) \leq P_{bat}^{Max.ch} \quad (12)$$

$$Soc_{bat}^{min} \leq Soc_{bat} \leq Soc_{bat}^{max} \quad (13)$$

Grid Model

The grid is the support with respect to daily microgrid dispatch finds out fundamental back-up or the possibility to not waste energy. Variables to identify the grid power exchange represent both the import (*In*) and export (*Out*) of the day-ahead market and the input and output power due to ancillary services (*AS*). The model considers the day-ahead grid exchanges as fixed and the input and output power due to ancillary services as variables to be optimized with respect to the economic convenience. It also constrains to buy AS power during periods when there is no grid power export due to day-ahead market, and to sell AS power during periods when there is no grid power imported due to day-ahead market.

$$\begin{pmatrix} P_{Grid,As}^{Out}(t) \geq 0 \Rightarrow (P_{Grid}^{In}(t) = 0 \; \& P_{Grid,As}^{In}(t) = 0) \\ P_{Grid,As}^{In}(t) \geq 0 \Rightarrow (P_{Grid}^{Out}(t) = 0 \& P_{Grid,As}^{Out}(t) = 0) \end{pmatrix} \quad (14)$$

The balance between sources and loads

The balance equation to set the power production tuned by power consumption is:

$$P_{Grid,As}^{In}(t) + P_{Grid}^{In}(t) + P_{Gen}(t) + P_{bat}^{DCH}(t) + P_{pv}(t) - \left(P_{Grid,As}^{Out}(t) + P_{Grid}^{Out}(t) + P_{bat}^{CH}(t)\right) = TOT_{load}(t), t \in T \quad (15)$$

The *objective* of the model is to minimize costs of production (as well as of energy import), and at the same time maximize revenue arising from the sale of energy to the grid. Import and export of active power with the grid encompass both energy exchanging and the provision of ancillary services.

THE EXPERIMENTATION

The experimentation was conducted taking as reference case study the RSE microgrid. The goal of the experimentation meant to show the economic benefit to participate the Ancillary Service Market (ASM) by microgrid operators, and at the same time, the increase of power system reliability to have different possible sources controlled by the same entity who delivers services. To this aim four use cases was set. Each one belongs to a specific season of the year: winter, spring, summer and autumn. Each use case is distinct for different trends of the following variables: PV production, electric and thermal loads, day-ahead and ancillary services prices. Prices for energy market and ancillary service market were selected for a mid-week day (Wednesday), of the half of January (winter), April (spring), July (summer) and October (autumn). In the following two figures are reported: the prices to buy or sell energy on the ASM, respectively, adopted for the scenarios settings.

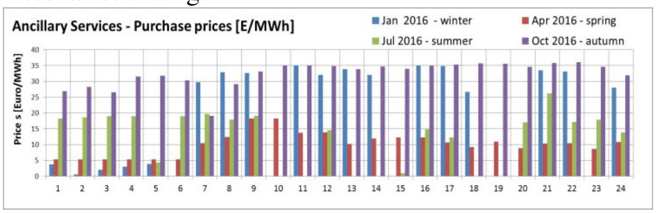

Figure 1 - ASM purchase prices for each scenario

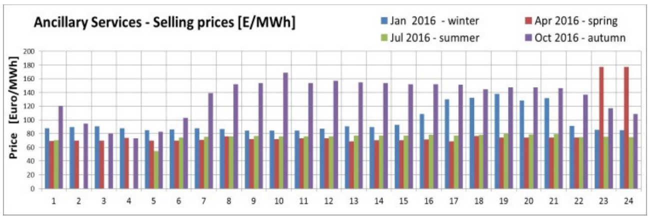

Figure 2 - ASM selling prices for each scenario

Each scenario proposes different thermal loads (very high in winter, and completely absent in summer), energy contribution of renewables (the sole PV production in this sense was considered), different types of electric loads.

Electric loads are mainly distinct about their flexibility: non-interruptible, cumulative - as electric vehicles recharge - and interruptible. The algorithm proposed is coded in the Mixed Integer Linear Programming tool Cplex© (Cplex is a trademark of IBM-ILOG).

The experimentation of each scenario consists first to compute scheduling and costs for the energy day-ahead market. The output of this step fix the energy to be exchanged with the main grid and related costs/revenues. Subsequently, scheduling and costs for the ancillary services are computed taking care to energy exchanges with the grid set in the first stage. Export of active power to supply ancillary services is allowed as extra power provision during daily periods with a first stage power export. Correspondingly, import of active power to supply ancillary services is allowed as extra power input during daily periods with a first stage power import.

The results reported for each scenario simulation consist of the *total cost* of the program set, and the costs of the generator and grid energy exchange. Further, the percentage of not supplied (electrical) load is reported. The load not supplied is the interruptible load quantity which for economic, or other, reason is not supplied in the daily program. The daily interruptible load quantity adopted for each scenario is 140 kWh.

	winter		*spring*		*summer*		*autumn*	
	DAM	ASM	DAM	ASM	DAM	ASM	DAM	ASM
tot cost	121,1	72,8	77,8	51,4	26,8	-3,2	96,7	50,1
cost gen	96,6	96,6	73,1	73,1	0	0	73,1	73,1
imp cost	27,3	2,04	5,8	2,2	27,5	0,3	25,2	8,2
exp rev	2,1	26,5	0,46	24,7	0	4,3	0,9	31,8
load not sup. [%]	74,4	0	70,9	0	78,7	0	74,4	0,0

Table 1 - Experimentation results: costs and not supplied load percentage

The results reported in the previous table demonstrate how the ASM constitutes a source of remuneration for the microgrid operator. In case all the bids on the ASM are accepted the microgrid cost is reduced of a quantity included between 50 and 66 % of DAM costs. If we also consider the quantity of interruptible load supplied when participating in the ASM, this market appear as a real opportunity for microgrid operator. DAM withholds more than 70%, while ASM accepts the whole quantity of interruptible load required.
If we consider that first of all microgrid performs the role to satisfies the need to supply local loads exploiting as far as possible its own resources, the possibility to reduce *de facto* the costs more than 50% is an appealing prospective.

In order to give a more complete view of the benefits arising by the side of power system operation, let us consider the analysis of the capability available provided by microgrid during each scenario. Then we compare these capabilities with that own by a single chp-generator (a typical equipment chosen to supply services).
Capability is the measure to overcome current power surplus, or deficit. Then, quantitatively is the measure of how much an equipment is able to lower or to rise the current power set-point in order to meet sudden requests. Generally, capability is distinguished into *up* (UP), maximum quantity to increase the current power set-point, and *down* (DW), maximum quantity to lower the current power set-point.
The computation of the capability of an equipment is performed by comparing the current set-point with the working limits: nominal and minimal power. Capability UP means the maximum value the current set-point can be increased with respect to the nominal power. Capability DW means the maximum value the current set-point can be decreased with respect to the minimal power. As in the microgrid the equipment involved are of very different technologies, the way to compute the capability for an equipment must analyzed case by case.

An electrical storage system is characterized by discharging and charging powers (at each time instant at most one of the two can be greater than zero), and also the state of charge (SOC). In a storage system capability UP means: to increase power discharge or, equivalently, to lower the power charging. Capability DW means: to decrease power discharging or increase power charging. Though, storage capability does not depend just on the nominal and minimal powers. It depends also on the SOC current value and the associated limits (e.g., in the specific case SOC can range between 15 and 90% of the storage maximum energy).
An electrical load absorbs power when it increases the power set point, in this case the capability UP is reduced and it is increased the capability DW.
The capability associated to the whole microgrid is computed as follows:

functionality	conditions	Equipment variables
Capability UP	Power increasing	PgenUP, PdchUP
	Load decreasing	PchDW, PloadDW
Capability DW	Load increasing	PchUP, PloadUP
	Power decreasing	PgenDW, PdchDW

Table 2 - Capability for an aggregation of equipment

For each scenario proposed the capability UP and DW have been computed, and results are proposed in the next four figures below. They also show the comparison with the capability of the single chp-generator.

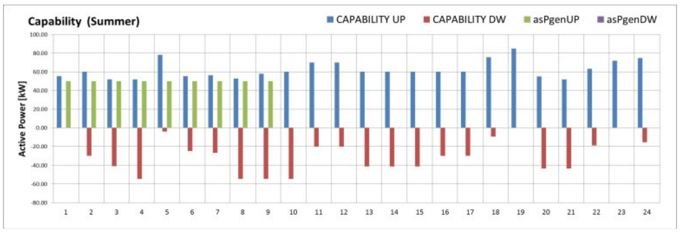

Figure 3 - Capability computed for the summer scenario

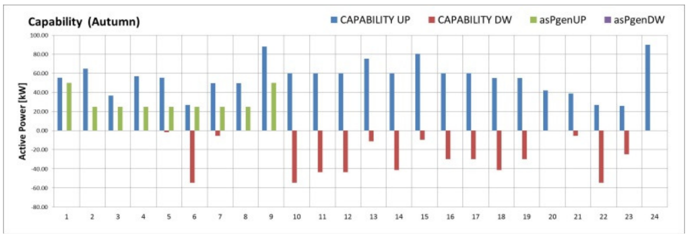

Figure 4 - Capability computed for the autumn scenario

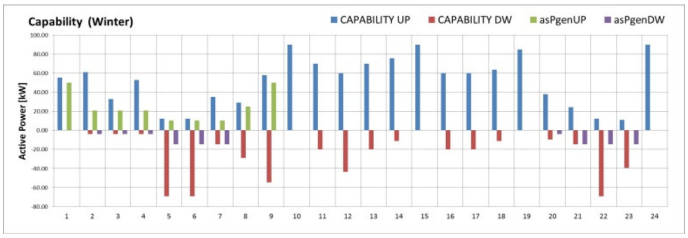

Figure 5 - Capability computed for the winter scenario

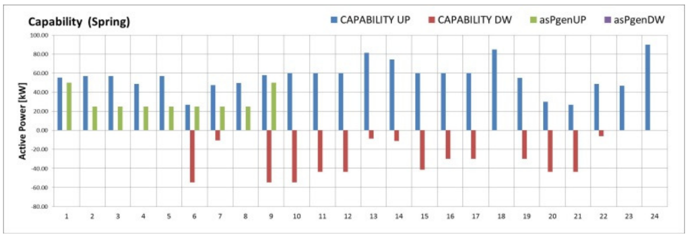

Figure 6 - Capability computed for the spring scenario

The results reported show the great flexibility of microgrid to support ancillary service provision. In particular, microgrid provides in all the cases considered a capability UP (blue line) not zero. Capability DW (red line) is not always available. Though, the comparison between the microgrid and the chp-generator capabilities is strongly in favor of the former. The latter, is available by means of capability UP and very rarely by capability DW. This result tells us that a microgrid is able to offer a much more flexible behavior with respect to a single component. To be honest, a (chp-)generator presents the advantage to be easily controllable by a centralized operator. The microgrid solution requires, to be exploit as much as possible, a decentralized controller installed in the microgrid in order to manage the interaction with the dispatch user, monitor the current status of the set of equipment considered, elaborate a strategy and set the set-point decided to each equipment. But the result gained provides a convincing warranty about the possibility to move towards a decentralized system operation avoiding dangerous states.

In conclusion, the different cases proposed say that the accepted bids proposed by microgrid are able to produce a relevant economical revenue to the operator, and provide enough margins to increase the reliability of the operation.

COCNLUSIONS

The paper proposed an algorithm to permit a microgrid operator to participate the ancillary service market in order to increase the revenue of its plant and at the same time to provide an important service for the whole power system. The experimentation conducted demonstrates the increasing in flexibility provision of services thanks to the participation of a number of different types of equipment, like generators, loads and storages to the process.

The proposed algorithm has been developed in the Mixed Integer Linear Programming environment Cplex (trademark of IBM-ILOG). The algorithm has been coded as a two stage program: the former to code the day-ahead market and the latter to code the day-ahead ancillary service market.

In the next future we are going to extend the proposed algorithm to deal with stochastic optimization techniques. This appears necessary in order to confine the uncertainties arising from the trends of different input variables, like PV production, load electrical and thermal and different prices for the energy and service markets.

Acknowledgments

The work was financed by the Research Fund for the Italian Electrical System under the Cont. Agr. between RSE S.p.A. and the Ministry of Economic Development Gen. Dir. for Nuclear Energy, Renewable Energy and Energy Efficiency - in compliance with the Decree of March 8, 2006.

REFERENCES

[1] Z.Ming, L.Ximei, P.Lilin, 2014, “The ancillary services in China: an overview and key issues”, Renewable and Sustainable Energy Reviews, Elsevier, 36 (2014) 83-90;

[2] Y.Li, F.Nejabatkhah, 2014, “Overview of control, integration and energy management of microgrids”, J. Mod. Power Sys. Clean Energy, (2014), 2(3):212-222;

[3] D.Aikema, R.Simmonds, H.Zareipour, 2013, “Delivering ancillary services with data centres”, Sustainable Computing: Informatics and Systems, Elsevier, 3 (2013) 172-182;

[4] M.Yao, Z.Hu, N.Zhang, W.Duan, J.Zhang 2015, “Low-carbon benefits analysis of energy intensive industrial demand response resources for ancillary services”, J. Mod. Power Sys. Clean Energy, (2015), 3(1):131-138;