# Optimal microgrid participation in coupled energy and ancillary services markets considering uncertainties using CVaR approach

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**Keywords**: Ancillary services, Bidding strategy, Conditional value at risk (CVaR), Microgrid, Renewable energy

## Abstract

In recent decades, the use of renewable energy resources (RES) and distributed energy resources (DER) has increased for various reasons (air pollution, government taxes, transmission line losses, etc). The need for ancillary services (AS) / flexibility services has increased due to the uncertainty and intermittency of RES and possible power system stability risks (loss of transmission lines, outage of centralized power plants, etc). AS are operational services provided to the transmission system operator (TSO) to maintain a balance between supply and demand, system security, reliability and flexibility as well as to provide appropriate quality of electrical energy. This paper presents a flexible grid-connected microgrid (MGs) which can increase its profits by simultaneously participating in the energy and AS/flexibility services markets (regulation up and regulation down, spinning reserve and non-spinning reserve) considering different effective variables (uncertainty of energy price, wind speed, solar irradiation and call for deploying AS). In addition, the MG's behaviour with different energy prices is described in the paper.

## 1 Introduction

In recent years, development of RES has seen a significant boost. Today, RES such as the photovoltaic systems (PV) and wind turbines (WT) are an integral part of the electrical grid [1,2]. On the other hand, using RES is generally increasing variability and uncertainty of power system [3]. Adding these challenges to power system's possible problems, makes the power system unstable and reduces its reliability. Provision of flexibility services/AS by using distributed generation (DG) and energy storage systems (ESS) in a MG can be a solution to these problems, while it increases the flexibility of power system. RES based power system needs more flexibility services/AS than before due to uncertainty/weather-dependency of RES [4]. This paper discusses regulation up and regulation down, spinning reserve and non-spinning reserve AS. Since the production volume of MGs mentioned in this paper is small and they also follow the market price (price taker) and their bid price has no significant effect on the market, they can have the most appropriate offer for simultaneous participation in the energy market (EM) and flexibility/AS markets to achieve the highest possible profitability with optimal planning.

## 2 Methodology

In this paper, optimal bidding strategy for participation in coupled day-ahead energy and AS markets with new objective function is modelled with considering uncertainty of energy price, wind speed and solar irradiation. The exact operating cost of providing AS and the cost function of production of different AS at the same time, are expressed in this objective function for the first time. To the best of the authors' knowledge, it is the first time that the relation between participation spinning reserve and non-spinning reserve is modelled. Uncertainty of wind speed and solar irradiation is modelled using Weibull and Beta probability distribution function (PDF). The probability of call for deploying AS is calculating for all available AS and Conditional Value at Risk (CVaR) is used for risk management.

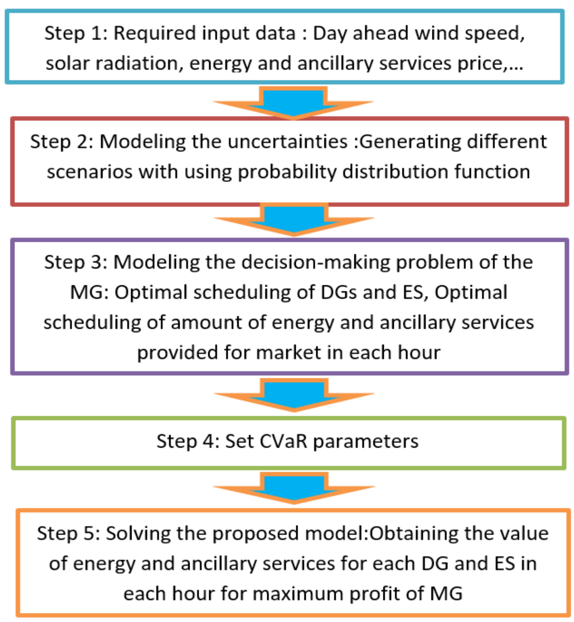


*Fig. 1 Schematic diagram of the proposed bidding strategy*

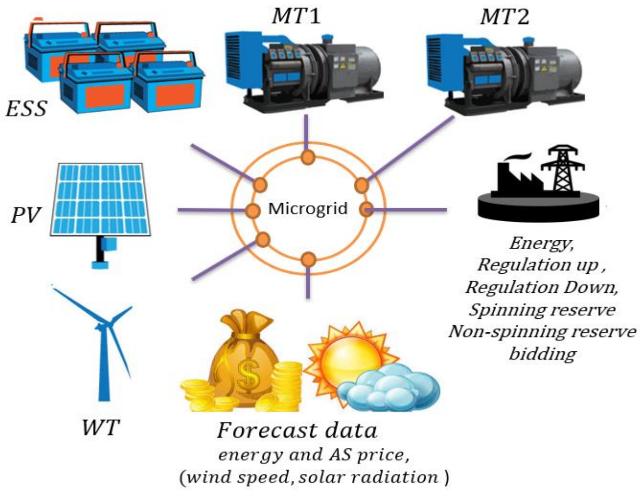


*Fig. 2 MG test system*

*2.1 Ancillary Service*

Frequency control is used to cover small fluctuations between supply and demand. Spinning reserves, are supplied by generation units that are online but not at full capacity, so they can increase their output power in 1-10 minutes and provide additional capacity to the system. Non-spinning reserves, are used to help the system recover from possible unplanned problems and failures [5,6]. For example, in the Nordic region electricity is traded in an open market. Differences in supply and demand lead to weakened frequency stability as well as increased risk of outages [7]. The responsibility of maintaining the system is assigned to the TSOs. To deal with this challenge, the TSOs rely on the provision of AS from other market players [8] such as, MGs. In these countries, ideally the AS should be sold under market conditions where it is technically feasible. The varied AS can be price-differentiated in terms of the ability to provide the service, availability and actual provision of the service when and as necessary [7].

*2.2. Uncertainties*

Uncertainties, including price of energy and AS, wind speed and solar radiation, can change MG's decisions. Different types of PDFs such as Gumbel, Weibull, Lognormal, Beta used to model these uncertainties in previous studies. In this paper Beta and Weibull PDFs are used to model uncertainties of solar radiation and wind speed. They are described in [9,10].

*2.3 Objective function*

In order to maximize the profit of the MG, the revenue difference from the cost should be maximized. The objective function of this is as follows.

$$mazimize \sum_{t=1}^{24} (revenue - cost) \quad (1)$$

$$Revenue\ of\ AS = \mathrm{R}_{as} + R_{asg} \quad (2)$$

$$(P_{as}.\gamma_{as}) + \lambda(\left(P_{as}.\gamma_{asg}\right) - C(P_{as}))$$

P is the amount of energy and γ is the price. The first part is related to the AS contract and it is paid regardless of the amount of production of these services [11]. The second part is related to the production of AS and is proportional to the amount of calls for AS (λ) [12]. The objective function for maximizing the profit of the microgrid is expressed as follows.

$$mazimize \sum_{s=1}^{s} \pi(s)\ ( \sum_{i=1}^{n} \begin{bmatrix} (\gamma_s^E \times P_{n,s}^E) \\ + (o\gamma_{ru,s} \times P_{n,s}^{ru}) + \lambda_{ru}(\gamma_{ru,s} \times P_{n,s}^{ru}) \\ + (o\gamma_{sp,s} \times P_{n,s}^{sp}) + \lambda_{sp}(\gamma_{sp,s} \times P_{n,s}^{sp}) \\ + (o\gamma_{ns,s} \times P_{n,s}^{ns}) + \lambda_{ns}(\gamma_{ns,s} \times P_{n,s}^{ns}) \\ + (o\gamma_{rd,s} \times P_{n,s}^{rd}) + \lambda_{rd}(\gamma_{rd,s} \times P_{n,s}^{rd}) \end{bmatrix} - \sum_{i=1}^{n} \begin{bmatrix} (1 - \lambda_{ru} - \lambda_{rd} - \lambda_{sp}) \times C_n\ (P_{n,s}^E) \\ +\lambda_{ru} \times C_n(P_{n,s}^E + P_{n,s}^{ru}) \\ +(\lambda_{sp} - \lambda_{ns}) \times C_n(P_{n,s}^E + P_{n,s}^{sp}) \\ + \lambda_{ns} \times C_n\ (P_{n,s}^E + P_{n,s}^{sp} + P_{n,s}^{ns}) \\ + \lambda_{rd} \times C_n\ (P_{n,s}^E - P_{n,s}^{rd}) \end{bmatrix}) \quad (3)$$

oγ is offer price of MG in contract. Revenue part of objective function has five parts. In the first term, the income of participation in the EM is modelled. In the other term, the income of participation in the regulation up, spinning reserve, non-spinning reserve and regulation down market is modelled. Cost part of objective function has four parts. In the first term, the cost of participation in the EM is modelled. With simultaneous participation in each of the AS markets, the total amount of energy produced changes, so the coefficient of the first expression decreases and its cost is calculated in the following expressions. The second term models the cost of participation in regulation up market. it is clear that the cost is proportional to the coefficient of call for AS. The third and fourth and fifth terms are similar to the second term for spinning reserve, non-spinning reserve and regulation down markets. With the start of participation in non-spinning reserve market, participation in spinning reserve market will not stop, this point can be seen in spinning reserve coefficient. In the fifth term, by participating in the regulation down market, the cost is reduced due to the reduction of the generator output power.

*2.4. Risk management*

For optimal planning the risk of forecasting wind speed, solar radiation and the price of energy and AS must be considered. CVaR index is added to the objective function and controls the effect of uncertainties on the objective function. Normally the confidence level is assumed to be between 0.9 and 0.99. CVaR is presented as follows [13,14]:

$$CVaR = var - 1/(1-\delta) \times \sum_{s=1}^{S} \pi_s \times \eta_s \quad (4)$$

The cost function changes as follows in Eq. (5)

$$maximize = w \times profit + (1-w)\ CVaR \quad (5)$$

*2.5. Constraints*

$$P_n^{min} \le P_n^E + P_n^r + P_n^s + P_n^{sp} \le P_n^{max} \quad (6)$$

$$P_n^E(t) - P_n^E(t-1) \le UR_n \quad (7)$$

$$P_n^E(t-1) - P_n^E(t) \le DR_n \quad (8)$$

$$P_{st}(t) = P_{st}(t-1) + \eta^{st} \times P_{st}^{sh} - \frac{P_{st}^{dsh}}{\zeta^{st}} \quad (9)$$

$$s_{sh} + s_{dsh} \le 1 \quad (10)$$

$$var - profit_s \le \eta_s \quad (11)$$

$$\eta_s \ge 0 \quad (12)$$

Constraint (6) limits the output power of each generator. Constraints (7) - (8) limit the minimum and maximum power generation changes per hour [15]. $\eta^{st}$and $\zeta^{st}$are efficiently of ESS charging and discharging. Constraint (9) models charge and discharge relationship with storage efficiency [4]. Constraint (10) ensures that the ESS cannot charge and discharge at the same time [3]. The following constraints in equations (11) - (12) must be observed for the calculation of CVaR [13,16].

*2.6. Probability of call for AS/flexibility service*

Different markets have always published different reports such as hourly energy consumption, average energy consumption, amount of hourly AS, etc. [17]. By dividing the average hourly AS by the average hourly electricity consumption, the probability of needing AS can be calculated.

$$\lambda = \frac{\text{hourly average AS requirement}}{\text{average hourly energy consumption}} \quad (13)$$

*Table 1 Probability of call for deploying AS*

| Type of AS | $\lambda$ |
|---|---|
| Regulation up | 0.0069 |
| Regulation down | 0.0067 |
| Spinning reserve | 0.055 |
| Non-spinning reserve | 0.032 |

## 3 Results

For the case study, ERCOT (Electric Reliability Council of Texas) market simulation has been carried out in order to determine the participation of each generator in all of the mentioned markets and also to present the bidding curve based on the real data of 12/7/2020. In the DAM, every day at 6 o'clock, ERCOT publishes system information related to energy and AS. Qualified units must submit their bids until 10 for participation in the energy and AS markets. The market will be held from 10 to 13:30 o'clock and then the market results will be announced [5]. The simulated MG contains two micro turbine (MT) units (both 2 MW), WT (1 MW), PV (2 MW) and ESS (2 MW). Weibull, and Beta PDFs are used to scenario generation of wind speed and solar radiation. Three main scenarios of wind speed and solar radiation are indicated in Fig. 3 and Fig. 4 [18]. Energy and AS prices and offer price of them for ERCOT market are present in Fig. 5 and Fig. 6 [17]. The probability of call AS data is provided in Table 1 respectively.

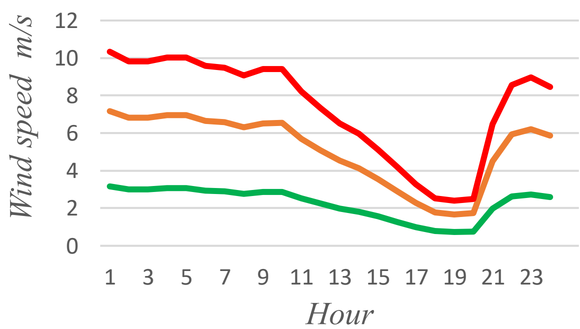


*Fig. 3 Wind speed scenario*

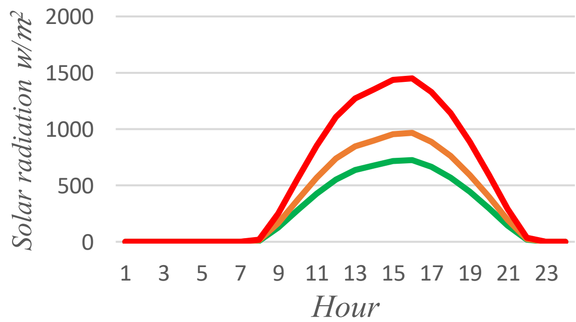


*Fig. 4 Solar radiation scenario*

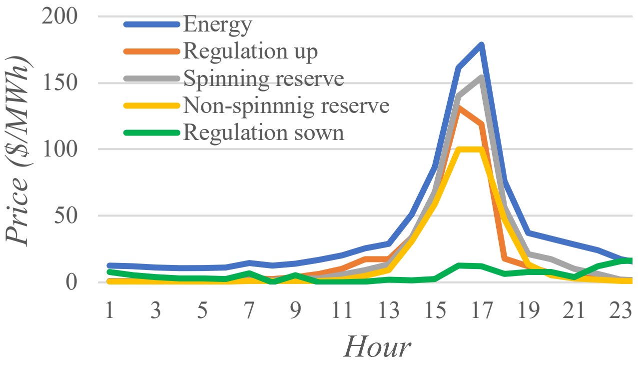


*Fig. 5 Energy and AS price*

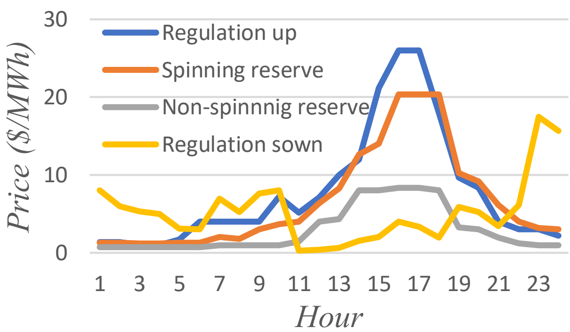


*Fig. 6 AS offer price*

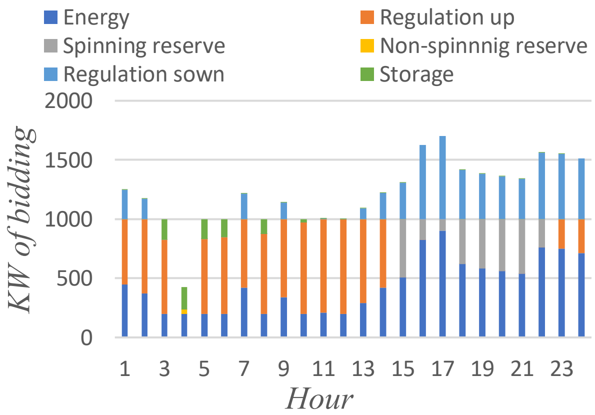


*Fig. 7 MT1 bidding*

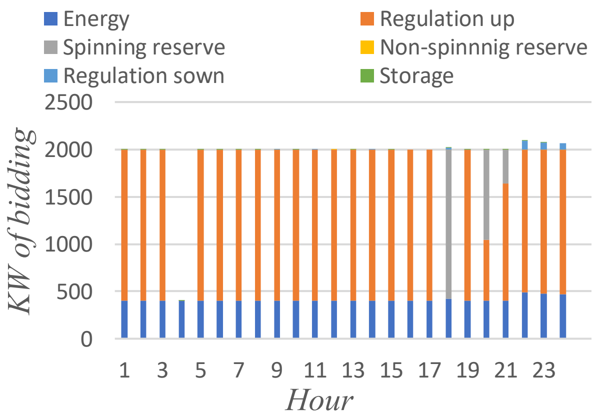


*Fig. 8 MT2 bidding*

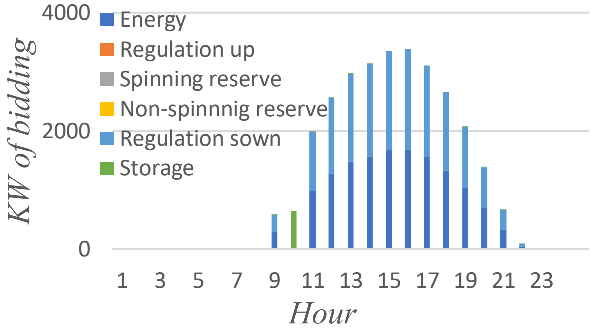


*Fig. 9 PV bidding*

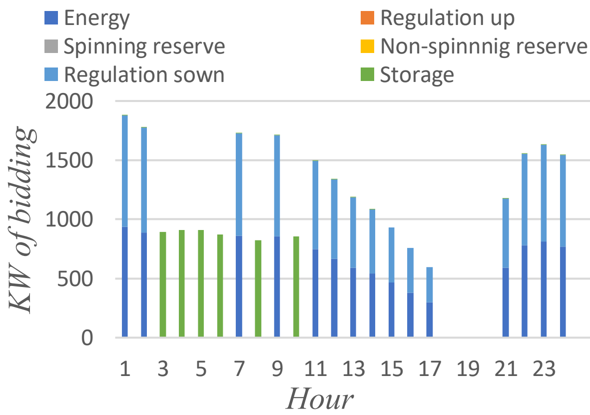


*Fig. 10 WT bidding*

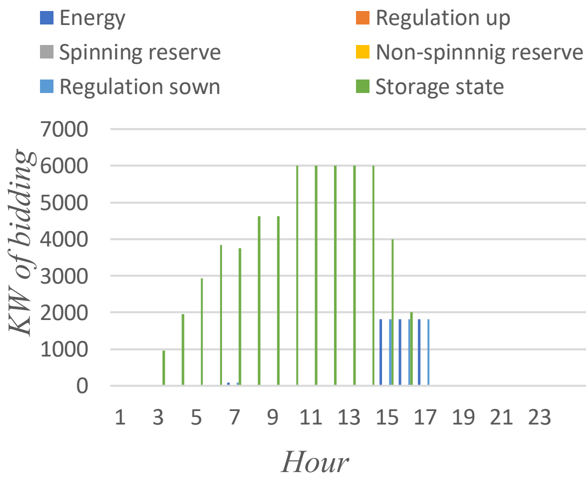


*Fig. 11 ESS state and participation at the end of hour and participation*

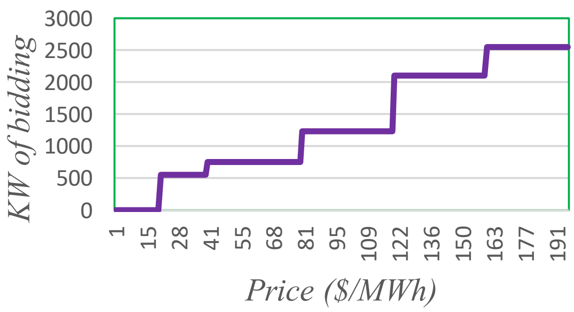


*Fig. 12 Bidding curve of MG at 10 o'clock*

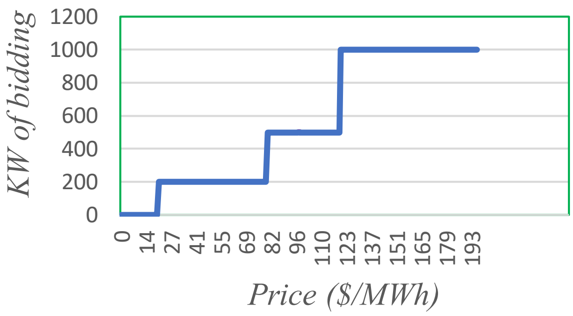


*Fig. 13 bidding curve of MT1 at 15 o'clock*

According to the results, RES has more participation in the EM, on the other hand, MTs only participate in the EM when the energy rate is high, because the operating cost of RES is lower than MTs. So, participation in the AS market has more profit for MTs. Usually RESs have more desire to participate in EM because of low operating cost (the probability of call AS presents that the generator is not always active with full contract capacity in AS market).

Due to the difference in the cost function of MT1 and MT2, their behaviour is also different. By considering that, energy production in the second unit is more costly, so this unit has more participation in the AS market. As indicated in Fig. 10, during the hours when energy is cheap, such as the early hours of the day, the MG stores energy and sells it during the hours when energy is expensive. All units participate in the regulation down market with all of their power, as it does not increase their production costs, but it should be noted that the market may require a limited amount of these services (no limit is assumed in this paper). It is clear that in both curves in Fig. 12 and Fig. 13, as energy prices rise, the MG tends to more participation in the energy market.

## 4 Conclusion

MGs could maximize their revenue by simultaneously participating in the energy and AS market, while increases reliability, stability and flexibility of power system. According to the results, generators with high operating costs (micro turbines) were more willing to participate in flexibility service/AS markets (except when the difference between the price of energy and AS was large). In addition, generators with low operating costs were more willing to participate in energy market than flexibility/AS markets. Due to the uncertainty of call for deploying AS, generators did not generate their full capacity at all times, hence their operating cost was reduced. Also, when the probability of calling for deploying AS is less, generators were more willing to participate in AS. MG stored energy in off-peak hours in order to maximize its profit by selling the energy during peak hours.

## 5 Acknowledgements

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