# MANAGEMENT AND DISPATCHING OF DISTRIBUTED OPERATING POWER RESERVE IN AN URBAN MICROGRID BEYOND DSO RISK DECISION

Xingyu YAN Xin WEN Bruno FRANCOIS Dhaker ABBES
Univ. Lille, Arts et Metiers Paristech, Centrale Lille, HEI, EA 2697 – L2EP, Laboratoire d'Electrotechnique et d'Electronique de Puissance, F-59000 Lille, France

## ABSTRACT

*Electrical system operators and automatic controllers use Operating Reserve (OR) power to mitigate the unexpected imbalance between power supply and load demand. This backup power should be carefully sized and dispatched to reduce operation costs while keeping a satisfying security level. With the integration of small sized intermittent renewable generators in distribution networks, the allocation of OR where they are connected is interesting in order to compensate directly these uncertainty sources and maintain the security and reliability. In this paper, we consider the provision of OR directly by distributed PV generators combined with energy storage systems. For an urban microgrid, comparisons are given with the OR provision by a micro gas turbine. A method for dynamic joint dispatching of OR power on both generator types is presented and tested. Results show new insights in the possibilities of OR dispatching with renewable energy sources.*

## INTRODUCTION

All electricity supply systems require mechanisms to ensure ancillary services provision with an adequate amount to ensure a desired security and reliability level. In electrical power systems, OR plays an important role to balance the power supply and load demand instantaneously in case of unexpected power shortage or load surplus [1]. Nowadays, OR is provided by conventional and centralized power plants as a constant reserve power in a fixed time horizon. However, for a scenario with a high penetration rate of renewable energy sources, it is not realist to consider only traditional deterministic ways for OR provision. Hence new assets, for example renewable energy based distributed generators (DGs) can be considered to provide also the required OR [2].

If the output power of a renewable generator based DG is reduced (degradation from the maximum power point) to create a power reserve, a part of the primary renewable energy will be lost because it is not sure to recover it (as the primary energy is intermittent). Therefore, in the past, active renewable energy generators with embedded storage systems have been proposed to be able to produce a prescribed output power while managing the inner energy with a dedicated local controller [3].

Previous work has mostly focused on operating and reserve power allocation, or storage utilization for system balancing in high levels of intermittent generation penetration [4]. However, these investigations did not consider making use of small intermittent renewable energy generators to provide reserve in an urban MG. Efficient and new technologies for operational and reserve power dispatching are needed to help MGs system operators to lower system operation costs, improve reliability, reduce emissions, and expand energy options.

The distribution and transmission of electricity to the loads are assumed to be planned through the electrical system by taking into account the filtering effect from uncorrelated renewable generations and loads. In the context of uncertainty from a bad forecasting, a new application of storage systems would be to manage the provision of a prescribed OR onto active DGs. Hence, a framework of an energy management system must be imagined to allow grid operators to make renewable generators controllable like conventional ones [6].

This paper proposes to dynamically dispatch both operational and OR power in an urban MG with a micro gas turbine (MGT) and Active PV Generators (PV AGs: PV panels with energy storage systems and a local controller). Two day-ahead optimal OR power dispatching methods are proposed: one with the OR provided only by MGT (conventional power plant), the other with the OR provided by both MGT and PV AGs. Then, a case study is considered within an urban MG to verify the proposed methods.

## PROBLEM DESCRIPTION

In the studied urban MG (Fig. 1), a residential network with several prosumers and PV AGs, controllable loads, and MGTs is considered. MGTs are connected to an AC bus and controlled by the local controller (LC). PV panels are installed on the roofs of residential homes with storages nearby.

To face the complexity resulting from the large number of small renewable generators, the method consists in considering an energy management system in order to master local uncertainty sources and avoid local network control problems. This decomposition of a distribution system into micro controlled areas is a way to make OR provision easier for the distributed system operator (DSO). The storage system in PV AGs with a local controller must manage the reserve power regarding the operating point and a daily power planning. The contribution of each DG is scheduled by taken into consideration the uncertainties in the considered local electrical system.

With collected data from smart appliances in demand side, DSO can use solar panels and storage devices bundled with inverters to provide ancillary services for voltage regulation and frequency control. However, an uncertainty is arising from forecasted PV power and load demand. The calculated uncertainty can be estimated by a probability density function (PDF) that can be used to calculate the probability that power generation cannot cover the load demand. According a prescribed risk (that is decided by the DSO), a probabilistic DSO risk-constrained method is proposed for OR quantification in this local MG [1].

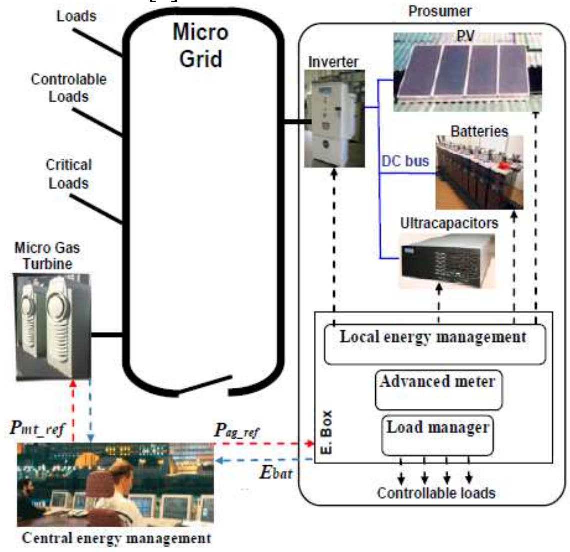


**Fig. 1** Control framework of PVAGs and one MGT in a MG.

## METHODOLOGY

### OR Dispatching Strategies

Different strategies for OR dispatching onto conventional generators and DG can be considered regarding the responsibility of the various sources of uncertainty. These OR dispatching strategies will have different influences on the electrical system security and on the required sizing of the distributed storage units in houses. Traditionally, conventional power plants, such as nuclear power plant and MGT, are used to provide the reserve power because they can produce a programmed power output, while PV power is considered as a non-dispatchable intermittent power source. Since the integration of PV power generation into the electrical system is increasing to a high level, it is necessary for PV generators to provide some ancillary services, such as OR provision. It is possible thanks to the energy storage system embedded in the PV AGs [6].
Before the OR dispatching, the OR is assumed to be calculated based on PDFs that are obtained with the forecast errors of PV power and load demand [7]. Then, two different OR allocation strategies are proposed: into the MGT only or into MGT and PV AGs.

**First strategy: OR provision by MGT**

The OR power is provided by MGT, while the PV AGs power is only used to supply the forecasted load demand. For the load supply, PV AG is considered as a prior source and MGT is used to provide the missing power. The overall OR dispatching algorithm is shown in Fig. 2.

***A. Operation during the day***

In each time step *t* during the day, two cases may appear:

a) If the predicted PV power ($PV_F^t$) is more than the predicted load demand $L_F^t$ ($PV_F^t \geq L_F^t$), then the PV AG power reference ($P_{AG\_n}^t$) is limited to the forecasted load demand and is dispatched to the *N* PV AGs according to their rated power ($P_{AG\_rated\_n}^t$):

$$P_{AG\_n}^t = L_F^t \cdot \frac{P_{AG\_rated\_n}^t}{\sum_{n=1}^{N} P_{AG\_rated\_n}^t} \quad (1)$$

MGT is just working to provide the OR power at the time step *t* ($P_{OR}^t$) (case 1.1 in Fig. 2):

$$P_{MGT}^t = P_{OR}^t \quad (2)$$

The PV energy surplus is automatically stored into batteries. So, batteries state of charge (SoC) must be checked to establish if they are available for loading the exceeding PV power (or to provide the missing PV power during the night). SoC is calculated:

$$\sum_{n=1}^{N} E_{Bat}^{t+1} = \sum_{n=1}^{N} E_{Bat}^t + \tau \times (PV_F^t - L_F^t) \quad (3)$$

The parameter $\tau$ is the duration of the available constant power (30 minutes for our study).

b) If $PV_F^t < L_F^t$, during the day, the power references of PV AGs are set with the day-ahead forecasted PV power (case 2.1 in Fig. 2):

$$P_{AG\_n}^t = PV_F^t \cdot \frac{P_{AG\_rated\_n}^t}{\sum_{n=1}^{N} P_{AG\_rated\_n}^t} \quad (4)$$

Then, batteries, which may produce or store power in case of, respectively, negative or positive forecast PV errors, locally manage the uncertainty coming from the bad PV forecast. MGT will provide deficit power and the OR, which is required by both PV power and load uncertainties:

$$P_{MGT}^t = L_F^t - PV_F^t + P_{OR}^t \quad (5)$$

***B. Operation during the night***

The extra PV energy stored in the battery bank during the day will be used in the night. The decisions are made according to the battery SoC and energy demand.

a) If the SoC is enough to feed the predicted load demand, as in equ. (1), then the MGT is just working to provide the OR, following the equ. (2). At each time step, the SoC is updated with the equation (3) with $PV_F^t = 0$. The reference power of PV AGs is equal to the forecasted load demand $L_F^t$ (case 3.1 in Fig. 2).

b) Otherwise, MGT must balance the remaining load demand and provide the OR. So we have a full MGT mode (case 4 in Fig. 2):

$$P_{AG\_n}^t = 0 \quad (6)$$

$$P_{MGT}^t = L_F^t + P_{OR}^t \quad (7)$$

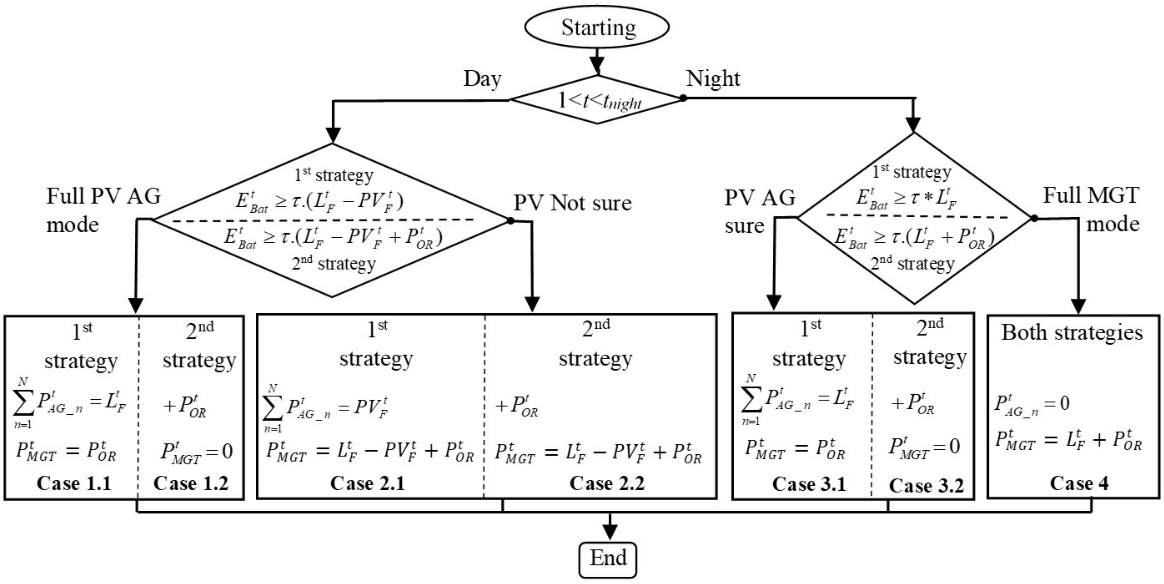


**Fig. 2** OR dispatching strategies with different scenarios.

**Second Strategy: OR provision by MGT and PV AGs**

***A. Operation during the day***

a) If the predicted PV power exceeds the predicted load demand and the necessary OR at time step $t$ ($PV_F^t \geq L_F^t + P_{OR}^t$), then the MGT will be shut down and an autonomous PV supply is then implemented (case 1.2 in Fig. 2):

$$P_{AG\_n}^t = (P_{OR}^t + L_F^t) \cdot \frac{P_{AG\_rated\_n}^t}{\sum_{n=1}^{N} P_{AG\_rated\_n}^t} \quad (8)$$

$$P_{MGT}^t = 0 \quad (9)$$

The energy surplus is automatically stored in batteries by the local EMS controller for the night use:

$$\sum_{n=1}^{N} E_{Bat}^{t+1} = \sum_{n=1}^{N} E_{Bat}^t + \tau \times (PV_F^t - (P_{OR}^t + L_F^t)) \quad (10)$$

b) If $PV_F^t < L_F^t + P_{OR}^t$, the MGT will be used to cover the remaining load demand and OR. Then, PV AGs power references are set as equ. (4) and MGT power reference follows the equ. (5). In this situation, the OR (treated as a part of the system load) is dispatched proportionally to generator power ratings: in PV AGs and MGT (case 2.2 in Fig. 2).

***B. Operation during the night***

a) If the stored energy is enough to feed the predicted load and the OR, MGT is switched off and we have an autonomous PV mode like equ. (8) and (9). The battery SoC calculation is refreshed and checked again at each time step as with equ. (10) but with $PV_F^t = 0$ (case 3.2 in Fig. 2).

b) Otherwise, we have a full MGT mode as with equ. (6) and (7) (case 4 in Fig. 2).

## CASE STUDY

An urban network with 110 kW of rated load, 55 kW of rated PV power, one MGT with rated power equals to 120 kW, the OR for 1 % of LOLP (Loss Of Load Probability) coming from forecasting uncertainties of load and PV power is taken into consideration (Fig. 3). The daily forecasted PV energy is 269.5 kWh and the total corresponding daily load demand energy is 1082 kWh.

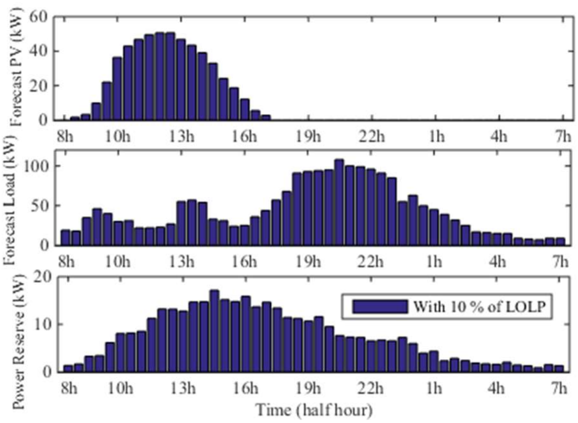


**Fig. 3** Day-ahead forecast PV power, load and OR.

Fig. 4 and Fig. 5 show power references for PV ($Pref_{PV}$) and MGT ($Pref_{MGT}$) after the OR dispatching among the power generators with both OR dispatching strategies. As shown in Fig. 5, from 11:00 to 13:00 and from 4:00 to 7:00 (next day) the OR and load demand are only provided by the PV AGs and the MGT is shut down.

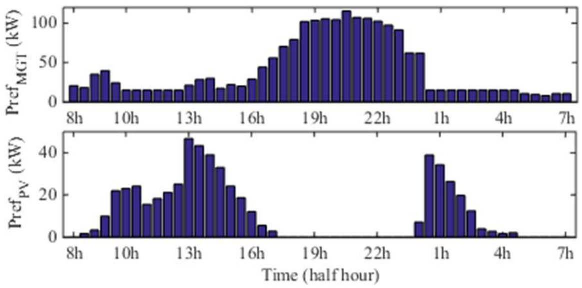


**Fig. 4** PV and MGT power references with 1st strategy.

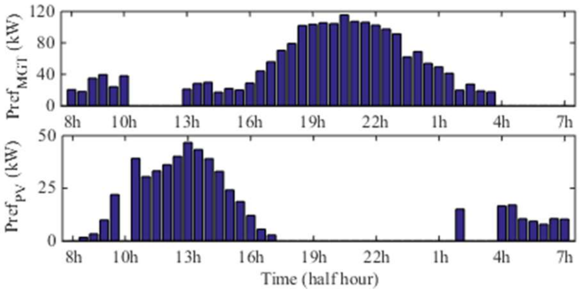


**Fig. 5** PV and MGT power references with the 2nd strategy.

Instead, in Fig. 4, the OR is covered only from MGT, which should work in all time steps.

Table 1 illustrates performance indices of both strategies on different aspects: percentage of OR provided by PV AGs, maximum energy storage in battery, and MGT power ratio.

**Table 1** Day-ahead OR dispatching results.

| strategy | OR on PV AGs (%) | $E_{bat\_max}$ (kWh) | MGT Power Ratio (%) |
|---|---|---|---|
| 1st stratery | 0 | 78.6 | 46.0 |
| 2nd strategy | 35 | 52.6 | 34.5 |

**Fig**. 6 illustrates the OR dispatching in both generators with the second strategy and provision percentages for each generator: 35% for PV AGs and 65% for MGT in this case.

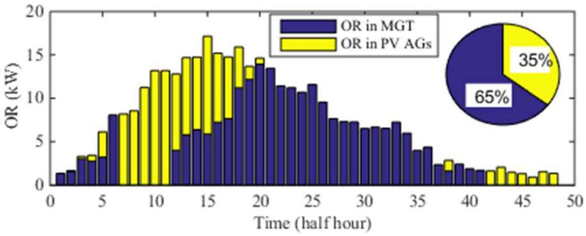


**Fig. 6** OR dispatching in different generators with 2nd strategy.

PV AGs provide the power both during the daytime and night. In the daytime the energy comes from PV panels while, during the night, it comes from the batteries. $E_{bat\_max}$ represents the maximum energy storage in the batteries. Compared to 52.6 kWh stored energy for the first strategy, much more battery capacity is required since 78.6 kWh energy has to be stored for the second strategy. MGT power ratio, which is highly related to its efficiency, is defined as the real power output of MGT divided by the rated power of MGT. Comparing the results of the two strategies shown table 1 MGT power ratio in second strategy is about 46%, which is greater than 34.5% in first strategy. This is because of the MGT is shut down during some time steps when the PV power provision can cover both load demand and OR.

## CONCLUSIONS

The integration of renewable energy sources into electrical grids is limited because of their intermittences and uncertain power production. Therefore, it is essential to have an appropriate OR and to dispatch it in a good way to ensure a good reliability of the electrical system. In this paper, a new OR dispatching strategy is applied to a distributed urban MG system including PV AGs and MGT. Two methodologies for an optimal planning and dynamic joint dispatching of both operational and OR power are carried out to ensure that both electricity generation markets and ancillary service markets can be optimized. The methodologies are applied to an urban MG application and promising results are obtained. The proposed methods show that renewable energy sources coupled with energy storage devices (PV AGs in this case) can more contribute in OR dispatching without losing power system security.

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