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Green Data Centres integration in smart grids: New frontiers for ancillary service provision

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ABSTRACT

The paper presents a study, conceived within the GEYSER FP7 co-funded European research project, on the ancillary services that Green Data Centres (GDCs) can provide, focusing, in particular, on spinning reserve.

More in detail, the main contribution of the paper is to show how GDCs can be involved in the secondary frequency regulation process of a smart distribution grid, for contrasting the disturbing effects of unexpected variation of the energy production.

With this aim, a real data centre, owned by Engineering S.p.A., is simulated as connected to the Medium Voltage IEEE 14-bus test grid where some RES-based generators are supposed to exist.

Simulations are carried out in order to evaluate the impact of power management actions to be executed by the data centre during under-frequency transients, due to an event of renewable energy facilities power production decrease. During this event, the effects of the spinning reserve provided by the data centre are deeply analysed.

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1. Introduction

During the last years, a large amount of human and industrial activities have required the recourse to Information and Communication Technology (ICT) leading to an empowerment of Data Centres (DCs) [1,2]. For instance, today in US the energy consumption growth of DCs is ten times bigger than the overall growth of electricity demand [3]; in Europe, instead, DCs requires about 40 TWh (about the 1.5% of the total European energy consumption) [4,5].

In addition, in the last few years, as a result of the increased use of Renewable Energy Sources (RES), such as wind and solar, new challenges have been faced. Indeed, the increase of renewable energy penetration has worsened the management of the power grid [6,7] causing also a spread of the energy prices. In such a context, the opportunity of employing Geen Data Centres (GDCs) in the management of power flows in the grid must be considered [8,9].

GDC is a facility that has a minimal effect on the natural environment. It is entirely built, managed and operated on green computing principles. It provides the same features and capabilities of a typical DC but uses less energy and its design and operation are environmentally friendly. DCs are highly automated and monitored loads and they are characterized by a certain level of demand flexibility [10,11]. For this reason, under well-defined conditions, it is possible to modulate the power loads of the IT equipment [12] as well as the cooling facilities service [9,13].

GEYSER (Green networked data centres as EnergYProSumErs in smaRt city environments) FP7 co-funded European project [14] imagines a scenario in which GDCs are flexible and cooperating "prosumers" able to contribute to the reliability and stability of the power distribution grid.

Empirical studies [15] show that, acting both on the "non IT equipment" [16] and via temperature adjustments (i.e. cooling plants and ventilation facilities, etc.) and therefore without affecting the ICT workload, the 5% of the total load in a DC can be shed in 5 min and the 10% of the load can be shed in 15 min [15,17].

In some cases, a wider range of flexibility can be achieved by acting also on IT workload management by geographically relocating it [18–20]. Moreover, typically DCs have on-site backup generators coupled to large scale energy storage systems [21] in order to ensure the absolute continuity of supply [22], that further increase the flexibility of the installation [23].

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Nomenclature

AGC	Automatic generation control
AS	Ancillary services
DC	Data Centre
DFIG	Double field inductor generator
DR	Demand Response
DQ0	Direct quadrature zero
DSO	Distribution system operator
FP	Framework programme
FRR	Frequency restoration reserve
GDC	Green Data Centre
HV	High Voltage
ISO	Independent System Operator
MV	Medium Voltage
PQ	Active and reactive power injected fixed
RES	Renewable energy sources
RMS	Root mean square
RR	Replacement reserve
RS	Regulation service
SL	Slack voltage value fixed
TSO	Transmission system operator
TMNSR	Ten Minute Non-Spinning Reserves
TMOR	Thirty Minute Operative Reserve
TMSR	Ten Minute Spinning Reserves

This paper presents some main results of the GEYSER research project on this issue. In particular, after describing the ancillary services that a GDC can provide to a smart micro-grid, the paper focuses on spinning reserve provision, presenting some case studies on a real existing DC. More in detail, the main contribution of the paper is to propose the possibility of involving GDCs in the secondary frequency regulation process for contrasting the effects of the unexpected variation of the energy production, in particular in micro-grid with high penetration of RES-based generators.

With this aim, a real data centre located in Pont Saint Martin (PSM), Valle d'Aosta (Italy), owned and operated by Engineering S.p.A., is simulated as connected to the Medium Voltage IEEE 14-bus test grid where some RES-based generators are supposed to exist. Simulations are carried out in order to evaluate the impact of power management actions to be executed by the data centre during under-frequency transients, due to an event of renewable energy facilities power production decrease. During this event, the effects of the spinning reserve that the data centre can provide are deeply analysed.

In the present work, it is assumed that the 14-bus test grid is isolated from the Italian transmission system, and that the secondary frequency regulation is performed only by the PSM Data Centre, thus showing more clearly its effects. It is important to underline that these hypotheses have no influence on the results of the study that leads to broader conclusions valid also for more extended power systems. In fact, when the GDC is considered connected to a not isolated grid, it will be able to participate to the secondary frequency regulation with the same actions, together with the other facilities connected to the Medium Voltage (MV) and High Voltage (HV) systems.

Although the paper does not want to propose a unique solution, the case studies presented in the following clearly show how GDCs can be used for secondary frequency regulation, and the results obtained by simulations can be easily generalized to other critical situations [24].

The paper is structured as follows:

- ○ in Section 2, it is described how GDCs can be integrated in Demand Response programs and how they can be used for providing ancillary services;
- ○ in Section 3, the characteristics of the test network and of the Pont Saint Martin DC are reported and the control system implemented for the secondary regulation is described;
- ○ in Section 4, simulations are performed for three different scenarios (no intervention of the DC, DC loads reduction, DC UPS activation), in order to evaluate the impact of the actions of the GDC during under-frequency transients due to a decrement of the power production by the renewable energy facilities of the micro-grid;
- ○ in Section 5, the results of the simulations are discussed and in Section 6, the conclusions of the work are presented.

2. Data Centres and ancillary services

Conventional power plants are fully efficient when their output is a constant amount of power and when they supply the "base load" to electrical grid's users; other power plants, known as peaking plants, change up and down their output to balance the supply with the demand. These plants are less efficient in the conversion of fuel to electricity.

To avoid the use of conventional power plants to cover peak load, cooperation Demand Response (DR) programs between DSO and prosumers could be used [25–27]. DR was conceived as a technique for balancing electricity supply and demand by regulating power consumption of users without impacting on conventional generation plants [28]. Facilities that can modulate their load and their production through energy storage and DR programs may help to increase production and distribution efficiency, cover peak demand, thus relieving the conventional power plants.

The use of DR programs is a crucial point and a key technology that allows the development of "smart electric grids" as shown in Fig. 1.

DR programs aim to increase grid efficiency, while incorporating significant amounts of clean renewable energy sources. They allow to implement a continuous collaboration between prosumers and grid operators in order to optimize power consumption during market-based pricing time [22] or to deal with power variations from not dispatchable RESs [8]. DR programs between DCs and smart grid allows to avoid greenhouse gas (GHG) emissions [29], congestion of the lines and wide recourse to conventional power plant [30]. It can also allow conventional energy producers to obtain cost savings and consequently energy consumers to buy energy at lower prices [30]. DCs are particularly suitable to adopt and benefit from continuous DR programs [31–33]. The power supply and state of IT equipment and cooling systems can indeed be continuously monitored and regulated [9,12]. DCs involved in DR programs can also provide ancillary services to the DSO [34,35] (Fig. 2) contributing, in this way, to a safer management of the power distribution grid [36–38].

The exchange of ancillary services between DC and DSO depends on:

- how quickly DC can change its own load or can activate/regulate its own backup equipment/generators;
- what is the cost for replacing the load or activating the generators;
- what kind of market conditions exploit these services.

The ancillary services that the GDC can offer are: Regulation Services, Thirty Minute Operative Reserve (TMOR), Ten Minute Spinning Reserve (TMSR), Ten Minute Non-Spinning Reserve (TMNSR) [39].

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