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# Intelligent droop control and power management of active generator for ancillary services under grid instability using fuzzy logic technology

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ABSTRACT

In this paper, a control and power supervisor for a flexible operation of a Renewable Distributed Generator (RDG) is introduced. This RDG consists of a combination of a wind system and a hybrid storage system made up of Batteries (BT) and Super-Capacitors (SC). RDG is associated with a load and a fluctuating grid to form an Active Generator (AG). According to the grid fluctuation, AG can operate in a grid-connected and standalone mode. The objective of this work is to investigate a novel control strategy for AG integrated into the grid in order to maintain its voltage and frequency in an allowable range and to ensure the continuity of the power supply in case of a grid fault. The structure of the proposed control strategy consists of a Fuzzy Logic Supervisor (FLS), an adaptive Fuzzy Logic Droop Control (FLDC) and a Fuzzy Logic Islanding Detection (FLID). FLS is developed to manage the power flows between the storage devices by choosing the optimal operating mode, thereby ensuring the grid stability and the continuous supply of the load by maintaining the state of charge of SC and BT at acceptable levels and to reduce stresses on BT and improve their life cycle. FLID is used to detect de standalone mode in case of grid failure. Finally, FLDC is used to control the active and reactive powers exchanged with the grid, ensuring its stability by maintaining its frequency and its voltage in optimal margins. The effectiveness of the proposed control method is validated by simulation results and compared with a generalized control technique.

## 1. Introduction

The significant increase in the population and areas of using electrical energy expected in the last few years must cope with the growing energy consumption associated with it. To do this, this evolution must result in intelligent management of an electrification network (Petronela et al., 2016). Therefore, the power grid is becoming more and more interconnected and meshed. One of the envisaged solutions concerns the reinforcement of the electricity supply network by the integration of innovative energy storage devices, new renewable and relocated production means, as well as an energy optimization of the grid architecture (Glasnovic & Margeta, 2011). The wind technology has become a favored form of renewable energy technologies because it is seen as clean and sustainable (Islam, Djamel, Abdel-Moumen, Bilal, & Ikram. El, 2018). The availability of wind energy depends on the climatic and geographical contexts of the installation region, which represents the major problem of wind turbines. Therefore, it is naturally very unlikely to have a concomitance between production and demand. In order to guarantee production, the aggregation of substation storage units will make it possible to overcome this problem. Hybrid Energy Storage Systems (HESSs) have become more and more important in Renewable Distributed Generators (RDGs) (Jia, Mu, & Qi, 2014). The wind technology application stresses the Batteries (BT) storage system, because it uses a large fraction of the energy stored in it (Matthieu, Arnaud, Karl, Moe, Marc, & Richard, 2017). The BT lifespan is limited by the charge/discharge cycle. Compared to BT, the Super-Capacitors (SC) storage system life is much longer and has much higher power density. Moreover, SC can provide a fast and effective energy output because of its high power density and high efficiency (Wang, Liu, Pan, & Chen, 2017). Thus, the adoption of SC in HESS is an effective solution to prolong the lifespan of BT in renewable energy production applications. The HESS technology can be passive, semi-active or purely active. Passive HESS is the simplest configuration, such as SC and BT directly connected to a DC bus without any power converter, and is characterized by its low cost. However, the performance of this configuration is limited because SC cannot be used effectively (Ziyou, Jun, Heath, Jianqiu, & Minggao, 2017). Semi-active HESS uses a single power converter. This topology combines good performance and low system cost (Ziyou et al., 2017). The purely active HESS configuration uses two DC/DC converters. It gives the possibility to control SC and BT currents simultaneously. Therefore, this configuration combines

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efficiency and good performance. For this reason, the purely active configuration is focused on in this study.

The key problem with HESS is its protection against over-discharge and overcharge, as well as the BT protection against the rapid fluctuation of charge/discharge cycles using SC. For this reason, the major task is to optimize the power flow management between BT and SC, which manages the reference current for each storage device. The most common of Energy Management Strategies (EMSs) are rule-based EMSs (Song et al., 2014). However, focusing on renewable energy, if RDG has to operate on different modes, rule development will become complex due to several variables and case studies. In this framework, fuzzy logic appears as a promising tool owing to the possibility of avoiding most of the mathematical stiffness and complexity in problem formulation and representing it based on human reasoning (Victor et al., 2016). EMS based on fuzzy logic is used in several applications, such as the energy management of HESS used in a tramway (Victor et al., 2016) and EMS for standalone RDGs (Erdinc & Uzunoglu, 2011). In this study, EMS based on a Fuzzy Logic Supervisor (FLS) is proposed to monitor RDG in standalone and grid-connected modes. The purpose of suggested FLS is to ensure a balance between production and consumption, to guarantee a continuous load supply by maintaining the State Of Charge (SOC) of SC ($U_{sc}$) and BT ($SOC_{bat}$) at acceptable levels, and to assist RDG to contribute to the improvement of electrical network performance.

On the other hand, the studied RDG is associated with a load to form an Active Generator (AG). AG can operate according to the grid stability in two main operation modes. First, the grid connection mode participates in system services by adjusting the frequency and amplitude of the grid voltage. Second, the standalone mode ensures a continuous power supply of the load in case of a grid fault. There is an intermediate mode to safety reconnecting AG to the utility grid. Thus, some research work has processed the regulation of the frequency and voltage in a connected or standalone mode. Table 1 show that the droop control method is commonly employed in RDG, which has more than one operation mode.

Consequently, this study is focused on a novel control technique based on EMS using FLS and adaptive FLDC, capable of monitoring AG in different operation modes and injecting active and reactive powers into the grid with high precision ensuring its stability.

This paper is structured as follows. Section 2 provides an overview of the wind hybrid generator configuration. Section 3 presents the modeling and control of RDG. Section 4 discusses the working principle of EMS based on FLS. Section 5 focuses on the FLDC technique. The simulation results and the discussion are given in Section 6. Section 7 concludes this report.

## 2. Active generator configuration

Before undertaking modeling, we need to define in more detail the architectures of the different parts that make up RDG, detailed in Fig. 1: a wind generator, SC, BT, and a DC bus link. RDG is associated with a balanced AC load to form AG. The latter can operate in a grid-connected mode or an islanded one, according to the stability status of the main power grid. In addition, we need to choose the most appropriate converter type to control each AG component, which will ensure the adaptation of this one to the continuous DC bus. The three-bladed wind generator absorbs mechanical power $P_m$, captured by wind speed $v$ passing through surface S covered by its blades. The turbine then generates torque $T_m$, which will drive at angular velocity $\omega_m$ the rotor of a rotating machine. This transforms the absorbed mechanical power into exploitable electrical power. We choose to use a Permanent Magnets Synchronous Generator (PMSG), able to operate at different speeds until it stops without stalling, which require little maintenance. To complete the power lack or excess, BT/SC HESS having two types of storage units is suggested. The role of this AG is double: maintaining the frequency and voltage of the main grid in the desired stability range and ensuring the continuous supply of the load in case of a grid failure. Indeed, a new control strategy based on FLS and FLDC will be applied to make the studied AG intelligent and able to meet the aforementioned objectives.

## 3. Renewable distributed generator model and control

### 3.1. Model of wind generator

The aerodynamic power produced by the turbine can be expressed by (Youssef, Saber, & Mohamed, 2017):

$$P_{aer} = 0.5\rho\pi R^2 v^3 C_p(\lambda,\beta) \tag{1}$$

where $R$ is the radius of the rotation of each blade, $\rho \approx 1,\ 2$ kg/m$^3$ denotes the air density, $v$ is the wind speed, and $C_p$ can then be represented as a polynomial function of $\lambda$ and $\beta$. In our case, this polynomial is defined by (Youssef et al., 2017):

$$C_p(\lambda,\beta) = 0.53\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 10\right)\exp\left(-\frac{18.4}{\lambda_i}\right) \tag{2}$$

$$\lambda_i = \frac{1}{\frac{1}{\lambda-0.02\beta} - \frac{0.003}{\beta^3+1}} \tag{3}$$

We deduce the expression of the generated aerodynamic torque as follows:

$$T_{aer} = \frac{P_{aer}}{\Omega_m} = \frac{0.5\rho\pi R^2 v^3 C_p(\lambda,\beta)}{\Omega_m} \tag{4}$$

This torque makes it possible to turn the rotor of PMSG, which is modeled in the park frame by the following expression (Masmoudi, Abdelkafi, & Krichen, 2011):

$$\begin{aligned} V_{sd} &= L_s\frac{di_{sd}}{dt} + R_s i_{sd} - p\Omega_m i_{sq} \\ V_{sq} &= L_s\frac{di_{sq}}{dt} + R_s i_{sq} + p\Omega_m i_{sd} + p\Omega_m \phi_m \\ T_{em} &= p\phi_m i_{sd} \end{aligned} \tag{5}$$

Fig. 2 illustrates a vector control of PMSG in the PARK frame. This strategy consists in keeping axis d constantly aligned with the flux vector of the magnet. The reference of direct current $i_d$ is kept at zero. The reference for quadratic current $i_q$ is determined by the electromagnetic torque deduced by the Maximum Power Point Tracking (MPPT) strategy as follows (Krim, Abbes, Krim, & Mimouni, 2017):

$$i^*_{sq} = \frac{T_{em-MPPT}}{p\phi_m}\ with\ T_{em-MPPT} = \frac{P_{MPPT}}{\Omega_m} = \frac{1}{2}\frac{\rho C_{p\max} R^5 \Omega^3{}_m}{\lambda_{opt}{}^3} \tag{6}$$

### 3.2. BT model and control

We choose for a main storage unit a BT bank, which must be connected to the DC bus through a bidirectional converter (DC/DC converter 3). We have retained the recent technology of the CIEMAT (Research Center for Energy, Environment and Technology, Espagne) BT model, which has very high energy density. An equivalent model for BT is depicted in Fig. 3. It is composed by voltage source $E_b$ in series with internal resistance $R_i$.

The expressions of BT quantities are expressed in the following (Cabrane, Ouassaid, & Maaroufi, 2017):

– The general expression of the BT voltage is as follows:

$$V_{bat} = n_b E_b + n_b R_i i_{bat} \tag{7}$$

– The expression of SOC is as follows:

$$SOC = 1 - \frac{Q_d}{C_{bat}} \tag{8}$$

Capacity $C_{bat}$ of BT is expressed as a function of charging and discharging current $i_{bat}$.

$$\frac{C_{bat}}{C_{10}} = \frac{1.67}{1 + 0.67\left(\frac{i_{bat}}{i_{10}}\right)^{0.9}}(1 + 0.005\Delta T) \tag{9}$$

where charge/discharge current $i_{10}$ corresponds to rated capacity $C_{10}$.

Fig. 5(a) represents the control of DC/DC converter 3 and the BT current: