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# Inertia response and frequency control techniques for renewable energy sources: A review

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ABSTRACT

Preservation of the environment has become the main motivation to integrate more renewable energy sources (RESs) in electrical networks. However, several technical issues are prevalent at high level RES penetration. The most important technical issue is the difficulty in achieving the frequency stability of these new systems, as they contain less generation units that provide reserve power. Moreover, new power systems have small inertia constant due to the decoupling of the RESs from the AC grid using power converters. Therefore, the RESs in normal operation cannot participate with other conventional generation sources in frequency regulation. This paper reviews several inertia and frequency control techniques proposed for variable speed wind turbines and solar PV generators. Generally, the inertia and frequency regulation techniques were divided into two main groups. The first group includes the deloading technique, which allow the RESs to keep a certain amount of reserve power, while the second group includes inertia emulation, fast power reserve, and droop techniques, which is used to release the RESs reserve power at under frequency events.

## 1. Introduction

Recently, air pollutants generated by fossil fuel power plants, such as carbon dioxide, nitrogen oxide, and Sulphur dioxide are causing serious environmental problems [1]. Acid rain and global warming are regarded as major causes of the environmental pollution [2,3]. In the United States, fossil fuel power plants emit about 2.2 billion tons of carbon dioxide ($CO_2$) annually [4]. These problems forced governments and other agencies around the world to set targets in increasing the application of RESs in the generation of electrical power [5]. China, for example, has set a target of generating over 15% of its total power from renewable energy by 2020 with 420 GW of hydro, 50 GW solar, 200 GW of wind, 30 GW of biomass. As shown in Fig. 1, several countries set different future prospective targets in increasing power generation from RESs. These plans are crucial in order to address the tremendous increase in world energy demand while simultaneously reducing the amount of pollutions.

Generally, integrated RESs in a power system decreases dependence on fossil fuel, improve voltage profile, and increase the reliability of power system [7–10]. However, the high penetration of RESs can lead to critical frequency stability challenges [11]. First, the RESs typically have low or non-existent inertial responses [12]. For example, the variable speed wind turbines are usually connected to the network by power electronic converter, which effectively decouple the wind turbine inertia from mitigating system transients. Furthermore, solar photovoltaic plants do not provide any inertia response to the power system. Therefore, replacing conventional sources with RESs will reduce the inertia of the whole power system. This fact is supported by [13,14] both of which predicted that the increasing number of RESs in the UK could reduce the inertia constant by up to 70% between 2013/14 and 2033/34. Due to this inertia reduction, the Rate of Change of Frequency (ROCOF) of the power system will be high enough to activate the load-shedding controller, even at a small magnitudes of imbalance. In [15], different penetration levels of RESs were used with a Synchronous Generator (SG) to cover 3.8 MW load demand. As reported in [15] and shown in Fig. 2, the ROCOF of the power system increase whenever the percentage-installed capacity of the RESs increases.

Second, an increase in the penetration level of the RESs decreases the number of generation units providing reserve power for primary and secondary control. For this reason, the frequency deviation will be increased, as reported in [16] and shown in Fig. 3.

To overcome the frequency stability challenges represented by small inertia response and reserve power, RESs must create new frequency control techniques to allow them to participate in frequency regulation operations. This paper presents a comprehensive review of inertia and frequency control techniques for solar PV and wind turbines. These techniques enable the RESs to increasingly stabilize the power system. This paper is organized in the following order. Section 2 will discuss the frequency response of conventional power

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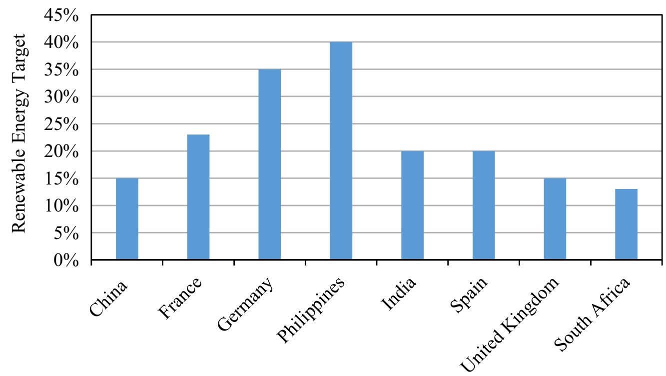


**Fig. 1.** Renewable energy targets by country for 2020 [5,6].

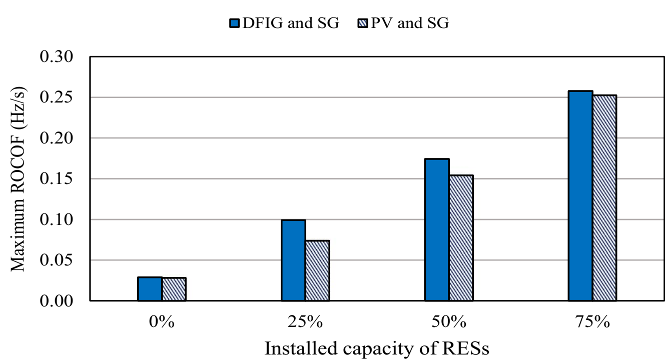


**Fig. 2.** Maximum ROCOF of the Microgrid for two types of RESs supply 3.8 MW load [15].

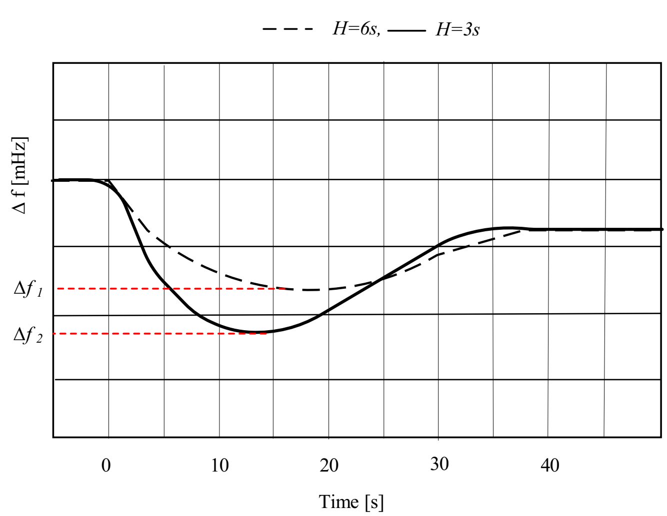


**Fig. 3.** Frequency deviation for two different inertia constants [16].

sources. Section 3 will present several inertia and frequency control techniques for RESs without ESS. Section 3.1 will present several inertia and frequency control techniques for RESs with ESS. Section 3.1.1 will explain the different soft computing approaches used with frequency regulation control. Section 3.1.1.1 will discuss the advantage and disadvantages of each control methods. The conclusions and future research will be presented in Section 3.1.1.2.

## 2. Frequency response of conventional power sources

The general frequency response with operation limits corresponding to England and Wales are shown in Fig. 4. During normal operations, the system frequency is close to 50 Hz. However, when an event occurs that causes generation-demand unbalance, the system

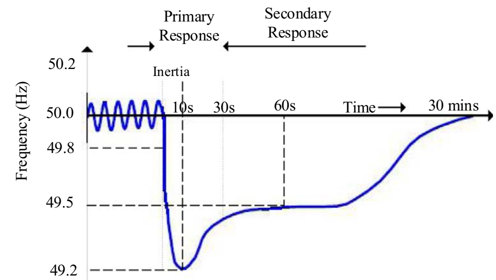


**Fig. 4.** Time frames involved in system frequency response [21].

frequency starts to decline with the frequency rates, depending on the total system inertia and the amount of unbalanced power, as given by the swing equation [17,18]:

$$\frac{df}{dt} = \frac{fo}{2H_{sys}S_B}(P_m - P_e) \tag{1}$$

where $df/dt$ is the rate of frequency change, $H_{sys}$ is the total system inertia constant, $S_B$ is the rating power of the generator, $P_m$, $P_e$ are the mechanical power and electrical power, respectively, and $f_o$ is the system frequency. Prior to any controller activation and due to inertia response, the synchronous generator releases the kinetic energy stored in its rotating mass, which lasts for ~10 s [18,19]. After that, if the frequency deviation surpasses a specific value, the primary frequency controller will be immediately activated. This controller use the generator governor to return the frequency to save values within 30 s [19,20]. After 30 s, a new control called the secondary control will be activated to return the system frequency to its nominal value.

As shown in Fig. 4, the secondary controller needs several minutes to recover the system frequency to its nominal value. Therefore, a reserve power should be available to cover the increase in power demands during this period. Finally, the remaining power deviation activates the tertiary frequency control. Differing from primary and secondary controllers, tertiary controller requires manual adjusting in the dispatching of generators or changes of the schedule periods. This paper does not deal with this type of controller [22]. Generally, Inertia and frequency control techniques for RESs is commonly divided into two main categories; control techniques for RESs without any support from ESS and control techniques for RESs with ESS. Fig. 5 illustrates the different techniques that fall under each category:

## 3. Control techniques designed for RESs without energy storage systems

In order to minimize the negative impact of high RESs penetration, different inertia and frequency control techniques for RESs with and without ESS can be considered. These techniques enable RESs, such as wind turbine and solar PV plants, to contribute to the frequency regulation.

### 3.1. Wind turbine

Wind energy is one of the most applied renewable sources throughout the world. Many countries that have wind energy potential started replacing conventional power plants with wind energy plants. Statistics show that future wind penetration in the U.S. and Europe will exceed 20% within the next two decades [23].

There are two main categories of wind turbine; fixed speed and variable speed [24]. A fixed speed wind turbine generally uses an induction generator that is connected directly to the grid and can provide an inertial response to the frequency deviation, even though this inertia is small compare to the synchronous generator. A variable speed wind turbine mainly uses a Permanent Magnet Synchronous Generator (PMSG), or DFIG. The PMSG is fully decoupled from the