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Flicker mitigation by reactive power control in wind farm with doubly fed induction generators

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ABSTRACT

This paper presents a novel wind farm control with the purpose to mitigate the flicker emission of doubly fed induction generators. The presented control strategy is implemented in a wind farm connected to a distribution grid with consumers. The control system is composed by two controllers in cascade, the wind farm control and the local wind turbine controller. The wind farm control adapts itself to the consumptions of the distribution network and generates the minimal reactive power which allows smoothing the fast variations of wind power output. In this sense, the wind farm control facilitates the integration of wind farm into weak power grids by exchanging reactive power with network. Moreover, the wind farm controller has to be stable, fast and robust and the wind farm dispatch function has to guarantees that the local wind turbine controller can exchange the reactive power set point with network. This controller has been developed with the simulation tool DigSilent PowerFactory v14.1.

1. Introduction

In recent years wind sector increased its share rapidly, in particular in European Union the wind power generation represented in 2011 10.5% of the power generation mix, while in 2000 this share was at 2.2% [1]. Furthermore, the penetration of distribution generation resources, like wind turbines, photovoltaic, etc., in distribution grids is increasing worldwide.

The stochastic nature of wind, electric power generated by wind turbines is intermittent and may affect both the power quality and the planning of power systems [2]. Regulatory legislation about the integration of distribution generation requires often the realization of specific grid integration studies. For power quality issues distributors may adopt the European EN standard 50160 [3].

An important power quality indicator is the voltage variations which produce the flicker phenomena. Flicker is defined as a subjective sensation of visual instability caused by the fluctuation of a light stimulus [4]. Flicker is induced by voltage fluctuations, which are caused by power flow changes in the grid [2]. The grid operator limits the amplitude of these fluctuations to ensure power quality.

The flicker emission in wind farms is produced when the wind turbine start-up and also during normal operation. During normal operation it is mainly caused by variations in the generated power due to wind speed variations, the wind gradient and the tower shadow effect [5]. Flicker can become a limiting factor for integrating wind turbines into distribution grids. Factors like network characteristics also affect flicker emission of wind turbines during continuous operation [6–8].

There are two ways to mitigate these voltage fluctuations caused by the wind turbines: firstly acting on the variations of the active power output of the wind turbines or using energy storage systems, and secondly, by voltage control exchanging reactive power with grid. The most suitable energy storage systems for mitigation of voltage fluctuations are flywheels, super-caps and batteries [2] due to their high ramp rates and short time responses for regulating active power. In fact, flywheels and super-caps can respond in milliseconds. The fast regulation of reactive power can be performed through the use of electronic power converters. In this sense, the grid side power converters of variable speed wind turbines can be used for this purpose, as well as additional equipment within the wind farm like Flexible AC Transmission Systems (FACTS) [9,10].

This paper focuses on the mitigation of flicker emission by a wind farm comprised by variable speed wind turbines. The main contribution of the paper is the design of a novel wind farm control system for flicker mitigation, which is carried out through the smoothing of the voltage profile at the Point of Common Coupling

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(PCC) of the wind farm. The smoothing of the voltage is through the fast regulation of reactive power exchanged with the network by the grid side power converters of the variable speed wind turbines, as proposed in [11].

The control system comprises two controllers in cascade (wind farm control and wind turbine control). The wind farm control sets out the reactive power set points for the local controllers of the turbines. As a difference with [6,11], an aggregated model of the wind farm is not considered, but it comprises the model of each wind turbine. Moreover, each wind turbine is exposed to a different wind speed level and it could receive different reactive power set points depending on its loading.

This paper is organized as follows: In Section 2, a review of network voltage variations and flicker emission is introduced; in Section 3, mitigation methods for these disturbances are presented; Section 4 focus on the description of the proposed wind farm control; Sections 5 and 6 show the study case and the simulation results; Finally, Section 7 summarizes the main conclusions of the work.

2. Voltage variations and flicker disturbances

The voltage variations are recognized today as relevant and standards have been issued to limit them, such as the European Standard EN 50160 [3]. This standard imposes statistical limits in the sense that a time limited deviation of exceeding them is acceptable.

The voltage variations can be divided into slow and fast voltage variations [3,8]. The slow voltage variations are considered within the time range of several second up to several minutes. The fast voltage variations, also known as voltage fluctuations, are registered in the range of milliseconds up to seconds.

The variability of the power output of the wind turbines provokes voltage variations at their connection point or PCC. The voltage variations are directly related to the typology of the wind turbine, i.e. the electric machine and the implemented control technics. In addition, these variations are also directly related to the nature of wind, such as mean wind speed, turbulences, interruptions and changes of direction of wind. Finally, these voltage variations are also affected by the grid characteristics, such as short circuit capacity ratio, resistivity of lines and the voltage level [5–7,12].

On the other hand flicker is a subjective sensation of visual instability caused by the fluctuation of a light stimulus [4]. Fast voltages variations may cause annoying luminance changes in lamps. In particular, the voltage fluctuations in the frequency spectrum from 0.05 Hz to 35 Hz are intended as flicker [7]. It is worth noting that this phenomenon is a discomfort for people and the discomfort is strongest when the frequency is at 8.8 Hz [7].

The quantification of flicker is complex as both physiological and physiological factors intervene simultaneously. The International Electrotechnical Commission (IEC) has standardized the quantification of flicker by proposing the so-called flickermeter. Flickermeter is described in standard IEC 61000-4-15 [13]. The flickermeter provides two terms of flicker indices: the short-term flicker severity P_{st}, and long-term flicker severity P_{it}. The short-term index needs the measurement of RMS voltage during 10 min while the long-term index uses the RMS voltage during 2 h [14]. Finally, the standard IEC 61000-3-7 [15] sets specific short-term and long-term flicker severities at the point of connection of a wind farm. These are 0.35 for the short-term index and 0.25 for the long-term index.

3. Voltage and flicker disturbance mitigation

When the flicker emissions are higher than the established limits, is necessary to apply strategies for mitigation. From literature Table 1 depicts some strategies for reducing the flicker emission of wind farms, highlighting the main the advantages and disadvantages of each one.

As it can be noted in Table 1, the strategies which do not act actively in reducing the magnitude of the voltage variations are the first two. These allow reducing the magnitude of voltage variations; however they are expensive and can generate environmental impact.

In particular, the first strategy (strengthen the grid and increase the voltage level), consists in building new power lines to increase the short-circuit capacity ratio and grid impedance ratio. According to [16], the flicker constitutes a power quality problem when the short-circuit capacity ratio at the PCC of the wind farm is below 10 and also considering a grid impedance ratio is below 2 (this ratio is an indication of the resistive nature of the grid and the distribution feeder strength). Furthermore, it is possible to reduce the flicker levels by also increasing the voltage level of the distribution lines above 35 kV [16].

The output power to the grid by large wind farms becomes smoothed due to the inertia of the wind turbines. Thus large wind turbines with high inertia favors reduced levels of flicker emission [8].

The strategies which act actively in reducing the magnitude of the voltage variations results to be more effective because they act actively on the disturbance. There are some strategies based on using storage devices for smoothing the net active power injected to the grid, but there are also some strategies based on exchanging reactive power with the grid.

The strategies related with energy storage use the energy in the DC link of back-to-back power converter of variable speed wind turbines [17,18] or include short-term storage devices in the wind farm [2]. The power injected or absorbed by these short-term storage devices smoothes the net power injected to the grid by the wind farm. The main advantage of these strategies is that they act on the origin of the disturbance, i.e. they affect the variability

Table 1
Summary of strategies for flicker emission mitigation.

Strategy	Advantage	Disadvantage
Strengthen the grid and increase the voltage level [5,8,16]	Low losses	High cost and environmental impact
Increase the inertia of the wind turbines [8]	Smoothing of the power generated	High cost
Energy storage in the DC link of back-to-back power converter of variable speed wind turbines [17,18]	Low cost	Low energy capacity
Short-term storage devices in the wind farm [2,19]	Fast response and active power regulation capability	The need of investments in additional equipment
Compensate voltage fluctuation by reactive power using FACTS devices [6,10,11,20–22]	Fast response and reactive power regulation capability	The need of investments in additional equipment
Compensate voltage fluctuation by reactive power using wind turbine [9]	Fast response and no need of additional equipment	Possible oversizing of the grid side power converter of wind turbines