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Sub-synchronous resonance in series compensated wind farm: A review

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ABSTRACT

Mitigating and minimizing the impact of the sub-synchronous resonance-related phenomena in wind power plants has become the focus of power system research. This paper is a review of these phenomena, such as SSR, SSCI and SSTI, in various types of wind power plants. The analysis and mitigation techniques are also presented. This review will help researchers in dealing with sub-synchronous resonance related issues in wind power plants.

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1. Introduction

Electricity produced from the combustion of fossil fuels produces CO_2 emissions that contribute to the greenhouse effect [1]. The energy dependence that certain countries have on fossil fuels generally also have an adverse effect on their economy [2,3]. Therefore, the use of renewable energy sources becomes necessary to address the adverse effects of fossil fuel combustion.

Global electricity production from renewable sources increased from 5.7% to 6.5% in the year from 2011 to 2012. The rising use of renewable sources has globally reduced approximately 900 megatonnes of CO_2 production and emission [4]. Renewable sources are low-carbon technologies. These renewable sources also offer countries around the world the chance to improve their energy security and spur economic development [5,6]. Hence, investing in these technologies is a smart option [7]. According to the World Energy Commission, the use of one million kW h of wind power can reduce up to 600 tonnes of emitted CO_2 [8]. Among all renewable energy sources, wind power offers the lowest greenhouse gas emissions [8–10].

The generation of wind power has developed notably quickly in the past decades [11,12]. Wind power has continued to be the leading source of renewable energy. The decline in equipment costs for the wind turbine, as well as the improvements in the performance of the technology, has been attractive to the investor [13]. At the end of 2014, the worldwide installations for wind power capacity reached 369,553 MW [14]. According to the World Wind Energy Association (WWEA) [15], the forecasted cumulative worldwide installations for wind power by 2020 is more than 1000 GW [16–18]. The Indian market forecast [19] has predicted that the global wind installed capacity may reach 1071.41 GW by 2020. Wind power is the most rapidly growing technology for renewable power generation. It has also been predicted that 12% of the worldwide total energy demand will come from wind power by the end of 2020. Currently, wind power shares 1.6% of the world's electricity generation. Forecasts indicate that by 2019, the share will be up to 8.4%. Because the installed capacity of the wind farms is growing rapidly, it is necessary to be able to transmit the generated power to the grid through transmission networks.

To accommodate the increased production by wind power, two options exist, where either new transmission lines need to be installed or the existing lines need to be enhanced for power transfer capabilities. The installation of new transmission lines is not an economical option. Series compensation is the effective means of enhancing the transfer capability of the transmission line. Series compensation is, therefore, the effective way of integrating large wind generation plants into the grid. Series compensation is the addition of capacitor banks in series with a transmission line. Series compensation also improves the stability and voltage controllability of the network.

As the installed capacity of wind power plants (WPP) is rapidly growing, large wind turbine generators are being integrated into electric power grids. The generated power needs to be transmitted through a transmission system that can tolerate large power flows. For an existing transmission network, the series compensation is known as an effective means of increasing the total available transfer capability [20–22]. In electrical networks, the series capacitor compensation can cause a significantly adverse effect called the sub-synchronous resonance (SSR) in which electrical energy is increasingly exchanged with the generator shaft system. This effect may result in damages to the turbine–generator shaft system [23]. In series compensated networks, SSR could be a potential point of origin for the failure of the turbine–generator shaft and the subsequent instability of the power system [20,24–27].

The first paper on the possibility of an adverse interaction between series compensation and turbine generators appeared in 1937 [28]. This interaction did not attract the interest of researchers until the 1970s, when an actual SSR event occurred. The adverse effect of the SSR phenomenon occurred for the first time in 1970 at the Mohave Generating Station (a coal-fired power plant), which is located in southern Nevada. After the incident, two shafts of the turbine–generator were found to be critically damaged. A hole was burned into the shaft due to insulation failure and subsequent arcing. The second failure occurred a few months later because the root cause analysis of the first failure was reported incorrectly. Due to the repeated incidents of shaft failure at the Mohave Generating Station, this issue was taken seriously. The root cause of this incident was found to be the sub-synchronous interaction between the turbine–generator and the series capacitor. The first paper on “Sub-synchronous resonance in series compensated Transmission Lines” was presented in 1973 [29].

SSR and its mitigation techniques for conventional turbine–generator system are well documented, however enough literature is not available on SSR phenomenon in the context of series compensated wind farm systems. Wind farm interaction with series compensated transmission line was discussed for the first time in [30]. This phenomenon may be of concern in wind power plant due to important differences exist with respect to conventional turbine–generators like, small to medium capacity plants, more (even more than 100) units, generator ratings are kW to few MW range, different types of generator such as synchronous or asynchronous (induction generators either squirrel cage, wound rotor or doubly fed and permanent magnet etc.), tower structure, generator operation at lesser speed, variable speed wind turbines (due to variable wind speed), less generator output voltage, requirement of collector cables from wind turbine to collector points, (length is in km and varied according to location of wind turbine), and very low torsional frequencies, (usually in the range