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Comprehensive overview of grid interfaced wind energy generation systems

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ABSTRACT

Wind energy is becoming more important in recent years due to its contribution to the independence of power generation industry from traditional fossil energy resources and availability of continuous harvest-able potential on earth approximately around 10^6 MW. This paper presents a comprehensive overview of grid interfaced wind power generation systems. This is intended to provide a wide spectrum on the status of wind profile, wind potential estimation, configuration/design of wind energy conversion systems, wind generators, power converter topologies used for grid integration of wind power, energy storage systems for wind power applications, power smoothing methods, HVDC links used for wind integration, international grid codes and maximum power point tracking methods to the researchers, designers, manufacturers, and engineers working on the grid interfaced wind power generation. More than 200 research publications on the topic of grid interfaced wind power generation systems have been critically examined, classified and listed for quick reference. This review is ready-reckoner of essential topics for grid integration of wind energy and available technologies in this field.

Contents

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1. Introduction

Recently wind power generation has been noted as the most growing technology with developments in megawatts capacity wind turbines, power electronics, and large power generators [1]. Wind power can reduce power losses, improve voltage profile, defer or eliminate system upgrades, reduce on-peak operating costs, and mitigate environmental pollution [2]. Wind energy conversion systems (WECS) have become widely used renewable energy (RE) sources in many countries for generating green, clean and sustainable electrical power due to their low cost and high efficiency. Currently the cumulative global installation of WECSs has exceeded 280 GW [3] and by the end of 2020, the installed capacity is expected to be around 1900 GW [4]. Development of power electronic converters and high performance controllers make it possible to integrate large wind power generation to the utility grid [5]. However, the intermittent and uncertain nature of wind power prevents the wind power plants to be controlled in the same way as conventional bulk units [6].

The knowledge of actual time-varying availability of wind speed is essential for accurately determining electricity generation in grid connected wind power plants [7]. High voltage direct current transmission (HVDC) has become a realistic approach for grid integration of wind farms because it has no stability limits [8]. The IEEE standard 1549 defines the basic requirements for integrating distributed generation units including wind power to the utility grids [9]. The modelling of wind turbines and generators plays an important role to achieve stability of power network [10]. Energy storage systems (EES) could absorb electricity when supply exceeds the demand and this surplus energy can be released when electricity demand exceeds the supply. This also helps in the power smoothing, enhancement in stability and power quality improvement [11]. Power electronic converters and custom power devices has emerged as effective tools for grid integration of wind addressing the system stability and improved power quality [12]. The use of multilevel converters has increased significantly in wind power applications owing to their advantages in high-power and high-voltage applications [13]. Further research is needed in the field of estimation of available wind profile, development of power electronic converters and their controllers, development of grid codes, development of high efficiency of wind generators, energy storage technologies for grid level applications, development of maximum power point tracking methods, and power smoothing methods for integration of large wind power plants to the utility grid without affecting the stability and reliability of power.

This paper aims at presenting a comprehensive overview on the topic of grid interfaced wind power systems. Over 200 research publications [1–239] are critically reviewed and classified into nine categories. The first category [1–13] is based on general concepts of wind energy and their grid integration. The second category [14–25] includes the concepts of wind profile and wind potential estimation. The third category [26–44] comprises of wind energy conversion system. The fourth category [45–125] includes the different generators used for wind applications and their power electronic converters. The fifth category [126–180] is on energy storage systems used for grid connected wind power applications. The sixth category [181–189] comprises of power smoothing methods. The seventh category [190–209] describes the HVDC systems used for grid integration of wind power plants. The eighth category [210–231] demonstrates the international grid codes for grid integration of wind energy. The ninth and final category [232–239] is on the maximum power point tracking methods for grid connected wind power plants.

This paper is divided into eleven sections. Starting with an introduction in Section 1, Section 2 covers wind profile and Section 3 describes wind energy conversion system. Detailed analysis of generators used for wind power applications and their power electronic converters are presented in Section 4. The energy storage systems and power smoothing methods for wind power applications are covered under Sections 5 and 6 respectively. HVDC links used for grid integration of wind power generation system are described in Section 7. International grid codes for integration of wind power and maximum power point tracking methods are presented in Sections 8 and 9 respectively. The future scope for research in the field of grid-interfaced wind power generation is presented in Section 10. Finally, the conclusions are drawn in Section 11.

2. Wind profile

An accurate quantification and characterisation of the available wind profile are necessary for optimal design of a wind farm. The topological and meteorological factors influence the wind characteristics across any site which in turn affects the dynamic loading of wind turbine and wind farm output [14]. The basic wind profile is generally taken at 10 m above the ground level and can