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Potential challenges of integrating large-scale wind energy into the power grid–A review

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ABSTRACT

Global warming is attracting a growing interest worldwide for the generation of large-scale energy from renewable energy sources as it is free from greenhouse gas emissions. Wind energy is one of the most promising renewable energy sources due to its availability and low cost and due to the fact that it is more efficient and advanced in technology. Hence, harvesting of large-scale wind energy is of prime interest today. However, large-scale integration of wind energy sources creates environmental, economic, social and technical impacts that need to be investigated and mitigated as part of developing a sustainable power system for the future. Government, utilities and research communities are working together to increase penetration of wind energy into the power grid and overcome potential barriers associated with this. This paper presents an extensive and useful survey on wind energy technology and associated implementation issues including effects of wind farms on the nearby locality. This paper also reviews the social, environmental and cost-economic impacts of installing large-scale wind energy plants. Finally, potential technical challenges to the integration of large-scale wind energy into the power grid are reviewed in regard to current research with their available mitigation techniques.

Contents

1. Introduction

Current power systems create environmental impacts and are a leading cause of current greenhouse gas (GHG) or global warming effects due to burning of fossil fuels, especially coal, as

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carbon dioxide is emitted into the atmosphere [1,2]. According to the report of the International Energy Agency (IEA), the world's total net electricity consumption as well as electricity generation is increasing day by day. The world electricity generation was 14,781 billion kWh in 2003 and is projected to be 21,699 and 30,116 billion kWh in 2015 and 2030 respectively, an average increase rate of 2.7% annually [3,6]. GHG emissions from electricity generation are approximately 40% of total emissions as most of that industry uses fossil fuels, particularly coal and oil, hence are a leading contributor to global energy-related CO_2 emissions [3]. Australia's abundance of coal imposes environmental costs in the form of GHGs, including 200 million tons of carbon dioxide equivalents (CO_2-e) released from the energy sector in 2008, more than a third of Australia's total CO_2-e emissions [4]. The CO_2 emissions around the world are given in Fig. 1 [5].

A recent burning issue is to achieve environment-friendly, economical and sustainable power transmission and distribution systems that are intelligent, reliable and green. Therefore, policy makers, power system planners, researchers, and power utilities are working together worldwide to reduce GHG emissions and hence, in 1997, a treaty was formulated called the Kyoto Protocol [6]. The objective of the Kyoto Protocol is to reduce GHG emissions into the atmosphere to a level that would prevent dangerous anthropogenic interference with the climate system [6]. Renewable energy (RE), in particular wind energy is the most promising of the RE sources which are free from GHG emissions, and it has potential to meet the energy demand due to its availability which encourages interest worldwide. It is one of the fastest growing and cost-effective resources among the different RE sources that have begun to be used worldwide for sustainable climate-friendly power systems [7,8]. Over recent years there have been dramatic improvements in wind energy technologies, and wind is increasingly becoming an important energy source. Wind energy can be exploited in many parts of the world, but the determination of wind energy potential depends on the meteorological dimensions of the wind direction, velocity and solar irradiation [9].

Winds are caused due to the absorption of solar energy on the earth's surface and in the atmosphere, and the rotation of the earth about its axis and its motion around the Sun. A windmill converts the kinetic energy of moving air into mechanical energy that can be either used directly to run a machine or to run a generator to produce electricity [10,11]. Wind energy plays an active role in developing a climate-friendly environment and makes the world more livable for humans as well as for all living creatures. Both large-scale and small-scale energy can be produced from wind turbines for utilities, industries, home owners and remote villages [12].

Since the beginning of the development of the wind power industry in the 1980 s, the rated capacity of wind turbines has increased from some tens of kW to today's MW turbines. At the same time, the trend has moved from installations including a single or a few wind turbines to planning of large wind farms ranging from some tens of megawatts to over 100 MW. At the beginning, wind energy was introduced and its use expanded in some European countries including Germany, Denmark and Spain. However, its energy-efficiency, clean, pollution free and cost-effective attributes drew the attention of politicians, industrialists and individuals, and hence wind energy generation has been greatly encouraged worldwide [9].

Wind energy is the fastest emerging energy technology, and total cumulative installed capacity of wind energy in the world by 2000 was 17,400 MW, while in 2011 the cumulative installed capacity is 237,669 MW as shown in Fig. 2. Annual installed wind capacity in 2000 was only 3,760 MW; with rapid growth, annual installed capacity in 2011 was 40,564 MW. In 2010, the rate of increase of wind energy generation globally was 24.1%, though there had been a slight decrease in the growth rate than earlier due to the worldwide financial crisis [13]. By the end of 2011, 26.7% of worldwide wind energy capacity was installed in China, 19.7% in the USA, 12.2% in Germany, 9.3% in Spain and 6.8% in India. Worldwide wind energy installed capacities from these five countries totaled 74%, and the remaining 26% was installed throughout the rest of the world including Europe, Asia, North and South America and Australia. The rise in the Chinese wind sector has constantly outperformed other countries, and in 2011 they added 18 GW of new wind power, which was half of the total wind power installed worldwide in 2011 [13]. According to the

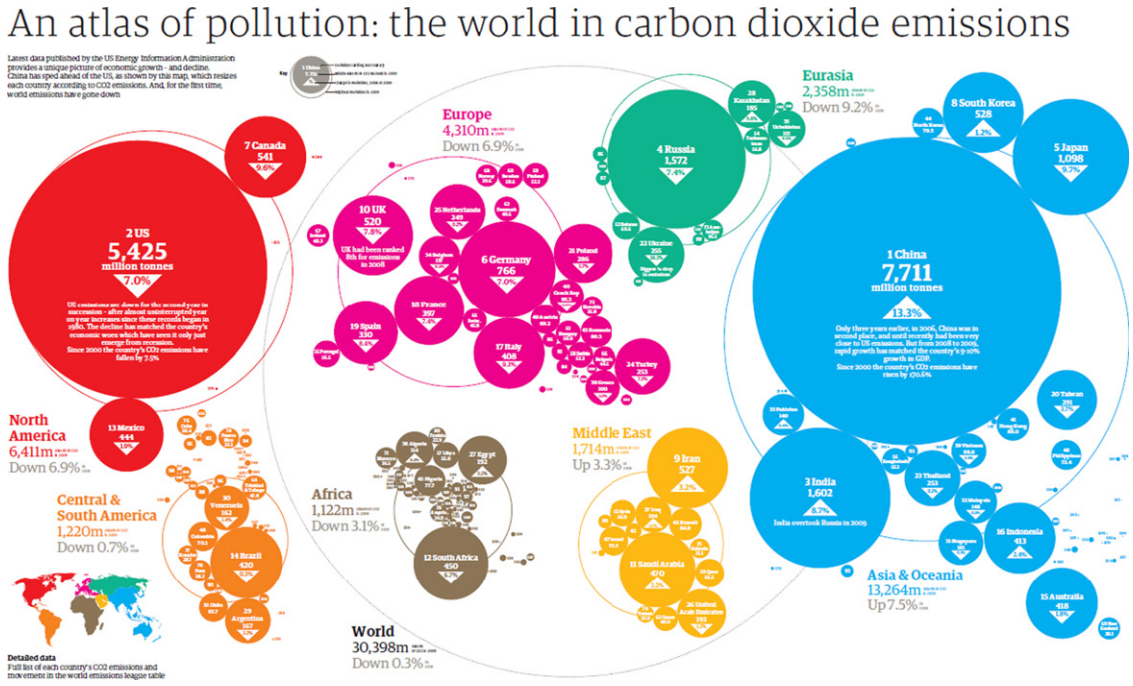

Fig. 1. Carbon dioxide emissions around the world [5].