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Power-quality issues and the need for reactive-power compensation in the grid integration of wind power

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ABSTRACT

The integration of wind power into national grids introduces a unique set of challenges. The wind-turbine generators are incapable of supplying the voltage and frequency control and they absorb significant amounts of reactive power particularly when there is a fault in the system. The utilities, the world over, are making their own Grid Codes which must deal with these new challenges being imposed by the integration of wind power with their respective grids.

This article addresses the technical issues which arise whenever the wind power is to be integrated into a national grid. These issues in general, and the power quality and the need for reactive-power compensation in particular are explored in the context of a realistic case study for a proposed 50 MW wind farm' integration to the Pakistan's national grid. The test systems are modelled in MATLAB/Simulink for this study. The article also highlights the role of static synchronous compensator (STATCOM) as a smooth reactive-power provider in improving the power quality of this wind-integrated power system.

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Abbreviations: STATCOM, Static Synchronous Compensator; LVRT, Low Voltage Ride Through; AEDB, (Pakistan's) Alternative Energy Development Board; WTG, Wind Turbine Generator; VAR, Volt Ampere Reactive; FACTS, Flexible AC Transmission System; NEPRA, (Pakistan's) National Electric Power Regulatory Authority; HESCO, (Pakistan's) Hyderabad Electric Supply Company; DFIG, Doubly Fed Induction Generator; PCC, Point of Common Coupling; IEC, International Electro-technical Commission; THD, Total Harmonic Distortion; AC, Alternating Current; DC, Direct Current; IGBT, Insulated Gate Bipolar Transistor; VSC, Voltage Source Converter; MSC, Mechanically Switched Capacitor; SCR, Silicon Controlled Rectifier; GTO, Gate Turn Off; XLPE, Cross-Linked Polyethylene; MV, Medium Voltage; HV, High Voltage; LV, Low Voltage; NGR, Neutral Grounding Resistor

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1. Introduction

Electrical energy is the most widely used form of energy worldwide. The world is currently experiencing severe energy shortages as the fossil-fuel deposits are decreasing at an alarming rate. The increased awareness about environmental hazards, caused by the burning of fuels, is also forcing the governments towards exploiting the renewable-energy resources. Wind is an important energy resource, abundantly available, and also the lower cost per MW as compared to most other renewable-energy resources. The world's production of electrical power from the wind has been increasing at a fast rate during the last two decades and the wind power is believed to be very promising resource in the near future. According to a report the worldwide wind power capacity reached 296,255 MW by the end of June 2013, out of which 13,980 MW were added in the first six months of 2013 [1].

The rapidly increasing population and industrial growth have resulted in a significant increase in the electric-power consumption during the last decade in Pakistan which is now facing acute shortages of electric power. In a hot summer season the unmet demand is around 7000 MW [2] which is about 1/3rd of the maximum load demand. Thus, it is imperative for Pakistan to exploit all available resources of electric-power generation.

Nature has gifted Pakistan with a huge potential of wind power in the southern parts of its Sindh province. The Gharo-Keti Bandar wind corridor possesses an exploitable potential of 60,000 MW [3]. In the last decade the Government of Pakistan set up a board - Alternative Energy Development Board (AEDB) - and mandated it to promote renewable energy in the country. The Jimpir Wind Power Plant, with a total capacity of 56.4 MW, is the first wind-power project developed in Pakistan by a Turkish firm - Zorlu Enerji - at a total cost of 143 Million US dollars [4]. The first phase of the project commenced with a generation of 6 MW – 5 machines, each having a capacity of 1.2 MW – in April 2009. The second phase of the project, to generate 50.4 MW, was completed in March 2013. The Turkish firm is selling energy to the Pakistan's national grid at a rate of 12.11 US cents per kWh, which should be extremely attractive to the foreign investors. Currently there are 45 different wind power projects being undertaken, in the Gharo-Keti Bandar corridor, of around 3200 MW capacity. For this purpose, the AEDB has allocated vast land for wind farms in the Sindh province (in three main clusters of Jhimpir, Khuttikun - Gharo - and Bhanbore) [3].

In the earlier days, the wind farms were of smaller size and utilized conventional squirrel-cage induction generators. Because of the variable nature of wind speeds these generators operated under a limited range of wind speeds. These generators used to have fixed capacitors as source of reactive power. When a fault occurred on an electrical power system, near the point of common coupling, to which a wind farm would be connected the fixed capacitor would not be able to provide a dynamically-changing reactive power and as a result low-voltage developed at the terminals of the generators would often switch off the wind generators. As the size of wind generators grew and the density of wind power into grids increased the vulnerability of the grids were anticipated and the need arose to regulate the integration of wind farms into the grids [5,6]. The power transmission networks regulators, in different countries, now establish their own Grid Codes which set out principles and procedures for a new connection to their bulk transmission systems [7]. The grid integration of wind farms poses stability, control and power quality issues as the wind turbine generators (WTGs) are of asynchronous type with their characteristics different from those of typical synchronous generators [8]. In order to be integrated into a power grid, which is dominated by conventional generators of synchronous type, wind farms are required to meet the same Grid Codes' requirements. However, asynchronous generators, that is, induction generators do not provide ancillary services to the grid such as voltage and frequency control, VAR generation and low-voltage ride through (LVRT) capability [9]. Ideally, the wind farms need to be connected to strong grids so that they do not affect the power quality in a detrimental way. The situation becomes more stringent when grid-connection point of a wind farm is weak in terms of its fault level or the short-circuit strength. It has been shown in Ref. [10] that a weak system, having a short-circuit ratio of 1.5, would not be stable for a small disturbance; thus not possessing small signal stability. Therefore, it is essential to perform a detailed technical analysis to determine whether a proposed wind farm will not adversely affect the grid at the point of common coupling.

For the successful grid integration of wind farms, different techniques are adopted based on specific requirements. These techniques generally make use of reactive-power compensation through FACTS devices. This article is aimed at evaluating the effectiveness of these techniques for the proposed wind farms in Pakistan to fulfill the Grid Codes requirements set out by the Pakistan's National Electric Power Regularity Authority (NEPRA). The work consists of preparing test systems for a typical 50 MW wind farm in MATLAB/Simulink. A realistic Pakistani power system is modelled using the actual parameters supplied by Hyderabad Electric Supply Company (HESCO), the local electric utility, and the integration of this wind farm is analyzed at two proposed locations. These test systems are subjected to different normal and abnormal operating conditions in order to determine the power-quality performance. The main objective of this study is to investigate the impact of a proposed 50 MW wind farm on the external grid' (of Pakistan) power quality. The article also analyses the effect of STATCOM, an important FACTS device, on this integration. The role of STATCOM is explored in the context of the power-quality issues: the article effectively addresses these issues, which arise when the wind power is to be integrated to a power system, in the form of a realistic case study.

Section 2 of the article gives an overview of the requirements for the integration of a wind farm with the national grid of Pakistan as set by NEPRA's Grid Codes. Section 3 gives a brief account of a doubly-fed induction generator (DFIG), the most commonly used machine in the wind-power generation and also used in this study. Then the requirement for reactive-power compensation in the operation of a wind farm, and the basics of