Issues with the delivery of power quality in wind farms

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CERTIFICATE OF ORIGINAL AUTHORSHIP

This thesis is the result of a research candidature conducted jointly with another University as part of a collaborative Doctoral degree. I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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This research is not entirely a mathematical theory or study. This research is based on actual constructed equipment and components used in wind farms. I have endeavoured to include lessons learnt from several years of construction in wind farms; all the hard work of engineers in this research therefore many people have contributed in this study so I want to thank many people who in some way contributed to the progress and research of the work contained herein.

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Table of Contents

Abbreviation

Abbreviation	Description
AC	Alternating Current
AEMO	Australian Energy Market Operator
ASIG	Asynchronous induction generators
CDEGS	Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis
CIT	Current Injection Test
DC	Direct Current
DFIG	Doubly Fed Induction Generator
EPR	Earth Potential Rise
GMR	Geometric Mean Radius
HIFREQ	CDEGS software module for electromagnetic field analysis
HV	High Voltage
LFI	Low Frequency Induction
LPS	Lightning Protection System
LV	Low Voltage
MV	Medium Voltage
NER	Australian Nation Electricity Rules
NSP	Network Service Provider
PCC	Point of Common Coupling
RSM	Rolling Sphere Method
SS	Substation
STTM	Short Term Trading Market
ZEST	Zigzag Switchgear Earth Transformer

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Abstract

Wind farms are designed to harvest wind kinetic energy; however, their generated power is dependent on their wind streams, and therefore their operation can impact system stability. Unlike conventional steams (gas or hydro power stations), wind farms normally require vast areas and MV distribution networks to collect generated power from each wind turbine and transfer it to a point of common coupling. Scattered wind turbines with variable generated power and long cable runs or aerial lines can create some power quality issues such as flicker, transients, voltage sags, frequency fluctuation, power factor and voltage fluctuations. Most wind turbines have large power electronic converters to complete the power conversion. Power electronic converters can create harmonics and commutation notches. These aspects are known as power quality issues.

Power quality issues are important because generated power from wind farms should be connected to a power grid to be delivered to the end user. To connect and operate wind farms, the generated power by wind farms should meet network service provider (NSP) and national codes. In Australia, the Australian Energy Market Operator (AEMO) defines nationwide power quality requirements for power stations including wind farms.

In this research the intention is to use real data extracted from established wind farms to assess turbines and power network operation. Real data are used as inputs for software simulation and power quality assessment for steady state and transient conditions. The following software is used:

- EDSA-Paladin software is used for detailed power system analysis, fault condition assessment and harmonic assessment.
- PSCAD-EMTDC software is used for wind farm steady state and transient operation assessment including turbine behaviour during the fault and inrush current (during turbine start –up).

During the analysis most of the power distribution components are modelled. The cable impedances including capacitance of cables are included in the power system analysis for both steady state and transient condition assessment.

Some manual calculation methods are proposed to calculate some of the power quality aspects such as flicker, fault levels and commutation notches. Manual calculations are used to validate software simulation as well.

The transient operation of a wind farm power distribution system is another important topic which is assessed in this research. Ferroresonance can be critical during wind turbine switching or fault conditions. This results in ferroresonant harmonics and overvoltages in the system.

The ferroresonance does not have a linear nature; therefore, it cannot be predicted by analytical methods. PSCAD-EMTDC software is used to analyse the behaviour of a wind farm power network in ferroresonant states. Results prove that ferroresonance is a function of the network components, specifically the length of cables and transmission lines. A detailed study should be conducted during the design stage prior to system installation.

The earthing system of a wind turbine and its interconnection can play an important role in wind farm power system failure. The settings of protection relays should be selected with respect to human and farm animal safety and equipment protection. In this research the following issues are discussed, and improved methods are presented:

- Soil resistivity test;
- Lightning protection system analysis;
- Lightning strikes earth potential rise;
- Earth fault analysis; and
- Current injection test.

To conclude this research some of the issues which have resulted in voltage sag, interruption, turbine failure and wind farm outage are presented with root cause analysis discussions.

This research is an attempt to assess different wind farm components and fundamental considerations which should be considered during planning, design, construction and operation in order to minimize power quality issues. The state of problems has been provided in Section 1-2 of this thesis.

This research brings together several analysis techniques and real wind farm scenarios to address power quality issues. Claims are made to originality in terms of bringing together several studies to get an overall power quality assessment of a wind farm and claims are made for some new techniques. These claims are summarized in Section 1-3 of this thesis and made for work in Chapters 2 and 3.