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Investigations of Grid-Connected Wind Power System – Low Voltage Ride Through and Power Quality Issues

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ABSTRACT: This thesis presents an investigation on system architecture, control and analysis of wind turbine generators to improve grid integration performance. First of all, the main grid connection requirements have been reviewed in terms of safety operation of transmission systems as well as the wind turbine configurations. Due to these requirements, there have been conscious efforts made by wind turbine manufacturers to design grid compatible wind turbines, which are able to improve turbine operating performance and eliminate negative impacts on the utility, with features such as strong fault ride-through capability, flexible voltage regulation and good power quality performance.

1. INTRODUCTION

Nowadays, wind energy is a major renewable energy source to integrate into the grid. The worldwide total installed wind turbine capacity is up to 160 gigawatt at the end of 2009 when the global financial and economical crisis started. However, the crisis seemed to have no negative impact on the general development of the wind sector worldwide. Many governments sent clear signals that they wanted to accelerate wind deployment in their countries and indicated that investment in wind and other renewable technologies is an answer to the financial crisis as well as to the still ongoing energy crisis.

Along with the increasing wind power penetration into grid, the interconnection requirements for grid connected wind farms are generally formulated in order to maintain the operation performance of the connected power utilities. In the past, there is little need to consider impacts caused by wind power penetration due its low percentage of the total network capacity. However, the related impacts will be becoming very serious due to rapid increasing wind power penetration into grid without auxiliarysolutions.

OBJECTIVES

The objectives of this research project are listed below:

Objective 1: Fault ride-through enhancement of the DFIG based wind turbine

It is well-known that the DFIG is sensitive to network disturbances, especially severe grid faults. The crowbar technology is usually utilized to help ride through grid faults in the conventional DFIG turbine.

Objective 2: Design of a robust power architecture for PMSG based wind turbine

Compared to DFIG, the PMSG based wind turbine has better grid integration performance since full-scale power electronics converter is utilized. An AC-DC-AC converter, named as back-to-back converter is usually used to bridge the AC generator and the AC network.

Objective 3: Development of voltage quality assessment method for grids with wind power penetration

Regardless of DFIG or PMSG, wind power generation will meet a significant percentage of the worldwide electricity demand in the next decade. Large wind power injection is able to affect the connected power transmission system.

Major contributions of thethesis

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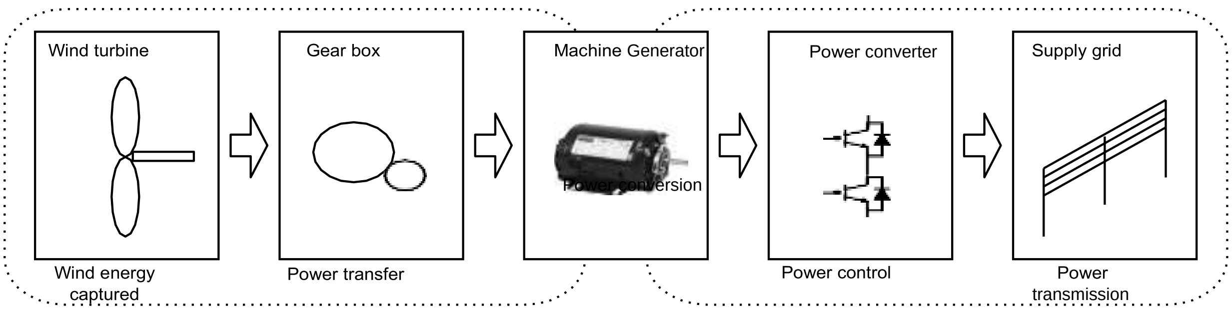
The major contributions documented in this thesis are given below.

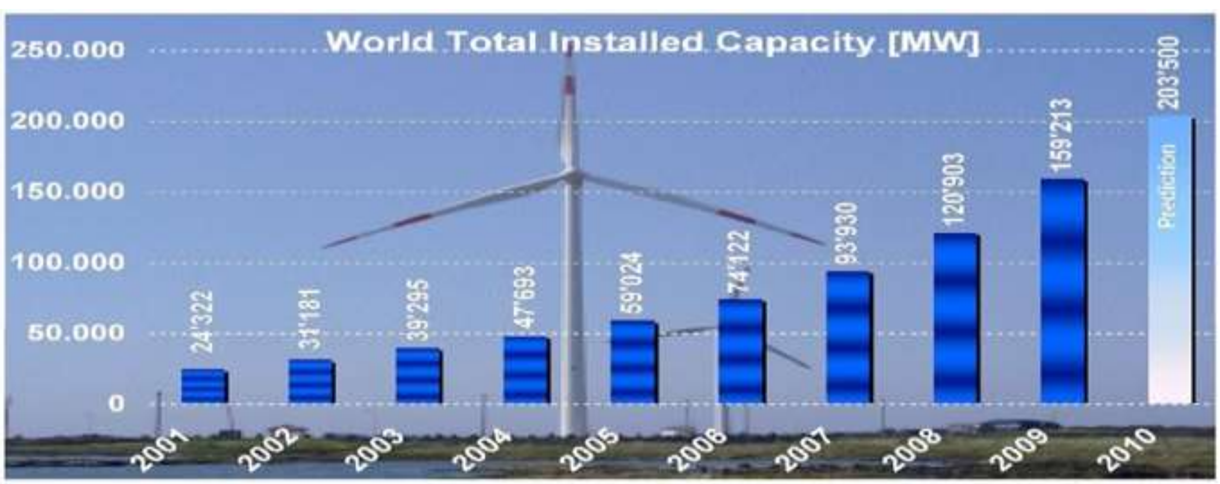
1. A feasible ride-through enhancement of DFIG based windturbine
2. Modulation, analysis and verification of three-switch rectifier based Z-Source inverter for full power converter in WTGapplication.
3. s3.Design of a robust PMSG wind turbine based on three-switch rectifier based Z-Source invertertopology
4. A voltage quality assessment method for grids with wind power penetration has been proposed in thisthesis.

The advances in wind turbinetechnology



In recent 2 decades, generation capacity of wind turbineshasincreased from tens‟kilowatts to more than 3 MW, while even larger wind turbines are being designed. Furthermore, a number of different generator concepts have been developed and tested. For the electrical system of wind turbines, some manufacturers have started to use asynchronous generator with wound rotor in their wind turbine design, while others have replaced the conventional induction generator by a synchronous generator. This development has introduced the use of power electronics as an interface in their design and led to the variable speed wind turbine. This is designed to pursue maximum aerodynamic efficiency over a wide range of wind speed, to reduce the mechanical stress in the gearbox and to improve the controllability of the active and reactive power which is growing in importance for integrating wind power into gridutility.

World total installed wind power capacity



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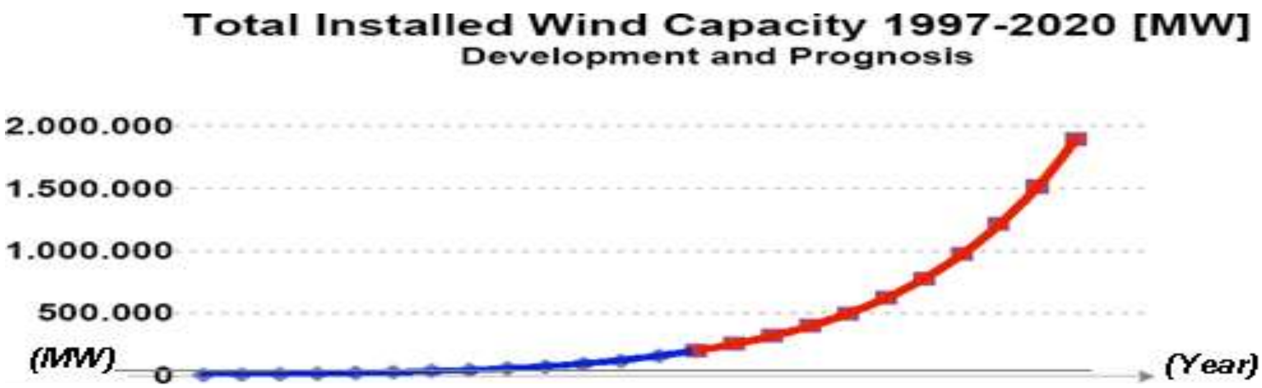

MODULATION AND ANALYSIS OF THREE-SWITCH BUCK-TYPE RECTIFIER BASED Z-SOURCE INVERTER

This chapter presents an integration of a three-switch buck-type rectifier and a Z-Source inverter for PMSG, which can overcome the drawbacks of existing configurations as mentioned in Section 2.6.2. It is prerequisite to explore the integrated topology named as the three-switch buck-type rectifier with Z-Source inverter in terms of modulation, circuit analysis and validation before doing system-level integration for PMSG based wind turbine. Hence, the modulation, analysis and demonstration of the three-switch buck-type rectifier based Z-Source inverter will be introduced in this chapter with aims to clarify the essential behavior of the developed topology. Then the design methodology, the simulation studies and experimental validation of the proposed architecture for PMSG wind application will be presented in the next chapter.

Parameters of the three-switch buck-type rectifier based Z-Source inverter

Items	**Value**
InputACsource	120V/ 50 Hz (line-to-line RMS) Commandedoutputvoltage 220V/ 25Hz (line-to-lineRMS)
Load resistance	30□
Loadinductance	25 mH
Inputpower factor	1
Switchingfrequency	5 kHz
Inductor $L_1$and L_2	3 mH
Capacitor $C_1$and C_2	470 uF

DESIGN OF A ROBUST PMSG TURBINE SYSTEM BASED ON THE DEVELOPED TOPOLOGY

The wind power captured by the turbine is converted by the PMSG and transferred to the grid via a three-phase three-switch PWM buck-type rectifier in series with a Z-Source inverter. The detailed power circuit is illustrated in Fig.5.2, which has been analyzed in Chapter 4. The main function of the generator-side PWM rectifier is to regulate the power factor of PMSG and to ensure sinusoidal generator currents. A small LC input filter can be designed to absorb the high frequency harmonics injected into the generator by the rectifier switching action. The grid-side inverter serves as a grid power interface to connect PMSG with network utility. The detailed generator-side and grid-side control scheme will be discussed in this chapter.

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DESIGN OF A ROBUST PMSG TURBINE SYSTEM BASED ON THE DEVELOPED TOPOLOGY

The modulation, analysis and demonstration of the three-switch buck-type rectifier based Z-Source inverter have been introduced in Chapter 4. This chapter presents the design of a robust PMSG wind turbine based on the aforementioned topology. Figure 5.1 shows the proposed PMSG based wind generation system, which provides high reliability, low capital cost, and harmonic-free characteristics in both generator and gridsides.

STATISTICAL VOLTAGE QUALITY ASSESSMENT METHOD FOR GRIDS WITH WIND POWER GENERATION

Regardless of DFIG or PMSG, wind power capacity will be meeting a significant percentage of the worldwide electricity demand in the next decade, especially in western European countries. Consequently, wind power will affect the operation of utility in terms of voltage regulation, frequency control and so on. Thus there is a need to devise reliable methods to accurately quantify the impacts so as to obtain the most appropriate and economical solution to mitigate the negative impacts. Hence, this chapter intends to develop a feasible voltage quality analysis for large wind power penetrated networks

Component Reliability Data

Component	**□(failures/yr)**	**Repair Time(hr)**
Generator unit	2	198
Overhead line	0.02/km	10
Transformer	0.01	200

Grid States and Probability when |ΔV| >0.1

Grid State *j*	**Element(s) of Plant Outage**	*prob*(*Z* (*j*) | □*V* |□10%)
3	One of G2 set	0.439108
4	One of G3 set	0.499100
6	Two of G2 set	0.022422
7	Two of G3 set	0.025452
9	Three of G1 set	0.003178
10	T7	0.002356
11	T6	0.002357
12	L4	0.002286
13	T5	0.001433
14	L1 or L2	0.001927
18	L3	0.000371

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Comparison of voltage deviation ΔV obtained from the conventional load flow study and from the proposed probabilistic method

Grid State *j*	Element(s) of Plant Outage	Voltage deviation Δ*V (%)*	
		Conventional load flow study	Proposed statistical method
3	One of G2 set	11.160	10.87
4	One of G3 set	10.106	10.923
6	Two of G2 set	12.471	11.595
7	Two of G3 set	12.992	12.742
9	Three of G1 set	10.060	10.871
10	T7	11.160	10.87
11	T6	10.106	10.922
12	L4	10.871	10.782
13	T5	10.543	10.311
14	L1 or L2	16.761	17.775
18	L3	10.332	10.512

Computational Time Comparision

Methods	Computational Time (s)
Monte Carlo Simulation (10000 trials)	***77.06***
Monte Carlo Simulation (20000 trials)	***156.89***
Proposed method	***1.63***

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CONCLUSIONS

This thesis has documented the investigation of the grid integration issues for wind based renewable energy conversion system in terms of architecture, control and analysis. The research includes a review of current wind market development, the advance of wind turbine technology and grid regulations for wind power penetration; Modeling of DFIG wind generation system and the potential ride-through enhancement solution; Modulation of an integration of three-switch buck-type rectifier and Z-Source inverter and its application for PMSG based wind turbine; and statistics-based voltage assessment method for large wind power penetration.

A strong increase of worldwide wind capacity is expected in the next decade. The turbine configurations have been reviewed in terms of different generators and the main grid connection demands has been reviewed in terms of safety operation of transmission systems. All these investigations are intended to clarify the potential challenges of modern wind turbines and thus provided a guide to define research objectives in this thesis. In fact, with the increase of wind power penetration into utility, it is desired to design a grid compatible wind turbine, which is able to improve turbine operating performance and eliminate negative impacts on the network, such as fault ride-through capability, flexible voltage regulation and power quality issue.

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