MITIGATION OF LOAD HARMONICS FROM GRID CONNECTED WIND TURBINE USING SHUNT ACTIVE POWER FILTER

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This thesis work is dedicated to my parents, Mr and Mrs Hafiz Mukhtiar Ahmed Qazi who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve. This work is also dedicated to my wife who has been a constant source of support and encouragement during the challenges of study and life. I am truly thankful for having you in my life.

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ABSTRACT

The increasing utilization of power electronics controlled devices in power system has increased distortion level in current and voltage waveforms in the form of harmonics. The increase in harmonic level also affects the performance of generator, thereby reducing its efficiency and lifespan. In this research, load harmonic mitigation method has been proposed for grid connected variable speed wind turbine generator using Shunt Active Power Filter (APF). The main advantage of this method is eliminating the effect of load harmonics from terminals of wind turbine generator and from the Point of Common Coupling (PCC). To evaluate the performance of shunt APF, two strategies have been utilized separately for extracting harmonic reference signal: the instantaneous reactive power method (*pq* method) and Synchronous Reference Frame (SRF) technique. To prove the effectiveness of the proposed system, MATLAB simulations have been carried out on 120 kV grid connected Permanent Magnet Synchronous Generator (PMSG) based wind turbine. Furthermore, nonlinear load is also attached to PCC under fixed and variable wind speed between 8 to 12 m/s separately. For proper operation of APF, switching pulses have been produced by hysteresis band current control. This technique decreases the magnitude of Total Harmonic Distortion (THD) to an acceptable limit set by IEEE-519 standard for harmonic control. Results have also shown that the shunt APF with SRF technique yields better performance under fixed and fluctuating wind speed compared to *pq* method.

ABSTRAK

Peningkatan penggunaan peranti terkawal elektronik kuasa dalam sistem kuasa telah meningkatkan tahap herotan gelombang arus dan voltan dalam bentuk harmonik. Peningkatan tahap harmonik juga akan mempengaruhi prestasi penjana, justeru akan mengurangkan kecekapan dan jangka hayatnya. Dalam kajian ini, satu kaedah memangkas harmonik beban telah dicadangkan untuk penjana turbin angin kelajuan boleh ubah sambungan ke grid menggunakan Penapis Kuasa Aktif Pirau (APF). Kelebihan utama kaedah ini ialah menghapuskan kesan harmonik beban daripada terminal penjana turbin angin dan juga Titik Gandingan Sepunya (PCC). Untuk menilai prestasi pirau APF, dua strategi telah diguna secara berasingan untuk penyarian isyarat rujukan harmonic: kaedah kuasa regangan ketika (kaedah *pq*) dan teknik Bingkai Rujukan Segerak (SRF). Bagi membuktikan keberkesanan sistem yang dicadangkan, penyelakuan MATLAB telah dijalankan ke atas Penjana Segerak Magnet Kekal (PMSG) turbin angin sambungan ke grid 120 kV. Selanjutnya beban tidak linear disambungkan ke PCC, dengan kelajuan angin tetap dan berubah secara berasingan di antara 8-12 m/s. Untuk penapis APF beroperasi dengan sewajarnya, denyutan pensuisan telah dihasilkan oleh kawalan semasa lingkaran histerisis. Teknik ini mengurangkan magnitud Jumlah Herotan Harmonik (THD) kepada had yang boleh diterima yang ditetapkan oleh piawaian IEEE-519 untuk kawalan harmonik. Keputusan juga menunjukkan bahawa APF pirau dengan teknik SRF mempunyai prestasi yang lebih baik di bawah kelajuan angin tetap dan angin membuai berbanding kaedah *pq*.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
APF	-	Active Power Filter
DC	-	Direct Current
DFIG	-	Doubly Feed Induction Generator
DSP	-	Digital Signal Processing
d-q	-	Direct-Quadrature Axis
FFT	-	Fast Fourier Transform
GHG	-	Green House Gases
HBCC	-	Hysteresis Band Current Control
HVDC	-	High Voltage Direct Current
I	-	Fundamental current
IGBT	-	Insulated Gate Bipolar Transistor
PCC	-	Point of Common Coupling
PI	-	Proportional Integral
PLL	-	Phase Locked Loop
PQ	-	Power quality
PWM	-	Pulse Width Modulation
RE	-	Renewable Energy
WT	-	Wind Turbine
SCIG	-	Squirrel Cage Induction Generator
SRF	-	Synchronous Reference Frame
THD	-	Total Harmonic Distortion
WECS	-	Wind Energy Conversion System
WRIG	-	Wound Rotor Induction Generator
WTG	-	Wind Turbine Generator
WTS	-	Wind Turbine System

LIST OF SYMBOLS

i_d	-	Stator direct axis current
i_q	-	Stator quadrature axis current
L_d	-	Stator direct axis inductance
L_q	-	Stator quadrature axis inductance
R_s	-	Stator resistance
u_{sd}	-	Stator direct axis voltage
u_{sq}	-	Stator quadrature axis voltage
P	-	Pole pair
ω_r	-	Rotor Speed
Ψ_m	-	Amplitude of flux induced
v_{La}, v_{Lb}, v_{Lc}	-	Three phase source voltages
i_a, i_b, i_c /i_{La},i_{Lb},i_{Lc}	-	Three phase load currents
v_α, v_β, v_0	-	Transformed source voltage (Clark's Transformation)
i_α, i_β, i_0	-	Transformed source current (Clark's Transformation)
i_α*, i_β*	-	Compensating current (*pq* theory)
i_{ca}, i_{cb}, i_{cc}	-	Reference current (*pq* theory)
i_{sa}, i_{sb}, i_{sc}	-	Extracted reference currents (SRF Technique)
$\overline{i_d}, \overline{i_q}$	-	Fundamental active and reactive current component
$\widetilde{i_d}, \widetilde{i_q}$	-	Harmonic active and reactive current component
αβ0	-	Stationary Frame axis
h	-	Harmonic
I_{sc}	-	Short circuit current
I_L	-	Load current
v_f	-	Actual supply voltage
I_f	-	Actual supply current

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CHAPTER 1

INTRODUCTION

1.1 Background

Generation of electricity from renewable sources such as wind, solar and wave in current scenario is really essential since the demand of power is increasing promptly and sources of fossil fuels are restricted. The non-conventional energy sources have significant contribution in power generation, the empathy and effective use of these sources is the plunge area in energy sector. Among all renewable sources, wind plays a dynamic role in energy generation. The location of wind turbine is very significant as the power output of wind is proportional to cube of wind speed [1].

The kinetic energy of air changed over into mechanical energy by windmill to directly operate a machine or to drive an alternator to generate electricity. Wind energy makes for a dynamic part in creating ecological neighborly atmosphere and draws the world more helpful for societies and for every living beings. Power for vast scale and small scale can be produced from wind turbines for utilities, commercial ventures, etc. Since early 1980's, the improvement of wind turbine energy, the rated capacity of wind turbines has expanded from a few several kW to today's MW turbines. Simultaneously, the pattern has moved from establishments, including a solitary or a couple wind turbines to arranging of substantial wind farms running from a few many MW to more than 100 MW [1].

Energy produced from wind turbines on vast scale diminishes the energy crises and anxiety can be surrendered from different wellsprings of energy era. Unexpectedly, the numbers of potential problems that must be contemplated when raising vast scale wind energy ranches for a practical power network. Installation and operation of wind farms network influence the living examples of the encompassing occupants, i.e., visual effects, clamor and demise of untamed life, etc. While combination of wind energy into the network likewise, makes potential specialized difficulties [1], that affect power quality (PQ) of the systems due to the variable nature of wind. The key potential difficulties that influence power quality because of expanded dispersion of wind vitality into the matrix comprise of, voltage fluctuation, power system transients and harmonics, reactive power, electromagnetic interference, switching actions, synchronization, long transmission lines, low power factor, storage system, load management, forecasting and scheduling [2, 3].

Power quality disturbances may be classified either between the quality of the supply voltage (source) or by the quality of the current drawn by the load. Advanced power electronic devices extensively used to rapidly draw harmonic currents and reactive power from AC mains due to their inalienable nonlinear V-I characteristics [4]. Different issues created by harmonic in the power network, furthermore have impact on customer items, for example, abnormal voltage waveforms, apparatus overheating, blown capacitor wires, transformer overheating, neutral current increment, low power factor, etc. [5-8]. Such non-linear loads contaminate the system by infusing current harmonics thus, crumbling the utility voltage and have a fall in supply voltage and escalated losses at point of common coupling (PCC). Because of presence of these harmonic, the total harmonic distortion (THD) level of the system increments above the harmonic standard set by IEEE under IEEE-519. Moreover, it affects the performance and efficiency of generator by adding intensified losses and producing extra heat. Thus, contributes to diminution of life span of generator [9].

The situation calls for alleviation of current harmonics instabilities in the cast of “filter devices” which are dexterous enough to deliver made-to-measure solution to harmonic generation. Generally as an Active Power Filter (APF), which is employed for mitigating these harmonics and eventually enhancing power quality of the system. APFs can likewise be connected to power system to supply compensation for harmonics, reactive power, and/or neutral current. APFs can also be utilized to eradicate voltage harmonics, terminal voltage regulation, to suppress voltage flicker, and to improve three-phase balanced voltage [8]. APFs can be classified according to the type of compensation required. On the basis of this criteria, APF can be categorized as voltage source APF and current source APF. A voltage source APF has a capacitor on the DC side with a managed DC voltage, though a current source APF has an inductor with a regulated DC current. In spite of the fact that the voltage source type is better as far as filter capacity for elimination of PWM carrier harmonics and losses, the current source type is better regarding the compensating current dynamics and reliability and protection [10].

1.2 Problem Statement

Different techniques have been used by the researchers in last decades to overcome the consequence of these harmonic contents and to supply consistent and sinusoidal power to the consumers which does not damage to their equipment. A. Prasad et al., [11] utilized passive filter to eliminate harmonics from the system, however passive filter have drawback that it only indemnify the system for under and over compensation. H. Sasaki et al., [12] proposed active filter recognized as active power filter (APF) to minimize harmonic effects from the system. F. S. dos Reis et al., [13] applied APF to mitigate harmonics from permanent magnet synchronous generator (PMSG) based wind turbine generator (WTG) while in islanding mode with fixed wind speed (12 m/sec). J. Tsai et al., [9] also proposed APF with its variable frequency operation under islanding mode of wind turbine system (WTS). A. Gaillard et al., [14] employed APF with doubly feed induction generator (DFIG) based fixed speed (8 m/sec) wind turbine to analyze the operational features of proposed system under the same islanding mode. A. Hoseinpour et al., [15] put forward modified modulation technique for APF with PMSG WTG under islanding mode with fixed speed (8 m/sec). All of them used different reference signal extraction techniques and modulation methods.

In this research, APF is proposed to use with grid connected variable speed wind turbine system to analyze the effectiveness of proposed system. Under this study, effect of wind turbine at point of common coupling (PCC) under varying nature of wind speed will be investigated. Furthermore, the effect of nonlinear load connected at PCC and on the wind generator, considering profile of total harmonic distortion (THD) level is the ultimate interest of this research. At the end, the effective solicitation of the proposed methodology will eventually function under international standard of harmonic control i.e. IEEE-519 with improved efficiency.

1.3 Objectives

The objectives of research are listed below,

(i) To develop MATLAB Simulink model for grid connected wind turbine generator based on permanent magnet synchronous generator (PMSG) subject to presence of harmonic with nonlinear loads.

(ii) To design PI controller based APF to tackle harmonic problems in the proposed system under unbalanced nonlinear loads.

(iii) To investigate APF with instantaneous reactive power technique (*pq* technique) and synchronous reference frame (SRF) technique to get similar or better results in accordance with IEEE-519 standard under fixed and fluctuating wind speed.

1.4 Scope

The scope of this research study will be as follow,

(i) PMSG based wind turbine will be used in this study with 120 kV grid system. The prevailing load situation in grid connected wind turbine, especially effect of non-linear load will be studied.

(ii) The proposed system will be studied under fixed (8 m/sec) and variable wind speeds (8-12 m/sec) for maximum power extraction from wind turbine.

(iii) The system design will be based on variable frequency shunt active power filter and PI controller.

(iv) MATLAB/Simulink software will be used to develop and test the proposed system model.

(v) Simulation results will be analyzed on the basis of control methods (SRF and *pq* technique), to determine which method is more suitable for the proposed case study.

1.5 Significance of Study

The significance of this research study is as follow,

(i) Describe viability of APF from practical applicability view-point using proportional integral (PI) controller under frequently faced load conditions and regularly experienced fault conditions and system being researched on are set aside, as they may be more prone to failing as well as more difficult for maintenance if put into practice.

(ii) Develop the integration principles of APF, based on instantaneous reactive power theory and synchronous reference frame technique, directly calculated from three phase a-b-c voltages and line currents using αβ0 and d-q reference frame respectively.

1.6 Organization of Thesis

The thesis is organized in a manner that Chapter 1 briefly describes the introduction of studied system, Chapter 2 providing an up-to-date literature review, Chapter 3 outlining proposed methodology while Chapter 4 representing results of the studied system and in the last Chapter 5 symbolizing conclusion and future recommendations.

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