UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

IMPACTS ON POWER FLOW AND QUALITY OF PENETRATING 50MW WIND PLANT INTO STAND ALONE GRID

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SUHAIB SALAM MOHAMMED AHMED AL-KAIALI

A thesis submitted
in fulfilment of the requirements for the degree of Master of Electrical Engineering (Industrial Power)

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2017

DECLARATION

I declare that this dissertation entitled "Impacts on Power Flow and Quality of Penetrating 50MW Wind Plant into Stand Alone Grid" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : SUHAIB SALAM AL-KAIALI

Date : 19/10/2017

APPROVAL

I hereby declare that I have read this project and in my opinion this dissertation is sufficient in terms of scope and quality for the award of Master of Electrical Engineering (Industrial Power).

Signature : ....

Supervisor Name : Assoc. Prof. Ir. Dr. Rosli Bin Omar

Date : 19/10/17

DEDICATION

To my beloved mother, handsome father and best and only one brother Harith My aunty Zainab and Uncle Jasim and Laith need to dedicate also my special friend and brothers in Iraq, Malaysia & Oman.

To Salim AL-Rubkhi Ahmed Abdul-Jalil , Ahmed Zuhair, Mustafa Ayad, Thamer Emad , Laith Nazzeh Bini Melham , My sister Zainab Majeed and Salma Mansour. All of them dedicate who encourage me to complete my study and make the possibility to overcome the ascription and help me to complete my study.

ABSTRACT

The demand for electricity is continuously growing due to the development in community's macro-economic parameters; Population and the Gross Domestic Product (GDP). Currently, electricity is mainly generated from conventional sources including fossil fuels (oil, coal, gas, etc.) and nuclear fuel. The increase in demand increases the concerns about depletion of fossil fuels, increasing of carbon dioxide (CO2) and other emissions, environmental pollution, and climate changes. Global energy agencies have been urged to look for sustainable and environment friend resources. Renewable energy resources especially wind and solar resources are found ambitious sources that can be developed to share other resources in supplying sustainable environmental friend power due to their economic benefits as compared with other resources and technologies. Energy generated from wind is growing faster than other renewable resources especially at areas with proper wind speed and characteristics capable to generate high power at small land and the possibility to interconnect wind networks with distribution or transmission power networks. Predictability of wind availability and characteristics is limited; therefore, the output of wind turbines cannot be controlled to the same extent as conventional generation technologies. This study involves assessing the impact of interconnecting a 50 MW wind plant at different penetration levels into a 132-kV grid powering a region in the sultanate of Oman isolated (islanded) from the main national grid. The assessment includes mutual impacts on power quality and flow, grid voltage flickering and performance of the network and the farm under steady state and disturbance conditions. The wind plant is constructed from an 18-equal capacity DFIG wind turbines modelled using the simulation from MATLAB/Simulink available in the college. Parameters of control and operation parameters were developed to fit the wind plant operating conditions. The penetration levels considered in the research include 1, 9 &18 wind turbines in operation respectively which represent 5.5 %, 50 % and 100 % of the maximum farm generation capacity. The research outcomes revealed that penetrating the wind plant at the levels mentioned above provide high accuracy of compliance with the national and international standards and codes and that it shall not conflict the requirements of power quality and security of supply restricted in grid code and regulations. The outcomes obtained also provide high degree of confidence for integrating the wind plant with the existing grid network at the proposed point of common connection (PCC) without any additional extra works required on the existing network rather than those required for adaptation requirements.

ABSTRAK

Permintaan untuk tenaga elektrik terus berkembang disebabkan oleh perkembangan dalam parameter makro-ekonomi masyarakat; Penduduk dan Keluaran Dalam Negara Kasar (KDNK). Pada masa ini, elektrik terutamanya dijana daripada sumber konvensional termasuk bahan api fosil (minyak, arang batu, gas, dan lain-lain) dan bahan api nuklear. Peningkatan permintaan meningkatkan kebimbangan mengenai kekurangan bahan api fosil, meningkatkan karbon dioksida (CO2) dan pelepasan lain, pencemaran alam sekitar dan perubahan iklim. agensi tenaga global digesa mencari sumber-sumber rakan lestari dan alam sekitar. sumber tenaga boleh diperbaharui terutama angin dan sumber solar terdapat sumber bercita-cita tinggi yang boleh dibangunkan untuk berkongsi sumber-sumber lain dalam membekalkan mampan kuasa rakan alam sekitar kerana manfaat ekonomi mereka berbanding dengan sumber-sumber dan teknologi lain. Tenaga yang dijana daripada angin berkembang lebih cepat daripada sumber boleh diperbaharui yang lain terutama di kawasan dengan kelajuan angin yang betul dan ciri-ciri yang mampu untuk menjana kuasa tinggi pada tanah yang kecil dan kemungkinan untuk saling rangkaian angin dengan rangkaian pengedaran atau penghantaran kuasa. Kebolehramalan ketersediaan angin dan ciri-ciri adalah terhad; oleh itu, output turbin angin tidak boleh dikawal ke tahap yang sama seperti teknologi penjanaan konvensional. Kajian ini melibatkan penilaian impak bersambung ladang angin 50 MW ke dalam grid 132 kV menjanakan kawasan yang dalam kesultanan Oman diasingkan daripada grid nasional utama pada tahap penembusan yang berbeza. Penilaian ini merangkumi kesan bersama mengenai kualiti kuasa dan aliran, kelipan voltan grid dan prestasi rangkaian dan ladang di bawah keadaan dan gangguan stabil. Ladang angin dibina daripada 18-sama turbin angin kapasiti DFIG dimodelkan menggunakan simulasi dari MATLAB / Simulink tersedia di kolej. Parameter kawalan dan operasi parameter telah dibangunkan untuk memenuhi syarat-syarat operasi ladang angin. Tahap penembusan dipertimbangkan dalam kajian ini, terdapat 5.5%, 50% dan 100% daripada kapasiti penjanaan ladang maksimum. Hasil penyelidikan menunjukkan bahawa menembusi ladang angin di peringkat yang dinyatakan di atas menyediakan ketepatan yang tinggi pematuhan dengan piawaian dan kod negara dan antarabangsa dan bahawa ia tidak boleh bercanggah keperluan kualiti kuasa dan keselamatan bekalan terhad kod dan peraturan grid. Hasil yang diperolehi juga menyediakan tahap keyakinan yang tinggi untuk mengintegrasikan ladang angin dengan rangkaian grid yang sedia ada pada ketika cadangan sambungan biasa (PCC) tanpa apa-apa kerja tambahan tambahan yang diperlukan di dalam sistem sedia ada dan bukannya yang diperlukan untuk keperluan penyesuaian.

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LIST OF ABBREVIATION

ρ	Air density
Λ	Tip Speed Ratio
Ωr	Rotor Angular Speed
A	Cross-Sectional Area of the Wind That Crossed the Blades
AC	Alternating Current
ASG AA	Synchronous Generator
ANSI	American Nation Standard Institution
$\beta°$	Blade Pitch Angle
CO2	Carbon Dioxide
Cp	Power Coefficient
Cgrid	Convertor Grid
Crotor	Convertor Rotor
D-axis	Direct Axis
DC	Direct Current
DFIG	Double Fed Induction Generator
EIA	Energy Information Administration
EMF	Electro Motive Force
FRT	Fault Ride Through
GC	Grid Code
GDP	Gross Domestic Product

GE	General Electric
GSC	Grid-Side Converter
GWEC	Global Wind Energy Council
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Isolated Gate Bipolar Transistor
IPP	Independent Power Plant
IRENA	International Renewable Energy Agency
KE	Kinetic Energy
kV	Kilo Volt
kVAR	Kilo Volt Ampere Reactive
kWh	Kilo watt hour
kW	Kilo Watt
LVRT	Low Voltage Ride Through
LOL	Line to Line
MW	Mega Watt
MPPT	Maximum Power Point Tracking
OECD	Organization for Economic Co-operation and Development
OETC	Oman Electricity Transmission Company
OHL	Over Head Line
PCC	Point of Common Connection
Pgc	C grid electrical power output
PI	Proportional – Integral
Pm	Mechanical power captured by the wind turbine and transmitted to th rotor.
Pr	Rotor electrical power output

Ps	Stator electrical power output
PWM	Pulse Width Modulation
PU	Per Unit
Qs	Stator reactive power output
Qr	Rotor reactive power output
Qgc	Cgrid reactive power output
Q-axis	Quadrature axis
Rpm	Revolutions per minute
RLC	Resistor Inductance Capacitance
RMS	Root Mean Square
RSC	Rotor-Side Converter
RSC	Short circuit factor
S	Slip
SCIG	Squirrel Cage Induction Generator
SG	Synchronous Generator
SLD	Single Line Diagram
SSC	Short Circuit Apparent Power
Tx	Transformer
Tm	Mechanical torque applied to rotor
Tem	Electromagnetic torque applied to the rotor by the generator
TSO	Transmission System Operation
UGC	Under Ground Cable
VH	High Voltage
VHF	High Voltage Limit

VL	Lower Voltage
VLF	Low Voltage Limit
VSC	Voltage Source Convertor
WPGS	Wind Powered Generation Station
WPP	Wind Power Plant
WT	Wind Turbine

LIST OF PUBLICATIONS

Rosli Bin Omar, Suhaib Salam Mohammed, Mohammed Rasheed and Marizan Sulaiman., (2017). " Aggregated Modelling Analysis of power flow from Wind Power Plant into Grid System Using MATLAB/SIMULINK Software", ARPN Journal of Engineering and Applied Sciences (JEAS).

CHAPTER 1

INTRODUCTION

1.1 Overview of Renewable Energy

Globally, demand for electricity is continuously increasing due to the development in community's macro-economic parameters; Population and the Gross Domestic Product (GDP). Power demands in Organisation for Economic Co-operation and Development (OECD) grow slower than those in non OECD members, since they demonstrate more increase in populations, GDP, and the industrialization activities. Figure 1.1 introduces World total gross domestic product 1990-2040 per region (Trillion 2010 US $) , while Figure 1.2 introduces World Energy Consumption (Trillion kWh) trillion=10^{12} (Singer and Peterson, 2016).

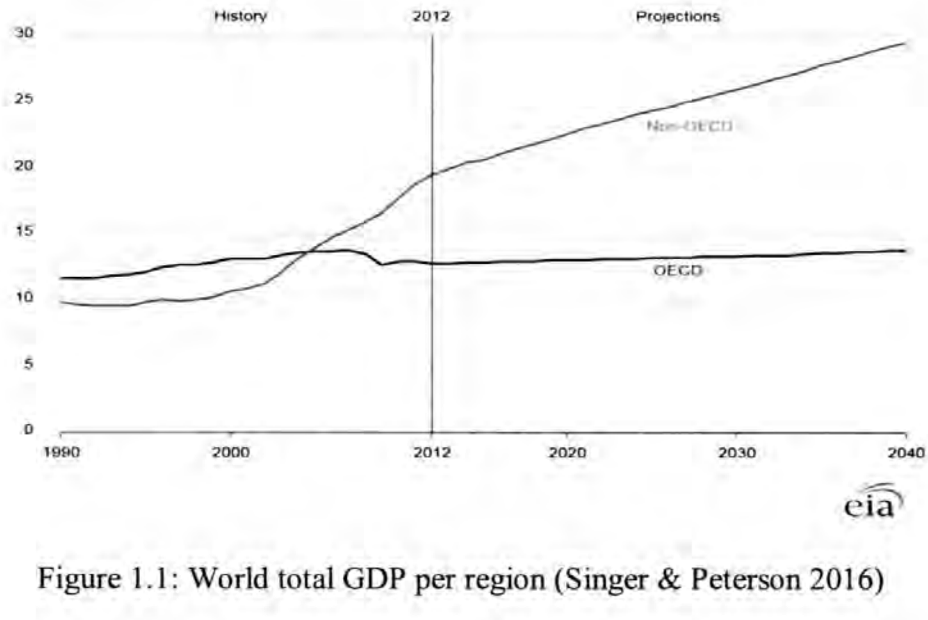

Figure 1.1: World total GDP per region (Singer & Peterson 2016)

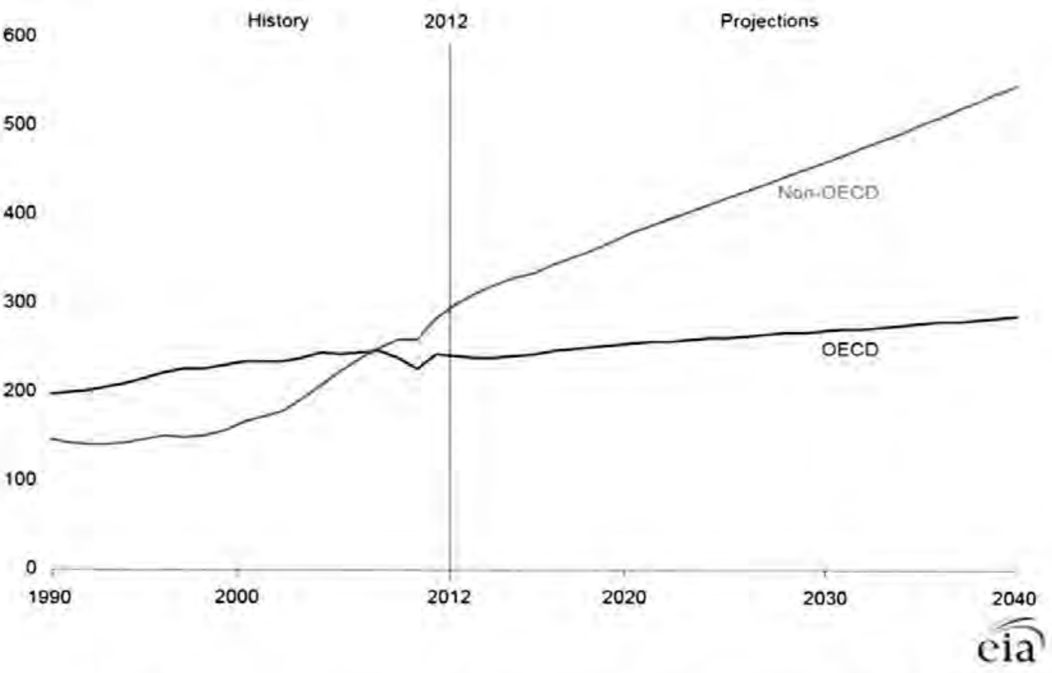

Figure 1.2: World energy consumption by region, 1990–2040 (quadrillion Btu) (Singer & Peterson 2016).

In consistent with the growth in demand at the required quality and security, complexity of electric power systems has evolved to meet the requirements of supply. Electric power is generated from different energy resources which are classified into two main categories, non-renewable and renewable energy resources. Non-renewable (conventional) sources are divided into two types; fossil fuels (oil, coal, gas, etc.) and nuclear fuel. Solar and wind are the main renewable energy resources. At present electric power is mainly generated from non-renewable resources as shown Figure 1.3.

Therefore, increase demand for electricity depends largely on fossil fuels with minors from hydro power and nuclear energy. The increase in fossil fuel consumption increases the concerns about carbon dioxide (CO2) emissions, environmental pollution, and climate changes. Renewable sources are big sources of energy, mainly from sun, wind, and seas, but the challenge is how to harnessing them. Recently more technological advance achievements have been developed to increasing the share of renewable resources in the deal of energy supplied. Different sources of renewable energy share the supply of energy to consumers. Including solar Energy, photovoltaic Systems, solar hot water, Solar Electricity, wind, Geothermal Energy, Geothermal Electricity Production, Bioenergy. Biofuels, Hydropower, Ocean Energy, Hydrogen & Fuel Cells.

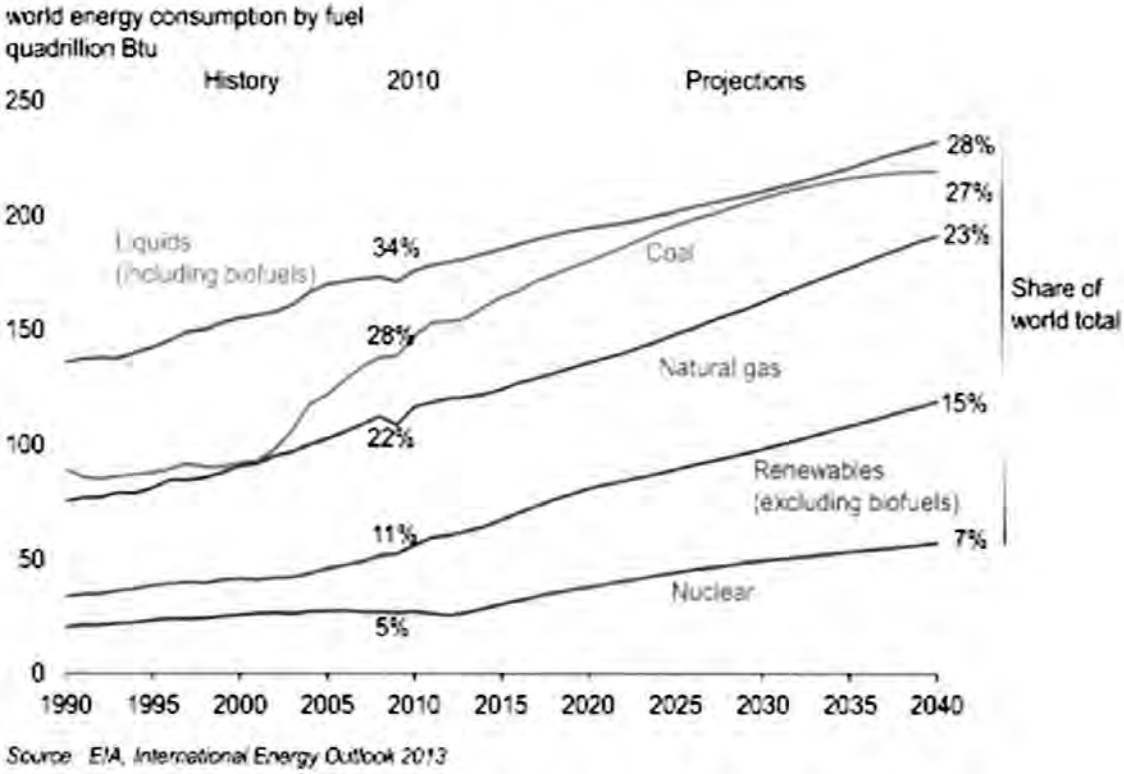

Figure 1.3: Share of world energy resources (Singer & Peterson 2016)

*(quadrillion) 10^{15} BTU, or 1.055×10^{18} joules

Demonstrates that solar and wind sources of power show significant increase in installed power capacity and it is expected to grow more as cost of energy shows more trend to reduction and it becomes competent to other conventional sources of energy and even lower Figure 1.4 Global Cumulative Installed Capacity 2000-2015(Badihi et al., 2015)(Mishra and Chowdhury, 2015).