AGGREGATED MODELLING ANALYSIS OF POWER FLOW FROM WIND POWER PLANT INTO GRID SYSTEM USING MATLAB/ SIMULINK SOFTWARE

Suhaib Salam Mohammed, Rosli Bin Omar, Marizan Sulaiman and Mohammed Rasheed
Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
E-Mail: mohamed_tchno@yaho.com

ABSTRACT

In consistent with the growth in demand, complexity of electric power systems has evolved to meet the requirements of supply. Power is generated from non-renewable, fossil fuels and nuclear fuel while renewable energy resources mainly include solar and wind. Power from Wind plants WP has shown a fast growth in the last decades due to their economic benefits especially at areas with the proper wind speed and the possibility to connect wind generators in distribution or transmission power networks. Conventional power unit generators are of high generation capacities, therefore smaller numbers are required in power plant, in other hand wind turbines WP are of smaller capacities therefore, Wind Power Plants (WPPs) consist of dozens or hundreds of low-power units. Time domain simulations of WPPs may take too much time if detailed models are considered in such studies while reduced order models used in interconnection studies of synchronous machines with full converter technology significantly reduce computational time (1, 2). The performance of all models is evaluated based on time domain simulations in the Simulink/MATLAB environment. The work includes the simulation of 50 MW WPP constructed from 18 MW doubly fed induction generators (DFIGs) aggregated (reduced) to one system of Nx2.78 MW generation capacity interconnected to existing conventional system network through 132 kV grid. The analysis includes active and power flow at the farm and the PCC terminals also power flow at PCC has been assessed for different level of WP penetration. Outputs from the MATLAB/SIMULINK modelling and simulation introduces the level of the grid voltage, current active and reactive power in the PCC and the wind farm terminal.

Keywords: wind power plant, coefficient of power, penetration level, double field induction generator, isolated grid system, rotor side converter, grid-side converter, point of common connection PCC.

1. INTRODUCTION

Electric Power demands especially in the developing countries grow more rapid to meet the increase of populations and the increased industrialization activities. 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. In any place of the world electric power can be generated from different energy resources. The resources can be classified into two main categories, specified as non-renewable and renewable energy resources while main renewable sources of energy are solar and wind. Currently power is mainly generated from non-renewable resources, therefore as electricity demand increased depending largely on fossil fuels with minors from hydro power and nuclear energy, concerns increased about carbon dioxide emissions that contributing to environmental pollution and climate changes [1].

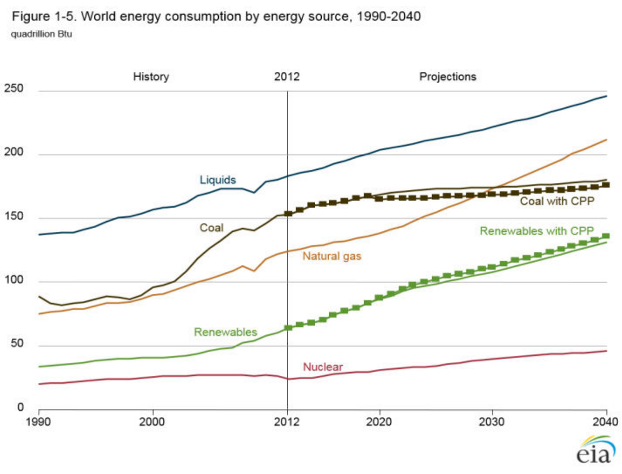


Figure-1. World energy consumption by source 1990-2040. (Source independent statistics & analysis U.S. energy. information administration. May 2016)

Renewable Sources are huge sources of energy are 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 sources in the deal of sources of energy supplied. The main problems that stand against the increase of spreading renewable energy sources are the cost of construction and reliability and security of power production in addition to legal and regulatory frame works power for production and supply.

Recently renewable power systems become cost effective competitor to the non-renewable and renewable energy resources. Governments in different countries involved in producing studies to assess the feasibility of generating part of power supplied from renewable energy sources to decrease governmental subsidy and reduce the impact of pollution. Electric power generation using wind turbines has attracted the attentions of utilities due to high generation capacity and low maintenance and cost. The level of penetration of wind power is increasing, therefore wind turbine systems is developing to continuously increase output power [2] Data source: GWEC, global wind statistics 2015.

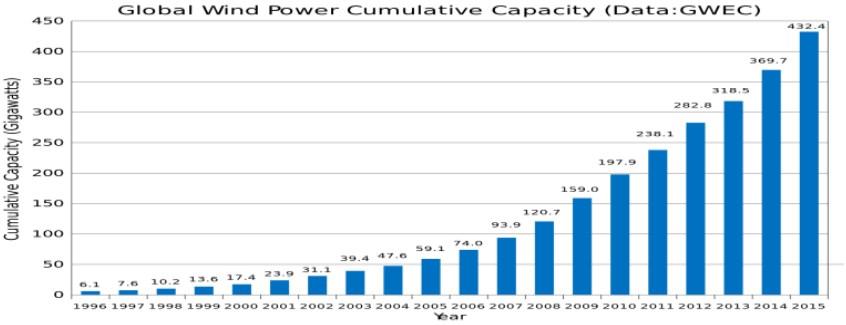
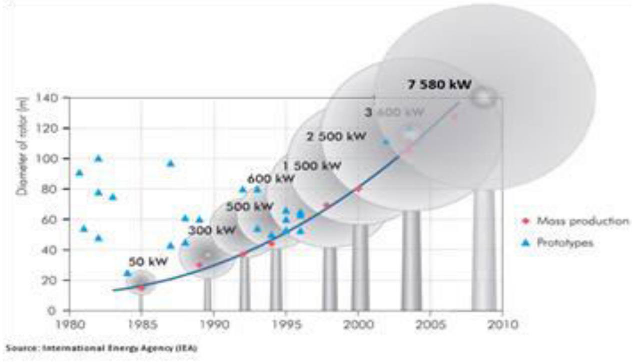


Figure-2. Global wind power cumulative installed capacity at the end of 2015, in gigawatts. (Data source: GWEC, global wind statistics 2015[[2]]).

2. MODELLING OF DFIG IN WIND POWER SYSTEM

As Penetration level of wind power into power systems, the generation capacity for individual wind turbine to decrease cost of installation, and operation and maintenance [2].



Source: International Energy Agency (IEA)

Figure-3. Size and power evolution of wind turbines over time.
Source: International energy agency IEA

To introduce optimal simulation to the wind turbine, it can be divided into sub-systems: turbine, transmission, generator, and converters. (6, 7).

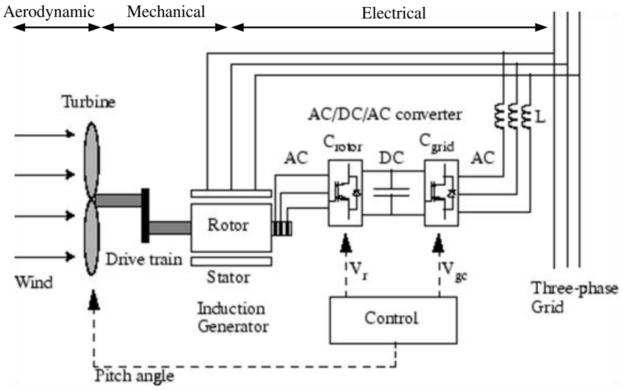


Figure-4. Double fed induction generator diagram.

2.1.1 Turbine modelling

Blades of wind turbine convert the wind power to mechanical power rotating the turbine shaft, maximum transferred power can be set in Betz equation (8) $P_m = \frac{1}{2}\rho \mathrm{A} c_p(\lambda, \beta) v_{wind}{}^3$ Cp Where ρ is density of Air density, A is the swept area, v_{wind} is the expected, mean wind speed value and is c_p the performance coefficient, the performance is the ratio between mechanical power in turbine rotor and the wind kinetic power. $c_p = \frac{P_m}{P_{wind}}$ λ is the Tip Speed Ratio (TSR) $\lambda = \frac{\omega_r}{v_{wind}}$ and defined as the ratio between the rotor synchronous speed and the velocity of wind

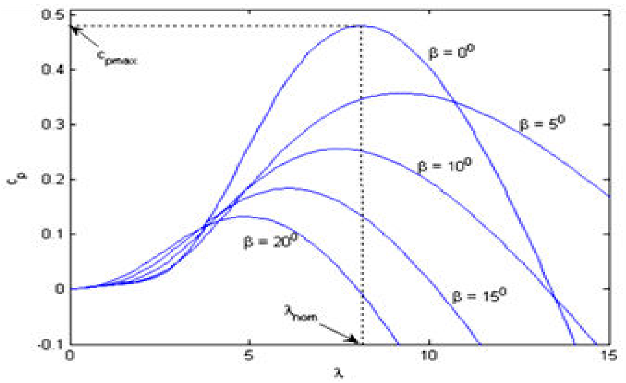


Figure-5. The relation between lamda with cp (Source MATLAB/SIMULINK software).

and presented as: ω_r represent rotor synchronous speed The performance coefficient is expressed in terms of tip speed ratio and blade pitch angle β as

$$c_p(\lambda,\beta)=c_1(\frac{c_2}{\lambda_i}-c_3\beta-c_4)e^{-(\frac{c_5}{\lambda_i})}+c_6\lambda$$

$$\frac{1}{\lambda_i}=\frac{1}{\lambda+0.08\beta}-\frac{0.035}{\beta^3+1}$$

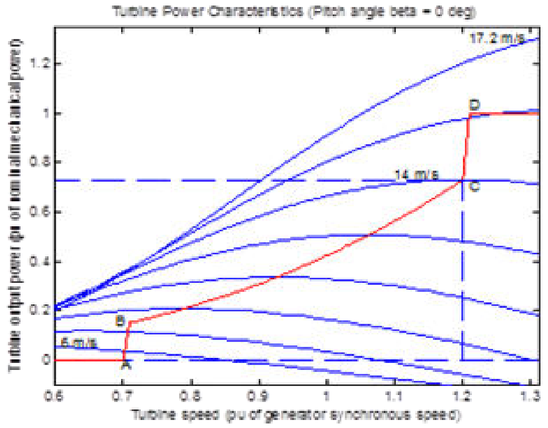


Figure-6. The relation of mechanical and electrical power depend of the wind speed (Source MATLAB/SIMULINK software).

2.1.2 Generator modelling

The Doubly-Fed Induction Generator (DFIG) concept has become one of the most favourable options in modern wind Power market to avoid the disadvantages of other types of WT such as Direct-in-line converter based ASGs, Doubly Fed Induction Generator DFIG System is used. Figure-4 shows a doubly fed induction generator (DFIG) with a four-quadrant ac-to-ac converter based on insulated gate bipolar transistors (IGBTs) connected to the rotor windings.

The stator in DFIG is directly connected to the AC grid, while the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Equivalent circuit and power flow equations can be presented as per Figure-7 and set of Ps, Qs, Pr and Qr [3].

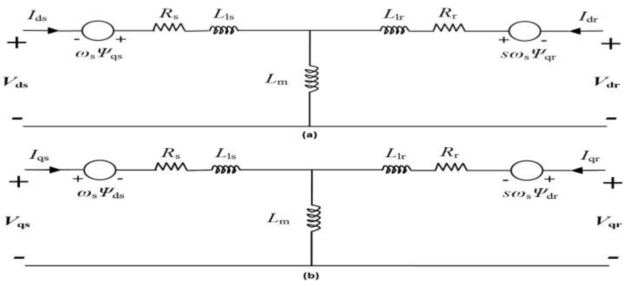


Figure-7. Equivalent circuit of DEIG [3].

$P_S= V_{Sd}\, i_{Sd}+v_{Sq} i_{Sq}$
$Q_S=V_{Sq} i_{Sd} + V_{Sd} i_{Sq}$
$P_{r=}V_{rd} i_{rd}+V_{Sq} i_{rq}$
$Q_S = V_{rq} i_{rd} + V_{rd} i_{rq}$

2.1.3 Modelling of back to back convertor

DFIG introduces good performance for controlling the active and reactive power generation, in a reasonable ± 30% range around the generator's nominal power [4]. The stator of the DFIG is connected to the grid while the rotor is connected to the AC/DC/AC converter. Rotor side converter is C rotor and Grid Side. The convertors both have the capability for generating or absorbing power and could be used to control the power or the voltage at the grid terminals [[4]]. In DFIG, back to back PWM power convertors are used to control the active and reactive powers independently and instantaneously with respect to design limitations. The limit output active power in high wind speeds is controlled with respect to maximum CP under nominal. The power converters are used to operate the rotor in various. The back-to-back converter configuration consists of bidirectional power electronic IGBT. A simulation model for back to back converter controlled DFIG system is available in the standard Simulink library. The simulation model for Back to Back Converter Controlled DFIG is executed with Matlab/Simulink 2011a version.

2.1.4 Aggregated (reduced) modelling of wind farm

Due to the wind diversity turbines are scattered in large area of on a site of large to help smooth the irregularity of wind. Modeling of wind farms for network integration studies is becoming an important issue. In a wind farm number of are increased as per farm size. Simulating each wind turbine for the whole wind farm leads to complexity and needs longer computational time. To reduce complexity and the computational time and the complexity, researchers simplify the whole wind farm by aggregated wind farm model (9). Reducing N wind turbines to a single wind turbine, the parameters for the equivalent machine are the active power in megawatts, the reactive power in megavolt amps reactive and the apparent power in megavolt amps. The parameters are given: Source

Peq = N * PMW per unit.
Qeq = N * Q MVAR per unit.
Seq = N * SMVA per unit.

MATLAB/SIMULINK software is used in the study analysis because of its powerful capabilities of solving power flow analyses in dynamic domain and it can solve the meshed distribution networks easily. Therefore, small to medium sized system's power flow can be analysed by this software either it is. Either positive sequence model or full multi-phase model.

2.1.5. Impact of grid-connected wind turbine systems

Connection of a new Wind Power Plant (WPP) to a power system may have negative impact on the network it may be connected, therefore Transmission System Operators (TSOs), normally ask for preliminary studies are performed with a focus on the WPP's impact on the grid. These studies are supported by mathematical models, which should reproduce with accuracy the WTG behaviour during some regular power system phenomena. Sources Voltage variations due the interconnection of wind power are the main problems with increasing level of penetration wind power with network of conventional generation stations.

In normal operational condition , the voltage quality of a wind turbine or a group of wind turbines may be assessed in terms of the following parameters:[1].

The voltage difference, ΔU, between the system and the connection point is given by

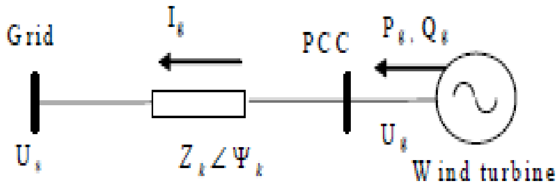


Figure-8. Simple system with an equivalent [6].

Voltage Equation indicates the relationship between the voltage and power transferred into the system. The voltage difference, ΔU, can be calculated with load flow methods as well as other simulation techniques [1]. The voltage at PCC should as per grid regulatory limits. Operation of wind turbines may affect the voltage in the connected network. This study introduces load-flow analysis to ensure that the farm installation does not bring the magnitude of the voltage outside the required limits.[5].

3. METHODOLOGY

The system is considered balance, therefore positive sequence of power flow; voltage and current are calculated using the MATLAB/Simulink at each instant of time.

To perform the assessment, the following system components have been modelled; wind model, rotor model, drive train model, double feed induction generator (DFIG) module converter models and connection line model. As the aim of the study is to assess the steady state and transient effect of wind farm on the existing grid therefore wind power plant WPP will be simulated as reduced model. Figure-9 presents discussed concept and the analysis will be done using the Matlab/Simulink software. The main scope of this study is to study the impact of level penetrating wind

In this study a farm of 50 MW maximum generation capacity is penetrated to an existing 132 grid network constructed from two power stations one of 273MW generation capacity and the other of 429MW. The network also includes 4 load buses. 132 kV overhead lines and underground cables are used to connect the power stations and load centres as introduced in table and (1) and Figure-9 as SLD. The effect of implementing the wind farm is analysed using the reduced mothed in MATLAB/SIMULINK software to assess the impact of the farm on flow of active and reactive power and bus voltage at the farm connection point and the PCC. Power station capacities and bus loads used in the analysis are tabulated in Tables 1 & 2.

First the Simulation was done for the system without connecting the wind farm with the system to get reference system and information about bus voltage, active and reactive power flow and current at the PCC without the WF. After the result is compare, the wind farm add to the system and see the effect of the wind farm on the reactive power and as a result its effect on the voltage control and power factor. Parameter values that control system to be within the limits of power quality required in grid code of the interconnected system under study. The assessment has been done with following system and operation conditions:

a) With wind farm connection but zero wind speed.

b) With 1x2.78 MW wind farm at full wind speed.

c) With 9x2.78 MW wind farm at full wind speed.

d) With 18x2.78 MW wind farm at full wind speed.

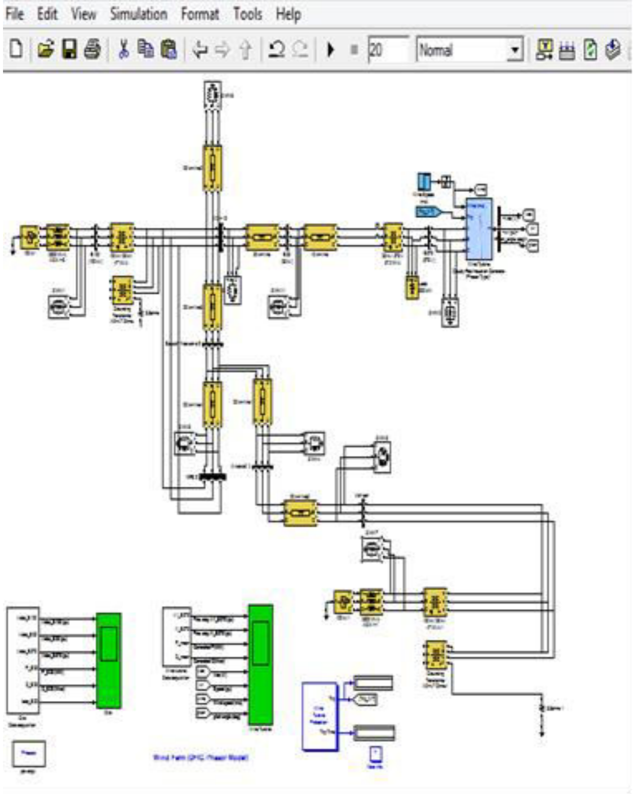


Figure-9. MATLAB /Simulink simulation.

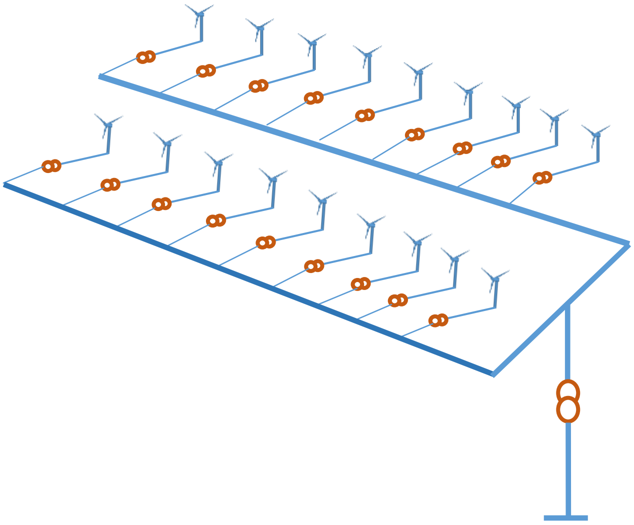


Figure-10. The 18x2.78 MW wind farm.

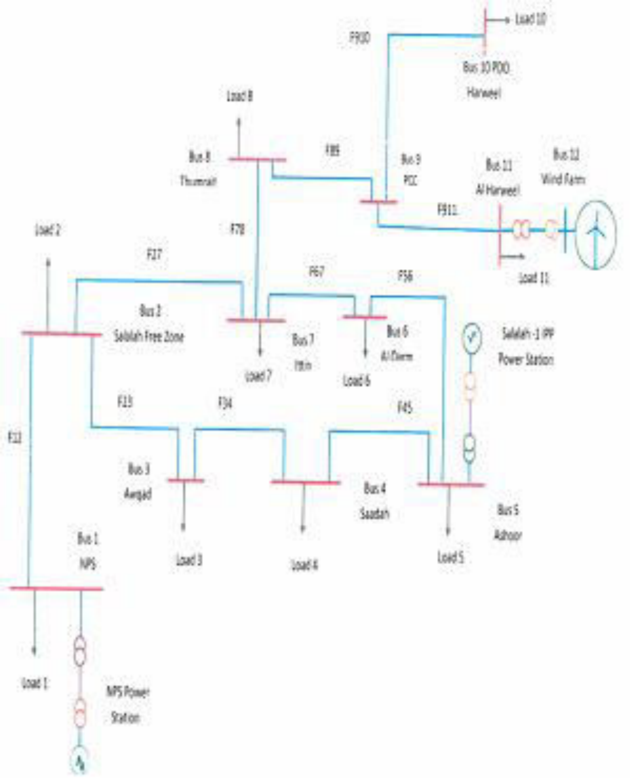


Figure-11. SLD of the system under analysis with aggregated WF.

Table-1. Power station capacities [7].

NPS	**273MW**
Salalah Free Zone	429MW

Table-2. Load data of grid [7].

Load	Active power MW	Reactive power MVAR
Al-Qaram	24.6	8.1
Ashoor	53.6	17.6
Awqad	102.4	33.6
Ittin	90.7	29.8
Saddah	57.7	19.0
Salalah free Zone	53.6	17.6
Thumariat	21.6	7.1
NPS	44.4	14.6

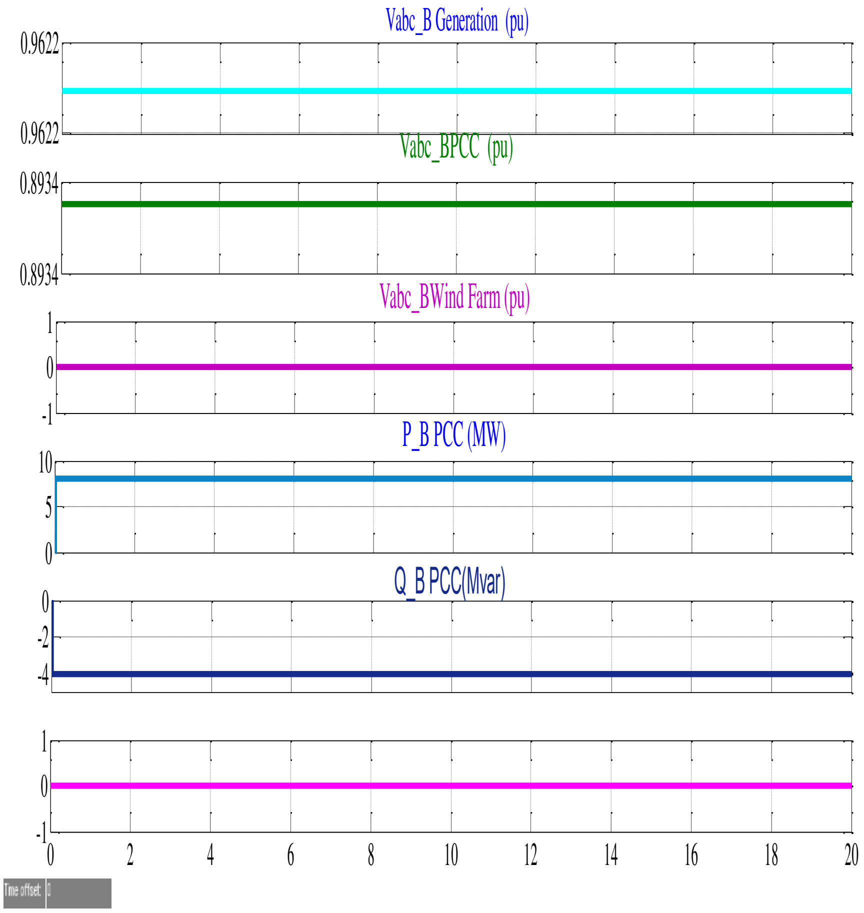


Figure-12. With wind farm connection but zero wind speed.

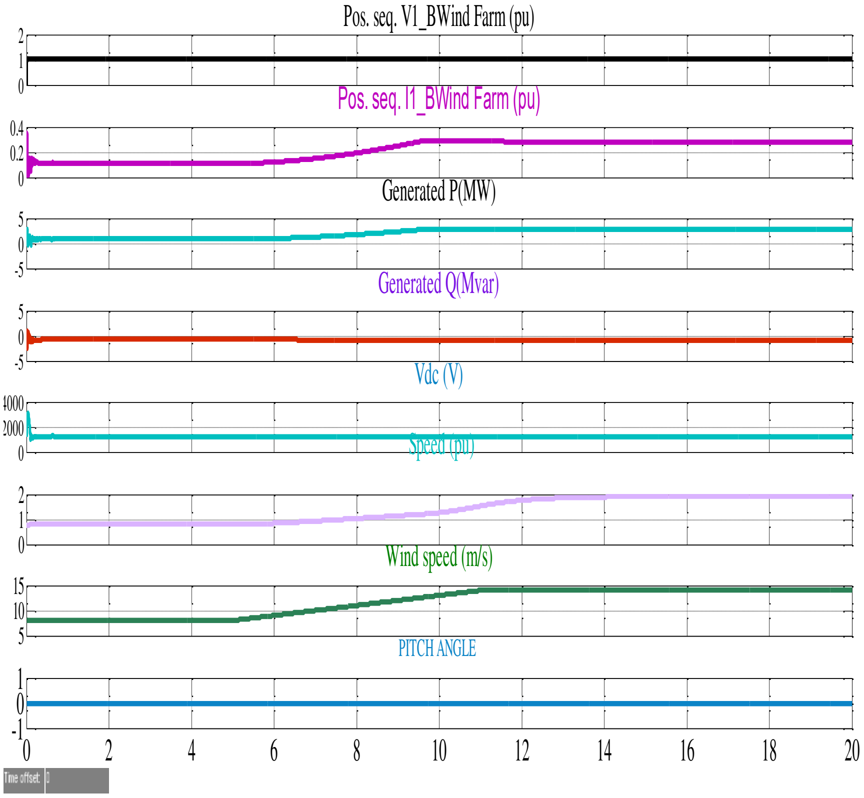


Figure-13. With 1x2.78 MW wind farm at full wind speed.

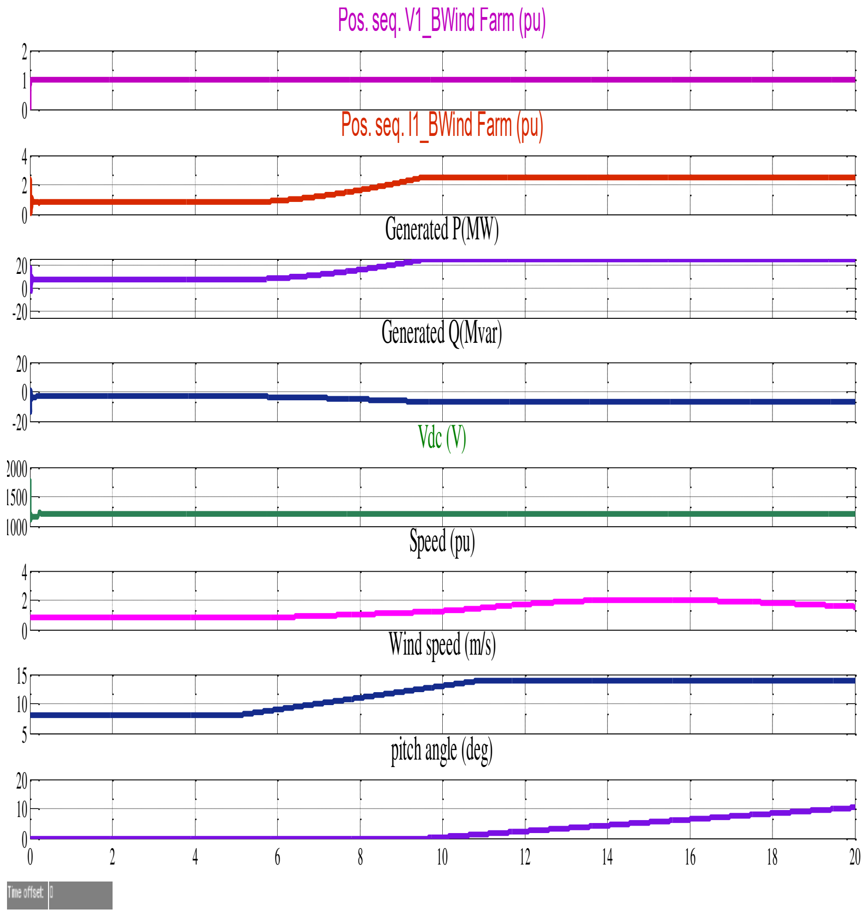


Figure-14. With 1x2.78 MW PCC at full wind speed.

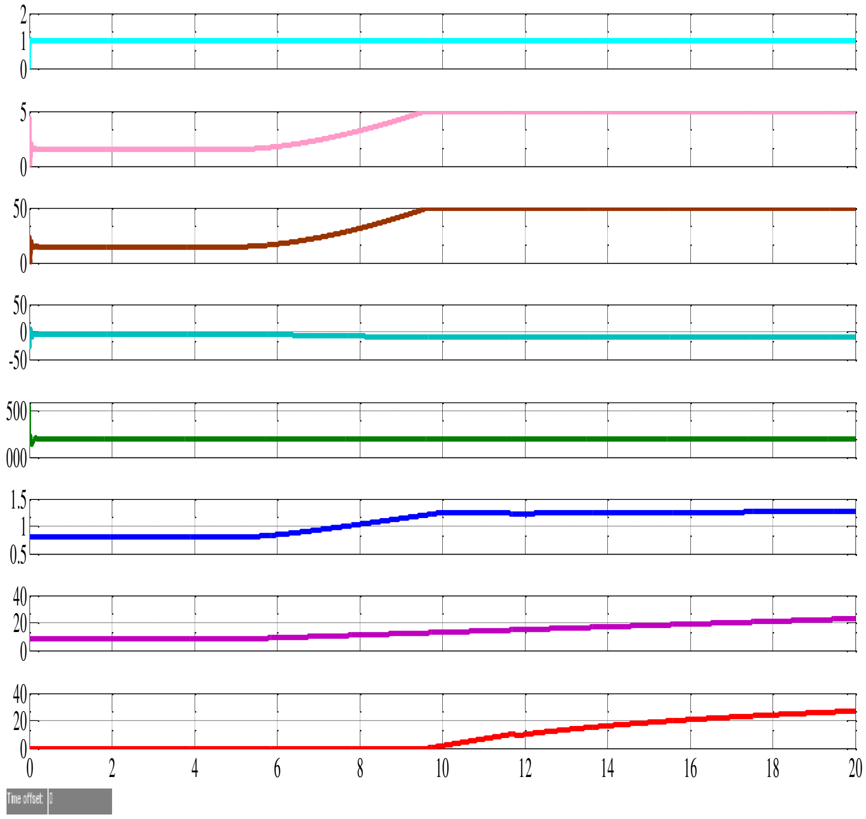


Figure-15. With 9x2.78 MW wind farm at full wind speed.

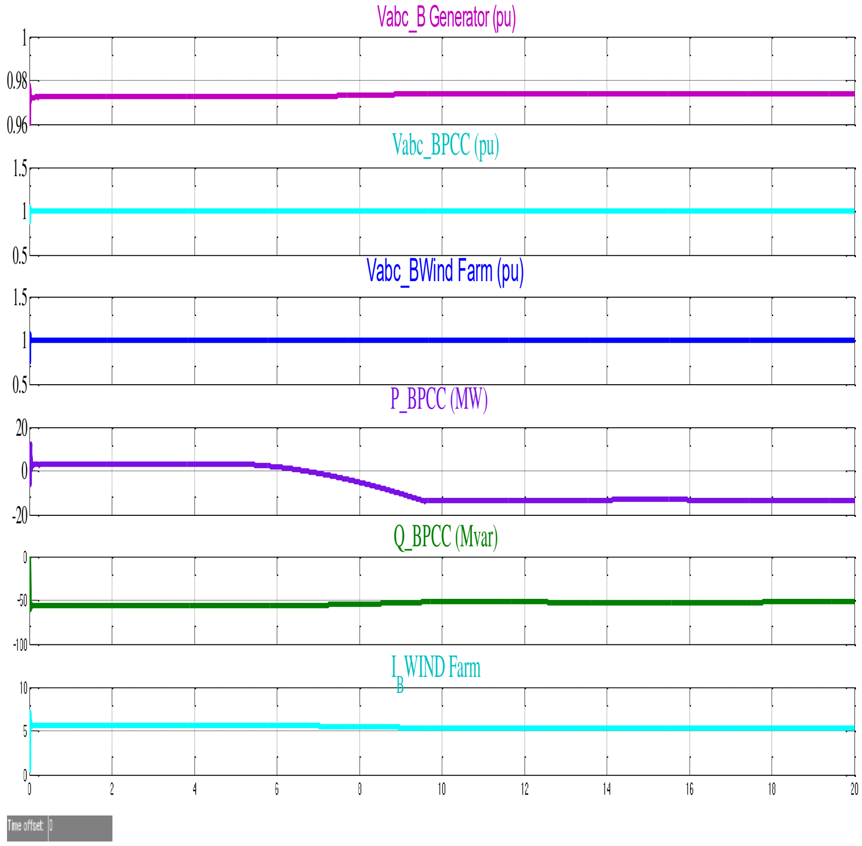


Figure-16. With 9x2.78 MW pcc farm at full wind speed.

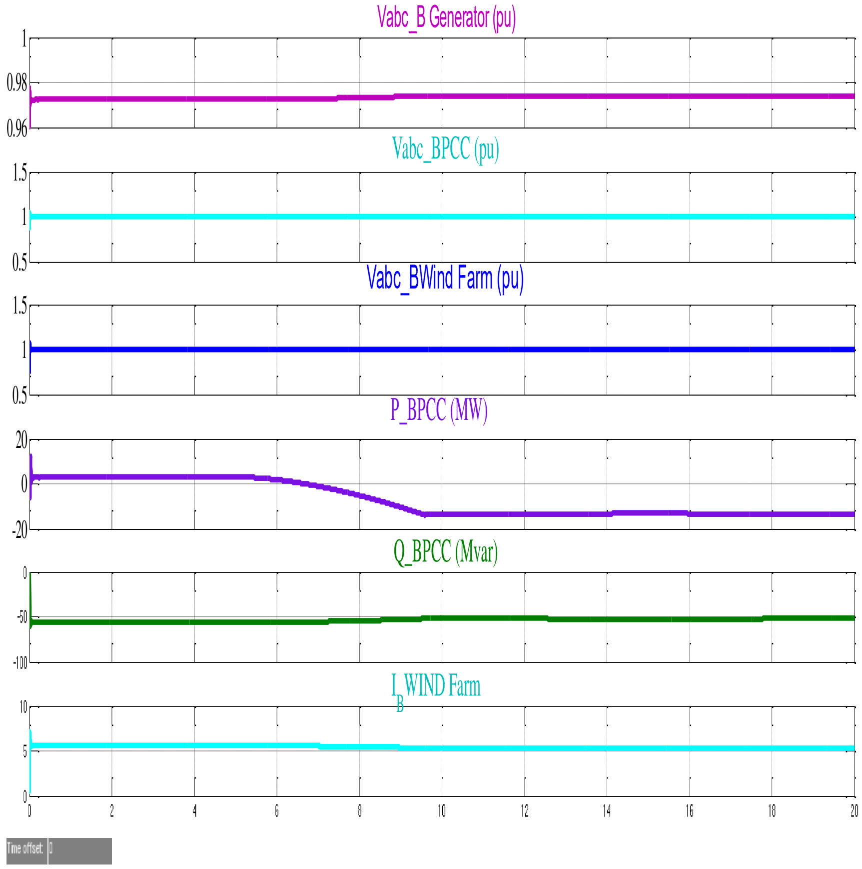


Figure-17. With 18x2.78 MW wind farm at full wind speed.

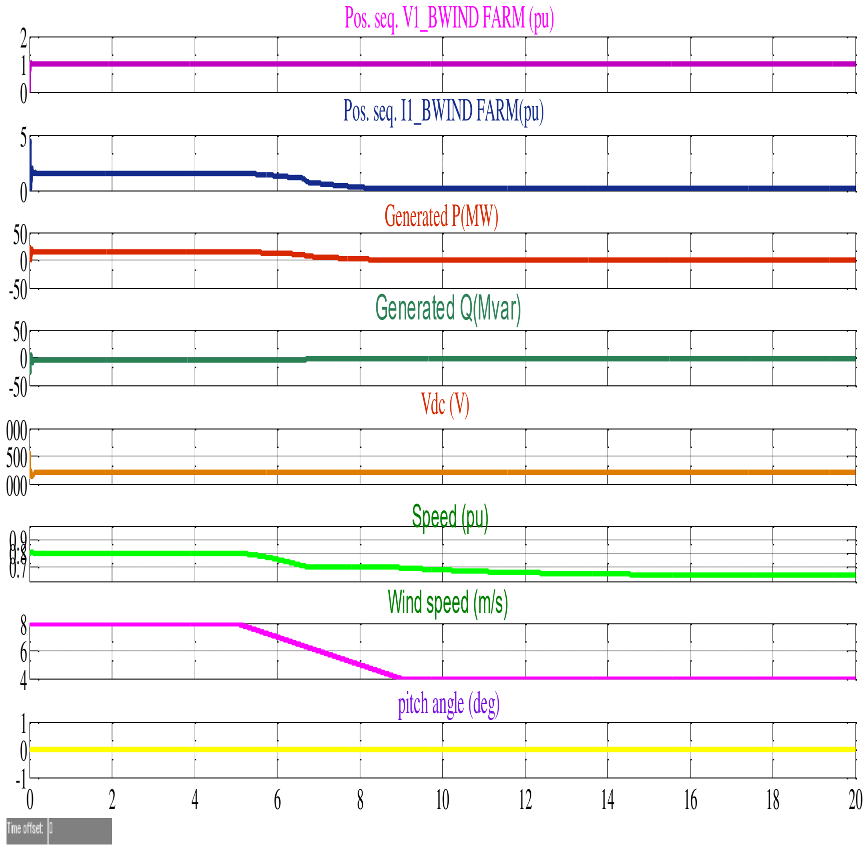


Figure-18. With 18x2.78 MW PCC at full wind speed.

4. RESULTS AND DISCUSSIONS

Figure-12 presents the load flow in the PCC without the WF been connected to the system, as the system is considered balance. In the figure bus voltage, current, active and reactive power is shown as output of the MATLAB/Simulink software. Those values are considered from to assess the impact of the WT farm at different penetration levels including 1, 25 and 50 MW. The characteristics and specification of the WT are set in the MATALB/Simulink in such a way to validate the output and operation control to be as per the specification of the turbine used in the analysis. The works have been done is stages, fist only one turbine is considered to be in operation and run the software to find the bus voltage, active and reactive power and current on WT bus and the point of common connecting PCC bus. The values are shown in Figures 13 & 14. The penetration level of the WF is increased by increasing the number of connected turbines to 9, Figures 15 & 16 introduce the voltage bus, power flow and current at WF and PCC buses. The same results are gained with the number of WT increased to 18 as shown in Figures 17 & 18. The results show that the aggregated method can be used to assess the impact of interconnecting WF to the existing grid and the values of active and reactive power flow increase direct proportional to the number of WT been in operation in the WF. Table 3 introduces the relation between number of turbines used in the WF and amount of active and reactive power flow in PCC and WF Bus.

No	Number of WT	WF power MW	Power at PCC MW
1	0	0	10
2	1	2.78	7.22
3	9	25	-10
4	18	50	-40

Table number of turbines and amount of active and reactive power flow in PCC and WF Bus.

Wind turbine characteristic can be operated in three conditions as per result. At speeds more than the rated value, 14 m/s in this case, the control of pitch angle has sensitive effect on keeping the rated speed with the acceptable limit to protect the turbine from over speed effect of wind which may cause fatigue of rotor if the wind speed increases more than 25 m/s.

CONCLUSIONS

From results it is concluded that the interconnection of a WF constructed from DFIG WT in the existing system under study can be done without negative impacts on the existing system. Also it is concluded that active and reactive power flow are increased as number of WT`s increase in the simulation which used the aggregate modelling of the system. Also it can be concluded that the DFIG reflects supporting effects to improve voltage at the PCC bus.

REFERENCES

[1] L. E. Singer and D. Peterson. 2016. International Energy Outlook 2016, vol. 484, no. May.

[2] C. Rica. No Title. pp. 2-5.

[3] E. P. Engineering. 2014. The Impact of Back-to-Back Converter used in Doubly Fed Induction Generator Driven by Wind Power. 3(17): 3614-3619.

[4] P. Chowdhury, I. Koley, and S. Sen. 2013. Modelling, simulation and control of a grid connected non conventional solar power generation system using. 2(4): 1183-1191.

[5] Z. Chen and S. Member. 2005. Issues of Connecting Wind Farms into Power Systems. pp. 1-6.

[6] G. Byeon, I. K. Park, and G. Jang. 2010. Modeling and Control of a Doubly-Fed Induction Generator (DFIG) Wind Power Generation System for Real-time Simulations. 5(1): 61-69.

[7] OETC Annual and C. Statement. Issue: April 2016 As Approved by the Authority for Electricity Regulation. no. April, 2016.

[8] The Central for climate and energy solution: Working together for the Environment and the energy. Climate for energy. Avalinable online in http://5.http://www.c2es.org/energy/source/renewables. Accessed: Nov. 23, 2016.

[9] Energy Procedia 74 (2015) 1162 – 1173 International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES15, Comparison between Aggregation Techniques for PMSG Wind Farm.