IMPACT OF WIND FARM ON POWER SYSTEM DYNAMICS AND STABILITY USING PSAT SIMULATION

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Abstract- *The electricity generation from the wind turbine varies from different times of day and seasons. This research paper provides an idea about the impact of wind farms in 14 bus interconnected system. 30 numbers of wind turbines with 2MVA ratings are connected in the bus of 6.6 KV voltage level. The impact of wind farms on power system dynamics and stability is studied using PSAT simulation. The static report of load flow is presented along with the voltage profile, power flow, and time domain in this report. The stability of the system is checked by the Eigenvalue analysis. The Eigenvalue analysis is done by the argand diagram. Roots of the equation are plotted to prove the system being stable. The 3 phase fault is predicted in an arbitrary bus which is cleared within a short period of time under the influence of windfarm. A model for the dynamic performance of a wind farm is presented. Moreover a wind speed model is briefly presented. The system gets more stable on the penetration of wind farms. Thus, the research paper has an idea of using a wind farm in the interconnected system as an advantage of stability and reliability for the better power system dynamics.*

Key Words: Power system, PSAT simulation, Stability, Power coefficient, Automatic voltage Regulator, Doubly fed induction Generator, IEEE-14 Bus

1. INTRODUCTION

The power system is considered as a complex system that comes into existence many years ago in response to the economic growth and rising power demand. The use of renewable energy in the system causes the modern system to be highly complex. The system of various buses with different or the same voltage level which increases reliability and increases load sharing is called interconnected system [1]. Here standard IEEE-14 bus system has been used. This bus system is observed for various analyses, such as load flow, Eigenvalue analysis, and contingency analysis. The wind farm has a huge impact on the 14 bus system after its penetration incorrect location. The Eigenvalue analysis makes us clear about the system is more stable after penetrating wind farm in the PSAT simulation. The fault is predicted in the bus system which led to the contingency analysis after the penetration of wind farms. Hence this project is centralized in the impact of wind farms on power system dynamics and stability using PSAT simulation.

2. OVERVIEW OF THE PROJECT

The cause of wind is due to the uneven warming of the earth by the sun, which makes the wind never depleting a free source of energy. Wind turbines are considered as an alternative energy source that uses this renewable wind energy to generate electricity. Since wind turbines are powered solely by wind, they do not cause pollution and are therefore environmentally friendly. Wind turns leaves that are connected to a generator, the generator then makes power (more on that later).

The given equation clarifies that power contains in the wind is the form of kinetic energy:

$$P = 0.5\rho AV^3$$

Where, ρ= Density of air, (kg/m^3),
A= Area covered that is normal to the wind speed (m^2),
V = Speed of wind (m/s),
P = Wind power

The wind turbines have horizontal and vertical axis orientation. They are connected with a generator that may be synchronous or asynchronous.

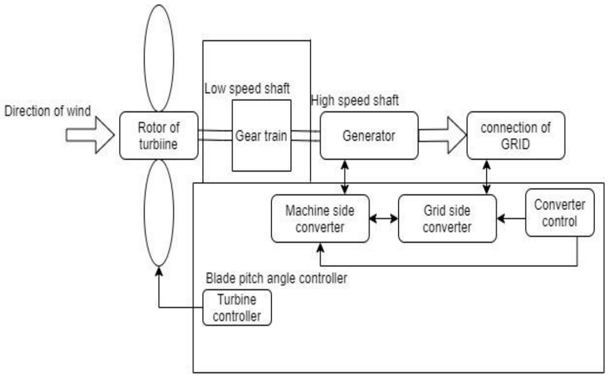


Fig-1: wind Turbine diagram

Some categories of wind turbine generators are constant speed wind turbine with squirrel cage induction generator, variable speed wind turbine with doubly fed (wound rotor) induction generator and variable speed wind turbine with direct drive synchronous generator are also various categories. [2]

2.1 Doubly fed induction generator (DFIG)

In the project the DFIG is used due to advantages such as high energy efficiency and controllability. Because of this, the variable speed wind turbine using DFIG is getting popularity. It is normally a standard, wound rotor induction generator which has the voltage source converter directly connected towards the slip rings of the rotor. The power converter is connected to the rotor winding whereas the stator winding is directly coupled with the grid which as shown in the figure.

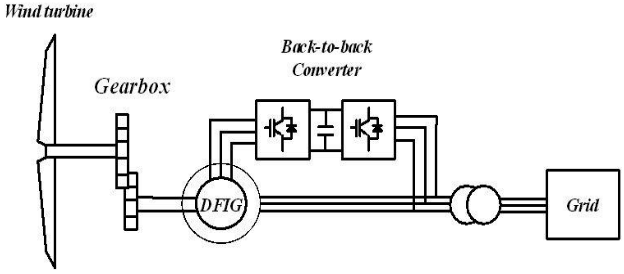


Fig -2: Doubly fed induction generator

The model of wind turbine with DFIG is shown in the figure below:

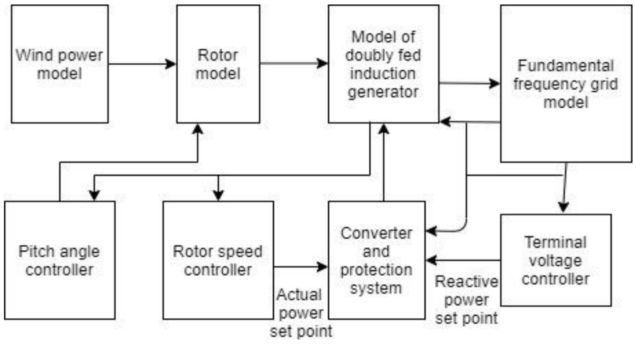


Fig -3: Model of wind turbine

As shown in the figure the converter system present enable two different way of transfer of power. The grid side converter present provides the DC supply in the converter of the rotor side which produces a variable frequency 3Φ supply to the generator rotor slip rings. The variable-speed operation of the manipulation of rotor voltage is due to the variable voltage into the rotor at slip frequency which enables control of the generator operating condition. For the case of low speed, the subsynchronous operating mode arises due to a drop in the rotor speed of the generator. In such cases the DFIG rotors took the power from the grid. [3]

2.2 Wind Power

Wind has been used by humanity from earlier ages. Their use can be traced back to the Middle Ages. Wind is used for pumping of water and grind grain for more than 3,000 years. In earlier times, fossil fuels were also considered as an important source of electricity. The use of fossil fuel causes more environmental damage and people were seeking for alternative resources. The cheapest, can be available anywhere, non-depleting, and has low environmental risk is wind energy that is adopted as the main energy source for the generation of power in the world. The different prototype of a wind turbine is developed. Scientists and researchers found that the wind turbine worked well under different site conditions. The use of wind energy for the generation of electricity was used by the end of the nineteenth century. The development and utilization of wind energy reach to peak and later developed offshore wind technology. Wind energy is more sophisticated and can produce more electricity than its predecessor. Because of this in the present, it becomes the most reliable source of energy. The power demand throughout the world is increasing day by day; the wind energy is one of the fastest-growing power sources that meet the present electricity needs globally. The attractive cost of generation is the major factor for the increment of wind energy as the major renewable source of energy. The cost of wind power can be lower compared with other most electricity generation technologies that are available in the present world.

Power contained in the wind is the form of kinetic energy. It is given as the following equation as:

$P = 0.5\rho A V^3$ ……………………………………………………… (i)

The manufacturing characteristic is the factor due to which the total wind energy can't be extracted from the wind turbine. According to the aerodynamic theories, the extracted power from the wind turbine can be expressed considering its effectiveness of conversion in wind energy into mechanical energy of wind turbine [Power coefficient $Cp(\lambda,\beta)$] and it can be given as :

$P = 0.5\rho\pi R^2 V^3 Cp(\lambda,\beta)$ ……………………………………… (ii)

$Cp(\lambda,\beta)$ It depends on the manufacture and it is a factor that represents the amount of wind energy that is converted to the mechanical power by a wind turbine. It is a function of λ (TSR, Tip speed ratio) and β (Blade pitch angle). TSR can be obtained from the manufacturer data and depends on the wind turbine geometry. Tip Speed Ratio(TSR), which is given by:

$\lambda = \frac{\omega t * R}{V}$ ……………………………………………………… (iii)

Where, ω_t = Wind turbine angular speed

The aerodynamic mechanical torque (Tm) of the wind turbine is given by the following equation:

$T_m = \frac{0.5\rho\pi R^2 V^3 Cp(\lambda,\beta)}{\lambda}$ ………………………………………… (iv)

$C_m = \frac{Cp(\lambda,\beta)}{\lambda}$ ……………………………………………………… (v)

$T_m = 0.5\rho\pi R^2 V^3 C_m$ ……………………………………………(vi)

An empirical equation which can be used to model for $Cp(\lambda, \beta)$ is

given by: $Cp(\lambda, \beta) = C_1(C_2 * \frac{1}{\lambda_i} - C_3 * \beta - C_4) e^{\frac{C_5}{\lambda i}} + C_6 \lambda$ ....(vii)

where λ_i is given by ;

$\frac{1}{\lambda i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$ ....(viii)

Values of C_1 to C_6 vary from one turbine to another. But typical values of those parameters are given by, $C_1 = 0.5176$, $C_2 = 116$, $C_3 = 0.4$, $C_4 = 5$, $C_5 = 21$, $C_6 = 0.0068$. [2]

2.3 Eigen Value Analysis

The investigation of small signal stability in the case of a power system is increasing day by day which is considered as the vital work in comparison with usual transient stability investigation. For studying the small-signal stability the Eigenvalue analysis is used. The results are difficult to be known through the study of transient stability analysis. So, studying eigenvalues does not have a history as long as that of transient stability analysis in the power systems area; the results obtained from the methods are difficult to verify experimentally. Because of this simulation software package for power system dynamics should be used for studying small signal stability carefully before applying to the real fields. In this paper, the Eigenvalue analysis capabilities of power system network with the use of dynamic simulation software package and the results obtained from the analysis are compared [4]

2.3.1 S-plane

The S plane is considered as the complex plane in which Laplace transforms are graphed in the fields of mathematics and engineering. It is a mathematical domain where, instead of viewing process in the time domain modelled with time best function, they are viewed with an equation in the frequency domain. The stability of the system is identified from the roots of the equation. The more the system becomes stable when more the roots are present towards the left-hand side of the plane. The system is considered unstable when one or more than on roots are present at the right side of the s plane.

2.3.2 Small signal stability

Small signal stability analysis is the stability of the power system network when it is subjected to small disturbances. When the small disturbance in the power system network can be suppressed and the deviation state variable remains for a longer period of time then the power system becomes stable. On the other hand if the magnitude of the oscillation increase for sustain indefinite the system becomes unstable. Many factors affect the power system small signal stability such as initial operating condition, strength of the electrical connection between the components of a power system network; various control devices characteristics, etc. The power system must be carried out the small signal stability analysis to access the network in other specified operating condition: small-signal stability is the inevitable and principal task of power system analysis. Any power system that is unstable in terms of small-signal stability cannot operate in practice. [5]

2.4 Contingency Analysis

In the energy management system the contingency analysis is the well-known function. The contingency analysis is the major task for the planning and the operation of the power system. In general, an outage of one transmission line or transformer may lead to overloads in other branches and/or sudden system voltage rise or drop. This type of analysis is used for the calculation of violation. Contingency can be defined as the non-functionality in the power system of a device such as a generator, transformer, transmission line, and more or the change of the device state which may include the possibility in a transformer substation of an unplanned opened circuit breaker. The main purpose of the contingency analysis to identify the deviation in the functioning of a device that occurred after a fault has been removed. [6]

3. METHODOLOGY

Here, PSAT is used for static and dynamic analysis of the electric power system. It is the MATLAB toolbox that helps to control the power system.[7] The method we are involved in accomplishing the project includes data collection from IEEE. After the collection of data the data calculation is done which is followed by PSAT simulation in MATLAB. This gives a result that is compared with the desired result and we proceed to analyze data if the result is obtained. This will lead us to a conclusion and final result. The sequential progression of MATLAB circuit construction and analysis of the result is done in a process which is shown in the flowchart below:

3.1 Flowchart

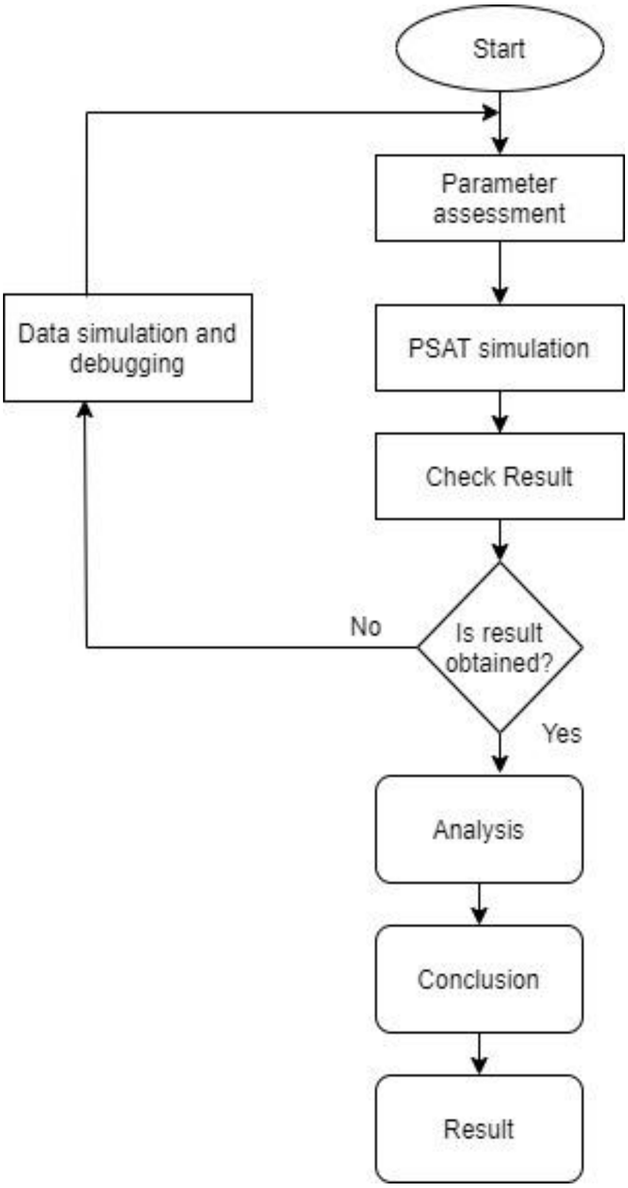


Fig-4: Work flow diagram

3.2 Parameters

The parameter assessment is performed by using the resistance and reactance between sending and receiving end voltage. Similarly, other parameters which are also included of the IEEE 14 bus system are mentioned below:

Sending End Bus	Receiving End	Resistance PU	Reactance PU	Half Susceptance	Transformer
1	2	0.01938	0.05917	0.0264	1
2	3	0.04699	0.19797	0.0219	1
2	4	0.05811	0.017632	0.0187	1
1	5	0.05403	0.22304	0.0246	1
2	5	0.05695	0.17388	0.0170	1
3	4	0.06701	0.171.03	0.0173	1
4	5	0.013350	0.04211	0.0064	1
5	6	0	0.25202	0	1
4	7	0	0.20912	0	0.932
7	8	0	0.17615	0	0.978
4	9	0	0.55618	0	1
7	9	0	0.11001	0	0.969
9	10	0.03181	0.0845	0	1
6	11	0.09498	0.1989	0	1
6	12	0.12291	0.25581	0	1
6	13	0.06615	0.13027	0	1
9	14	0.012711	0.27038	0	1
10	11	0.082050	0.19207	0	1
12	13	0.220922	0.19988	0	1
13	14	0.17090	0.34802	0	1

Bus No	Bus Code	Voltage Magnitude	Angle degree	Load MW	Load MVAR
1	1	1.060	0	30.88	17.78
2	2	1.045	0	0	0
3	2	1.010	0	131.88	26.6
4	0	1	0	66.92	10
5	0	1	0	10.64	2.24
6	2	1.017	0	15.68	10.5
7	0	1.09	0	0	0
8	2	1	0	0	0
9	0	1	0	41.30	23.24
10	0	1	0	12.60	8.12
11	0	1	0	4.90	2.52
12	0	1	0	8.54	2.24
13	0	1	0	18.90	8.12
14	0	1	0	20.86	7

Bus No	Bus Code	Gen. MW	Gen. MVAR	Gen. Qmin	Gen Qmax	Injected MVAR
1	1	40	-40	0	0	0
2	2	232	0	-40	50	0
3	2	0	0	0	40	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	2	0	0	-6	24	0
7	0	0	0	0	0	0
8	2	0	0	-6	24	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0

Source: IEEE 14-Bus data sheet

4. SIMULATION RESULT

4.1 Fourteen Bus systems without wind farm

In PSAT, load flow analysis was performed using Newton Raphson's method. It takes several iterations for the power flow and Trapezoidal integration method for time-domain simulation. In this interconnected system, the slack bus is placed in BUS 1. The slack bus works as a balancing unit under various fluctuations in generation and consumption. PV bus is placed in BUS-2. Generator with AVR and TG are placed in BUS 2, BUS 6, BUS 3, and BUS 8. The 11KV voltage level in BUS5 is steeped down to 6.6KV in BUS6. Also in BUS 4 to BUS 9, BUS 4 to BUS 7 and from 18KV to 6.6KV in BUS 8 to BUS 7. Thus three voltage levels are used in 14 BUS interconnected systems.

The model of 14-Bus system is shown below:

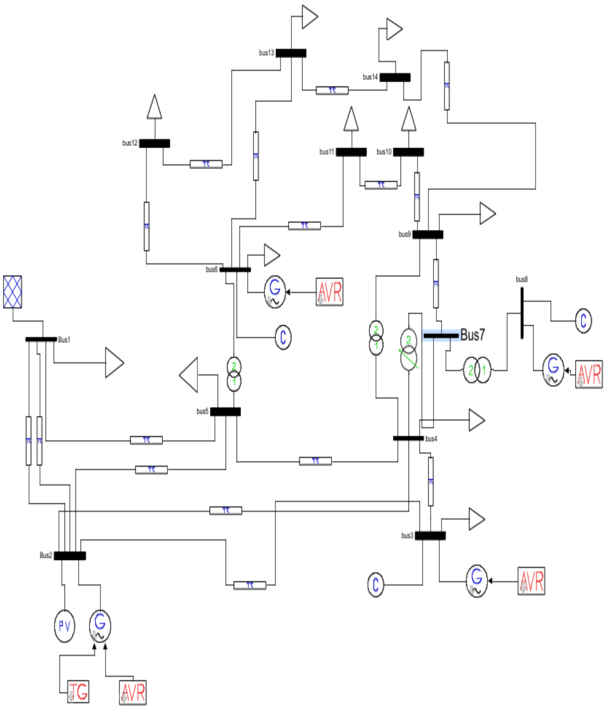


Fig-5: Model of 14-Bus system

When we do load flow analysis for 14 bus system, the power flow is obtained in 0.2 sec.

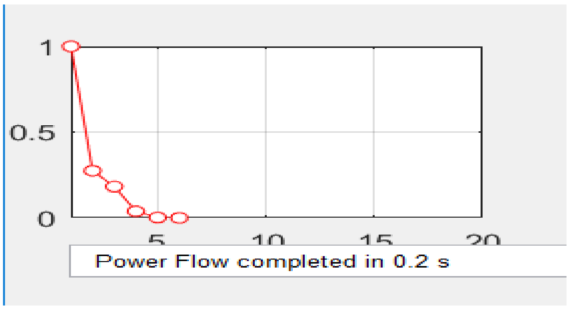


Fig-6: Power flow of 14-Bus system

The power flow is performed using the NR method. This took 6 iterations with maximum convergence error of $5.481*10^{-6}$. On load flow, the initialization of the synchronous machine is completed. When we performed time-domain simulation by using trapezoidal integration method, it took 7.497sec

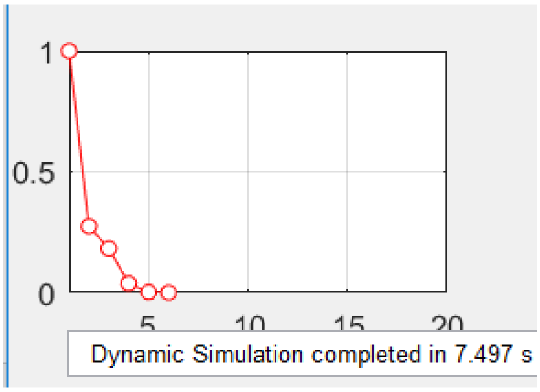


Fig-7: Time domain of 14-Bus system

Time-domain simulation includes the Trapezoidal integration method. In this 14 bus system, there is no penetration file set. The simulation time of the dynamic behavior took several steps which completed in the percentage of the time. Thus dynamic simulation completed in 7.5497sec. When we took a static report we found the stable values.

The voltage profile of 14-Bus system without wind farm is shown below:

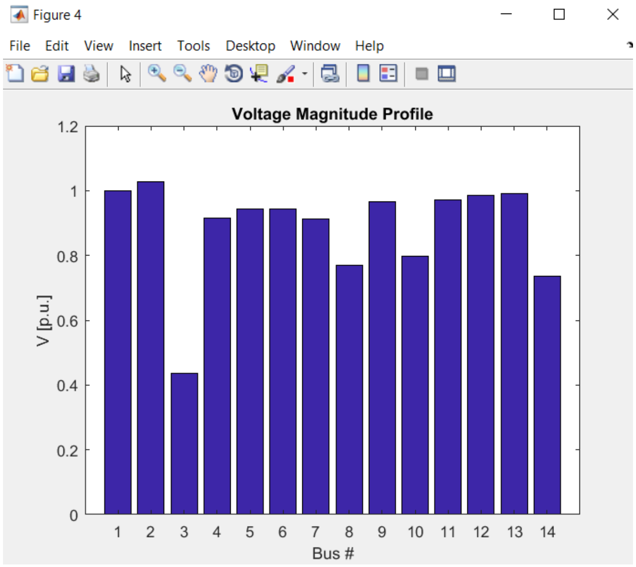
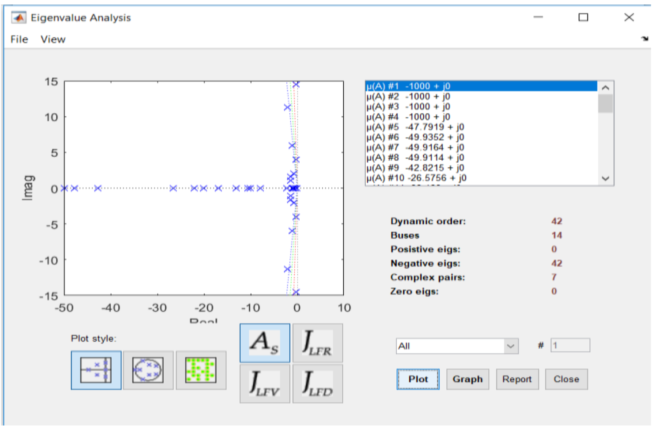


Fig-8: Voltage profile of 14-Bus system

Several SSC (static synchronous compensator) is used in the 14 bus system .BUS-6, BUS-3, and BUS-8 are connected with SSC each. The voltage level is seen dropping in BUS, However, the voltage level maintained in overall BUSES.

The Eigenvalue analysis of 14-Bus system which shows the system being stable is shown below with a concept of S-plane:



μ(A) #1 -1000 + j0
μ(A) #2 -1000 + j0
μ(A) #3 -1000 + j0
μ(A) #4 -1000 + j0
μ(A) #5 -47.7919 + j0
μ(A) #6 -49.9352 + j0
μ(A) #7 -49.9164 + j0
μ(A) #8 -49.9114 + j0
μ(A) #9 -42.8215 + j0
μ(A) #10 -26.5756 + j0

Dynamic order:	42
Buses	14
Posistive eigs:	0
Negative eigs:	42
Complex pairs:	7
Zero eigs:	0

Fig-9: Eigen value analysis of 14-Bus system

In the 14 BUS system, the system is well synchronized and voltage profile is maintained. There are 42 roots in the left of the s plane. the system is seen stable in s plane and z-plane both.

The plot of rotor angle Vs time for 14-Bus system is shown below:

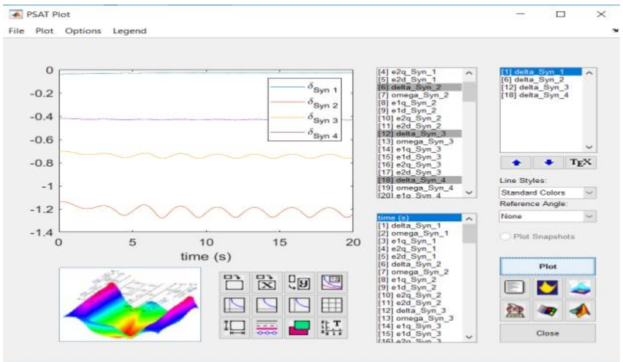


Fig-9: Plot of rotor angle Vs time for 14-Bus system

Since we have used 4 dynamics components in the system, we need to see the plot of the rotor angle of all 4 synchronous generator versus time, the oscillation of the rotor angle is damped within the short period of time which makes the system dynamically stable.

4.2 Fourteen Bus systems with wind farm

The penetration of wind farm in the BUS-1 is not possible because the singularity is likely in this case. The penetration in the BUS-14 is taken as a case for study. This modal below shows the 14 bus system with a wind farm with 30 wind turbines with a 2MVA rating.

The model of 14-Bus system with wind farm is shown below:

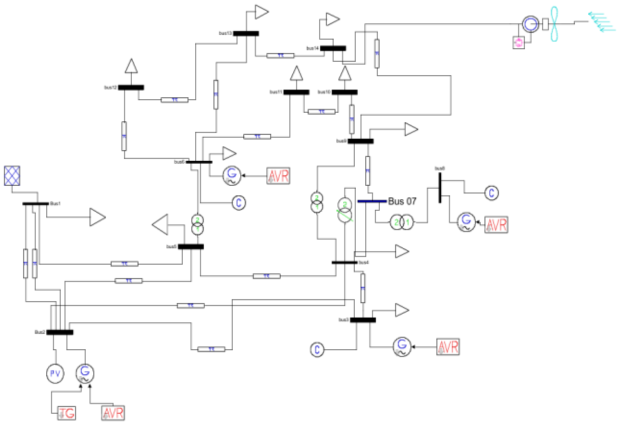
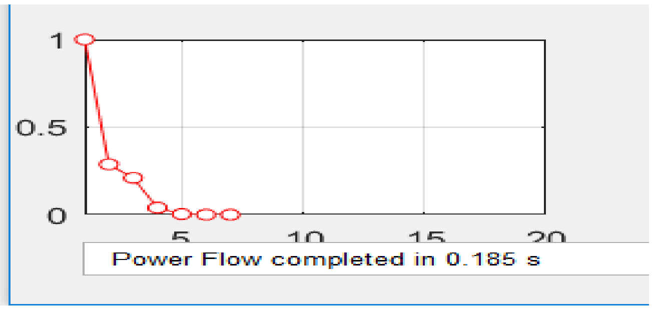


Fig-10: 14-Bus system with wind farm

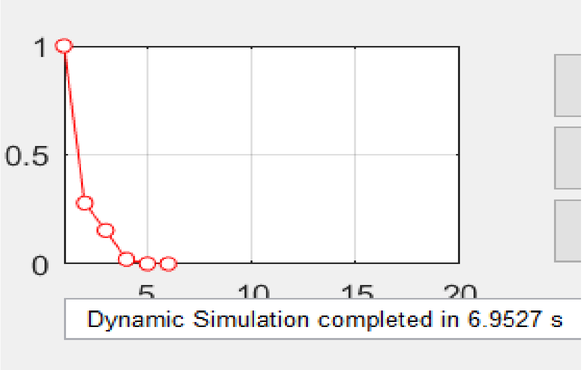
When we perform load flow analysis for 14 bus systems with wind turbines being synchronized in the grid, the power flow is obtained in 0.185 sec.



Power Flow completed in 0.185 s

Fig-11: Power flow of 14-Bus system with wind farm

When we perform time-domain simulation by using trapezoidal integration method for 14 bus system with the wind turbine, it took 6.9527sec



Dynamic Simulation completed in 6.9527 s

Fig-12: Time domain of 14-Bus system with wind farm

The voltage profile of 14-Bus system with wind farm is shown below:

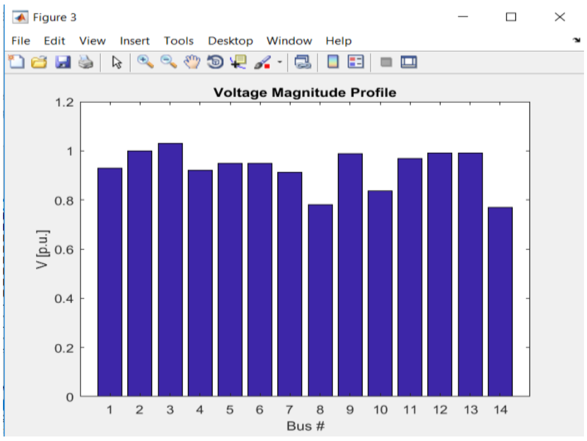
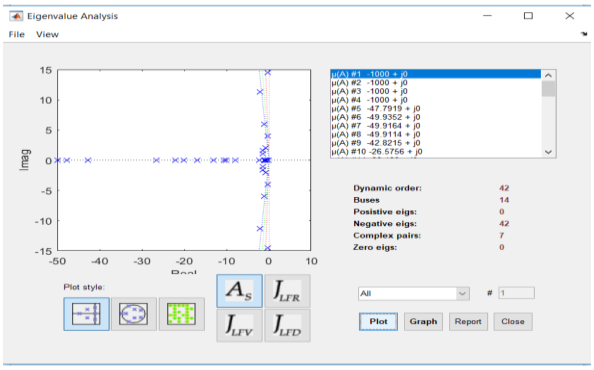


Fig-13: Voltage profile of 14-Bus system with wind farm

The Eigenvalue analysis of 14-Bus system with wind farm which shows the system being stable is shown below with a concept of S-plane:



μ(A) #1 -1000 + j0
μ(A) #2 -1000 + j0
μ(A) #3 -1000 + j0
μ(A) #4 -1000 + j0
μ(A) #5 -47.7919 + j0
μ(A) #6 -49.9352 + j0
μ(A) #7 -49.9164 + j0
μ(A) #8 -49.9114 + j0
μ(A) #9 -42.8215 + j0
μ(A) #10 -26.5756 + j0

Dynamic order:	42
Buses	14
Posistive eigs:	0
Negative eigs:	42
Complex pairs:	7
Zero eigs:	0

Fig-14: Eigenvalue analysis of 14-Bus system with wind farm

The plot of rotor angle Vs time for 14-Bus system with wind farm is shown below:

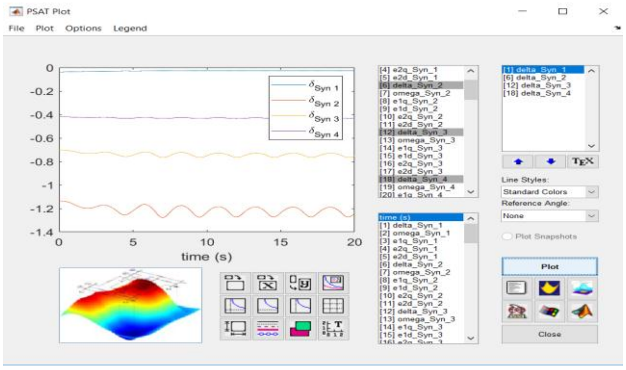


Fig-15: Rotor angle Vs time for 14-Bus system with wind farm

4.3Fourteen Bus system with wind farm predicting 3 phase fault at Bus 7:

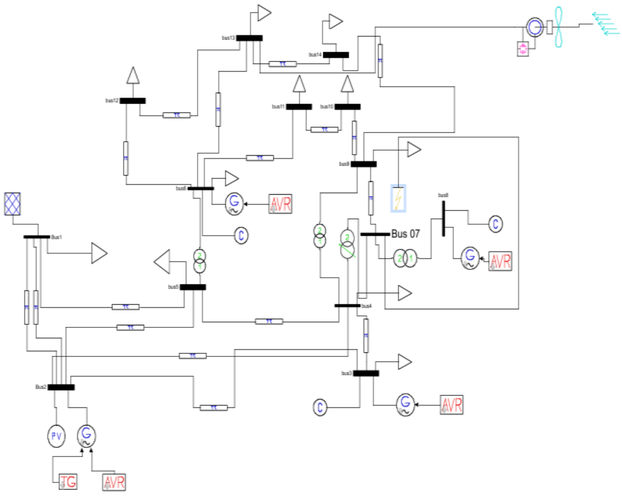
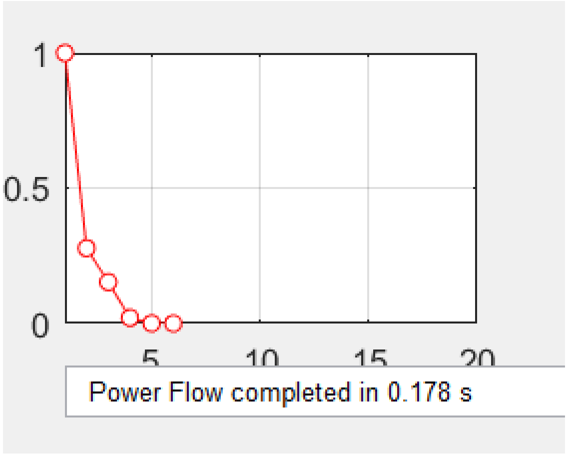


Fig-16:14-Bus system with wind farm after predicting fault at bus 7

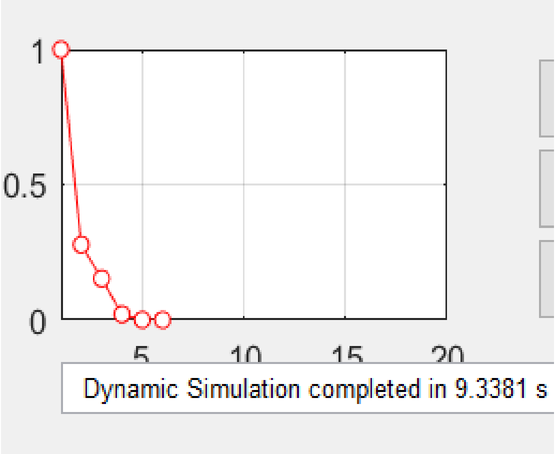
When we perform load flow analysis for 14 bus system with wind turbine being synchronized in the grid after creating a fault in bus7, the power flow is obtained in 0.178sec



Power Flow completed in 0.178 s

Fig-17: Power flow of 14-Bus system with wind farm and fault

hence we perform time-domain simulation by using trapezoidal integration method for 14 bus system with wind turbine after fault, it took 9.3381sec



Dynamic Simulation completed in 9.3381 s

Fig-18: Time domain of 14-Bus system with wind farm and fault

The voltage profile of 14-Bus system with wind farm after fault is shown below:

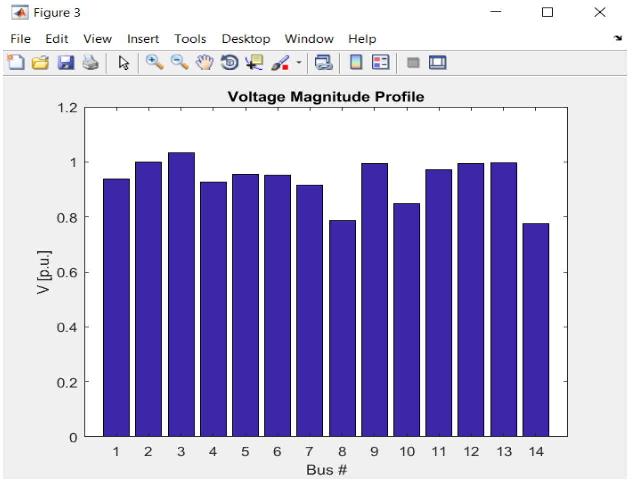
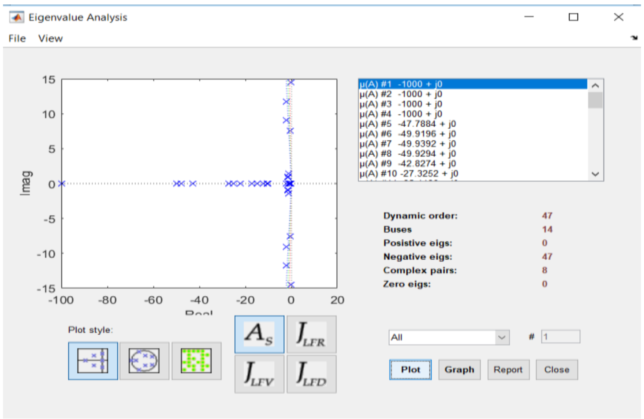


Fig-19: Voltage profile of 14-Bus system with wind farm and fault

The Eigenvalue analysis of 14-Bus system with wind farm after fault which shows the system being stable is shown below with a concept of S-plane:



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μ(A) #1  -1000 + j0
μ(A) #2  -1000 + j0
μ(A) #3  -1000 + j0
μ(A) #4  -1000 + j0
μ(A) #5  -47.7884 + j0
μ(A) #6  -49.9196 + j0
μ(A) #7  -49.9392 + j0
μ(A) #8  -49.9294 + j0
μ(A) #9  -42.8274 + j0
μ(A) #10 -27.3252 + j0

Dynamic order:       47
Buses                14
Posistive eigs:      0
Negative eigs:       47
Complex pairs:       8
Zero eigs:           0
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Fig-20: Eigenvalue analysis of 14-Bus system with wind farm and fault

The plot of rotor angle Vs time for 14-Bus system with wind farm after fault is shown below:

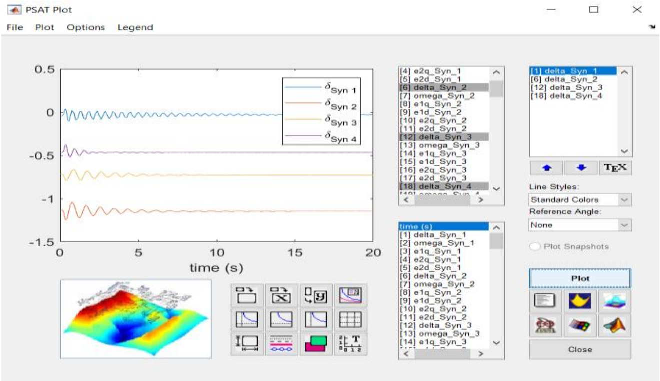

Fig-21: Rotor angle Vs time for 14-Bus system with wind farm and fault

5. CONCLUSIONS AND RECOMMENDATION

The result of the impact of wind farms in the IEEE 14 Bus system with and without fault is compared. The dynamic response of the system is analyzed. Under the several attempts in the penetration of wind farms in different buses among 14 buses, the penetration of wind farms must not be done in bus 1 and can be penetrated in all other buses after matching the voltage level. While comparing the fault clearing time and Eigenvalue analysis, it was concluded the best location for the wind farm is bus14. Wind farm should not be locate randomly because it has an impact on the system stability. The 14 bus interconnected system becomes more stable on proper placement and penetration of wind farms with a suitable number of wind farms and suitable ratings. Thus, the impact of the wind farm on power system dynamics and stability using PSAT simulation is done and it was found that the system gets more stable and has better dynamics response after the analysis which is done based on PSAT simulation outputs.

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