

LOAD FLOW ANALYSIS OF AN ENHANCED IEEE 14 BUS TRANSMISSION SYSTEM WITH A WIND FARM CONNECTED WITH ANYONE BUS OF IEEE 14 BUS

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Abstract: This paper presents MATLAB Simulation and load flow analysis of an Enhanced IEEE 14 Bus System with a wind Farm connected with anyone bus of IEEE 14 Bus Transmission System. Load Flow analysis is the most important part of the Electric power studies and design. It is important for planning, operation, economic scheduling and exchange of electric power between utilities. From it can be obtained the real and reactive power voltage magnitude and phase angle at each bus and the complex power flowing over each transmission line in order to have an efficient operating power system. A load flow analysis takes more time to produce accurate results because of continuously changing in load demand and power generation. In this analysis iterative or Numerical methods are used. In these iterative techniques are included Gauss Seidel and Newton Raphson method in solving all these methods a lot of iteration is used to get accurate result which is very enlarged or lengthy process and also difficult to solve by hand and consumes more time. The purpose of this paper to enhance a user-friendly software to perform power flow analysis for IEEE 14 bus system. For this The MATLAB software will be helpful for user and analyze become easier. We have used the wind farm on any one Bus of IEEE 14 Bus System to enhance its performance. In wind farm system, two methods are proposed, for the simulation of wind farms with asynchronous generators in the load flow analysis. Both methods are based on the steady-state model of the induction machine. The first involves improving the conventional PQ Bus, and second involves modeling the generators in steady state in the bus where the wind farm is located.

Index Terms - Load Flow Studies (LFS), Newton Rapson (NR) method, Wind Farm System (WFS).

I. INTRODUCTION

The load flow studies to determination of current, voltage, active power and reactive power at various points in an electric power operating under normal steady – state condition. Load flow analysis are used in future expansion of existing power system and designing of a new power system. A load flow analysis method consuming more time and therefore prevent to produce an accurate result to a load flow solution because of continuously change in high demand of power and generation [1]. When system operate in steady state condition, then load flow method gives the real and reactive power, voltages at each bus in power system [2]-[3]. Load flow calculations provide power flow and voltages for a specified buses of transmission system. For this calculation, we required for the analysis of steady state as well as dynamic performance of transmission system [4]. In load flow analysis iterative techniques are used. These iterative techniques are included Gauss Seidel and Newton's Raphson method [5]. In this era, wind energy is a kind of Renewable energy and becomes more and more important in many countries. Wind energy continues to be one of the fastest growing energy technologies and it looks set to become a major generator of electricity throughout the world [6]-[7]. The modeling and simulation were done using MATLAB simpcase toolbox for load flow [9]. Wind energy has its own characteristics, such as discreteness, randomness, and uncontrollability. For this reason, and in order to investigate the effects of wind farms at anyone bus of IEEE 14-bus system, adequate models must be used. Modeling of wind forms in the load flow analysis was presented by A. Fejj and et al which is extended to a large network in this work [10]. Power flow analysis was performed using Newton Raphson Method as the system considered is a transmission system [12]. This paper presents MATLAB Simulation and Load flow analysis of an enhanced IEEE 14-bus Transmission system with a wind farm system connected with anyone Bus of IEEE 14 Bus System. Meanwhile MATLAB Simulink technique is beneficial for showing how much the power at the bus can be increment before recognize voltage instability. Load flow analysis and MATLAB Simulink Technique are applied upon the IEEE 14-Bus transmission System.

ASSUMPTION OF LOAD FLOW ANALYSIS

- Generator is modeled as complex power injection.
- Load will be modeled as constant complex power demand.
- Transmission line is modeled as π – modeled or short transmission line.
- Frequency of supply is maintained constant.
- Lumped parameter model is used.
- No HVDC links are considered.
- Harmonics in supply are neglected because for every harmonic Ybus will be separately defined and we need to run separate analysis.

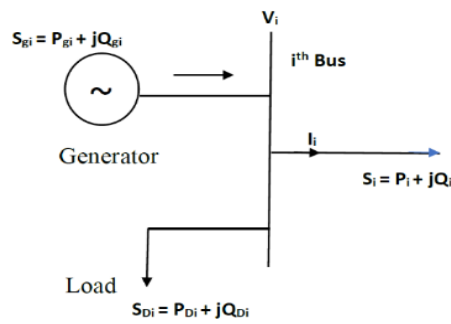


Fig. 1. Load flow of Bus system

II. BUS

A bus is a junction at which one or more than one lines, loads and generators are connected in a power system. 4 quantities are associated with each bus or node. There is voltage amplitude ($|\vec{v}|$), active power (p), phase angle (θ), and reactive power (q). In power flow study 2 out of 4 quantities are specified and the remaining 2 quantities are to be calculated. The buses are mainly classified into 4 categories, based on which two parameters are known [13]-[16].

A. Slack Bus (Swing Bus or References Bus)

For the swing bus voltage magnitude ($|\vec{v}|$) and angle of voltage (δ) are known. Whereas, active power (p) and reactive power (q) are variables, which is obtained through the load flow solutions. Usually there is only one swing bus in a given power system. It is basically one of generator bus, which is made to take the additional active and reactive power to supply losses in power system transmission line

$$\sum_{k=1}^n P_k = \text{losses}$$

Generally, bus of largest generating station is selected as swing bus. Slack bus has zero drop or constant frequency due to zero drop only additional load demand can be meet out by slack bus.

B. PQ Bus (Load Bus)

In this type if bus, active power and reactive power are known. Therefore, a voltage magnitude ($|\vec{v}|$) and voltage angle (δ) are unknown. The load buses are more common in power system approximately 85% bus are load bus. In this bus P_{Gi} and Q_{Gi} is either zero or not specified. It means no generator is connected to the bus voltage is allow to very within $\pm 5\%$, so we have also limited for voltage is P_v bus violet, this limit. Then it is converted into P_v bus where $|v| = \text{violetlimit}$.

C. PV Bus (Generator Bus)

In this bus always a generator is connected to it. P_i and V_i are known whereas, Q_i and S_i are unknown. Approximately 10% bus are P_v bus. If P_v bus violet reactive power limit then it is converted into PQ Bus where $Q_i = \text{violetlimit}$.

D. Voltage Controlled Bus

If a compensator is placed at any bus to limit the voltage, then it is said to be voltage-controlled bus. At voltage-controlled bus $P_i = 0$, $|v_i| = \text{constant}$, so voltage-controlled bus is considered as PV bus. For bus having fixed shunt reactor or capacitor is consider as PQ.

III. METHODS

Newton's Raphson

This method is a gradient method. For finding the solution of nonlinear algebraic equations we use derivatives of functions. This method has faster convergence than gauss Seidel method.

Let us assume a set of 2 nonlinear algebraic equation

$$f_1(x_1, x_2) = k_1 \quad (1)$$

$$f_2(x_1, x_2) = k_2 \quad (2)$$

Let us assume initial value of unknown as x_1^0, x_2^0 and Let $\Delta x_1^0, \Delta x_2^0$ be the correction to be find to the initial values, give actual value, Therefore,

$$f_1(x_1 + \Delta x_1^0, x_2 + \Delta x_2^0) = k_1 \quad (3)$$

$$f_2(x_1 + \Delta x_1^0, x_2 + \Delta x_2^0) = k_2 \quad (4)$$

Now, expanding this equation around the initial values, by Taylor's Series, We have,

$$f_1(x_1^o, x_2^o) + \left[\Delta x_1^o \left(\frac{\partial f_1}{\partial x_1} \right)^o + \Delta x_2^o \left(\frac{\partial f_1}{\partial x_2} \right)^o \right] + \text{higher order terms} = k_1 \quad (5)$$

after neglecting higher order term,

$$f_1(x_1^o, x_2^o) + \Delta x_1^o \left(\frac{\partial f_1}{\partial x_1} \right)^o + \Delta x_2^o \left(\frac{\partial f_1}{\partial x_2} \right)^o = k_1 \quad (6)$$

Now, equation (8) and (9) can be written in matrix form

$$\begin{pmatrix} \left(\frac{\partial f_1}{\partial x_1} \right)^o & \left(\frac{\partial f_1}{\partial x_2} \right)^o \\ \left(\frac{\partial f_2}{\partial x_1} \right)^o & \left(\frac{\partial f_2}{\partial x_2} \right)^o \end{pmatrix} \begin{pmatrix} \Delta x_1^o \\ \Delta x_2^o \end{pmatrix} = \begin{pmatrix} k_1 - f_1(x_1, x_2) \\ k_2 - f_2(x_1, x_2) \end{pmatrix} \quad (7)$$

and,

$$\begin{pmatrix} \Delta x_1^o \\ \Delta x_2^o \end{pmatrix} = \begin{pmatrix} \left(\frac{\partial f_1}{\partial x_1} \right)^o & \left(\frac{\partial f_1}{\partial x_2} \right)^o \\ \left(\frac{\partial f_2}{\partial x_1} \right)^o & \left(\frac{\partial f_2}{\partial x_2} \right)^o \end{pmatrix}^{-1} \begin{pmatrix} k_1 - f_1(x_1, x_2) \\ k_2 - f_2(x_1, x_2) \end{pmatrix} \quad (8)$$

where, $\begin{pmatrix} \left(\frac{\partial f_1}{\partial x_1} \right)^o & \left(\frac{\partial f_1}{\partial x_2} \right)^o \\ \left(\frac{\partial f_2}{\partial x_1} \right)^o & \left(\frac{\partial f_2}{\partial x_2} \right)^o \end{pmatrix}$ is Jacobian matrix,

$\begin{pmatrix} \Delta x_1^o \\ \Delta x_2^o \end{pmatrix}$ is correction vector, $\begin{pmatrix} k_1 - f_1(x_1, x_2) \\ k_2 - f_2(x_1, x_2) \end{pmatrix}$ is mismatch vector

Similarly,

$$\begin{pmatrix} \Delta x_1^o \\ \Delta x_2^o \\ \vdots \\ \Delta x_n^o \end{pmatrix} = \begin{pmatrix} \left(\frac{\partial f_1}{\partial x_1} \right)^o & \left(\frac{\partial f_1}{\partial x_2} \right)^o & \dots & \left(\frac{\partial f_1}{\partial x_n} \right)^o \\ \left(\frac{\partial f_2}{\partial x_1} \right)^o & \left(\frac{\partial f_2}{\partial x_2} \right)^o & \dots & \left(\frac{\partial f_2}{\partial x_n} \right)^o \\ \vdots & \vdots & \dots & \vdots \\ \left(\frac{\partial f_n}{\partial x_1} \right)^o & \left(\frac{\partial f_n}{\partial x_2} \right)^o & \dots & \left(\frac{\partial f_n}{\partial x_n} \right)^o \end{pmatrix} \begin{pmatrix} k_1 - f_1(x_1, x_2) \\ k_2 - f_2(x_1, x_2) \\ \vdots \\ k_n - f_n(x_1, x_2) \end{pmatrix} \quad (9)$$

Newton's Raphson for load Flow

Using equation (4) and (5), real power is known at both PV & PQ buses and Reactive power at PQ buses

$$P_i = \sum_{k=1}^n |Y_{ik}| |V_i| |V_k| \cos(\theta_{ik} + \delta_k - \delta_i)$$

$$\therefore P_i = P_i(|V_i|, \delta_i) \quad (10)$$

And,

$$Q_i = - \sum_{k=1}^n |Y_{ik}| |V_i| |V_k| \sin(\theta_{ik} + \delta_k - \delta_i)$$

$$\therefore Q_i = Q_i(|V_i|, \delta_i) \quad (11)$$

$$\text{If } \Delta P_i = P_{i(sp)} - P_{i(cal)} \quad (12)$$

$$\text{and, } \Delta Q_i = Q_{i(sp)} - Q_{i(cal)} \quad (13)$$

Where, the subscript 'sp' and 'cal' denote the specified and calculated values respectively.

Now, using equation (12), It can be written as,

$$\begin{pmatrix} P_{i(sp)} - P_{i(cal)} \\ Q_{i(sp)} - Q_{i(cal)} \end{pmatrix}_{(PV+2PQ) \times 1} = \begin{pmatrix} \left(\frac{\partial P_1}{\partial \delta_1} \right) & \left(\frac{\partial P_1}{\partial |V_i|} \right) \\ \left(\frac{\partial Q_2}{\partial \delta_1} \right) & \left(\frac{\partial Q_2}{\partial |V_i|} \right) \end{pmatrix}_{(PV+2PQ) \times (PV+PQ)} \begin{pmatrix} \Delta \delta_i \\ \Delta |V_i| \end{pmatrix}_{(PV+2PQ) \times 1} \quad (14)$$

$$\begin{pmatrix} \Delta P_i \\ \Delta Q_i \end{pmatrix}_{(PV+2PQ) \times 1} = \begin{pmatrix} J_1 & J_2 \\ J_3 & J_4 \end{pmatrix}_{(PV+2PQ) \times (PV+PQ)} \begin{pmatrix} \Delta \delta_i \\ \Delta |V_i| \end{pmatrix}_{(PV+2PQ) \times 1} \quad (15)$$

Where,

$\begin{pmatrix} \Delta P_i \\ \Delta Q_i \end{pmatrix}$ is mismatch vector, $\begin{pmatrix} J_1 & J_2 \\ J_3 & J_4 \end{pmatrix}$ is Jacobian matrix and $\begin{pmatrix} \Delta \delta_i \\ \Delta |V_i| \end{pmatrix}$ is correction vector

$$\text{and, } J_1 = \left(\frac{\partial P_1}{\partial \delta_1} \right)_{(PV+PQ) \times (PV+PQ)}, J_2 = \left(\frac{\partial P_1}{\partial |V_i|} \right)_{(PV+PQ) \times (PQ)}, J_3 = \left(\frac{\partial Q_2}{\partial \delta_1} \right)_{(PQ) \times (PV+PQ)},$$

$$J_4 = \left(\frac{\partial Q_2}{\partial |V_i|} \right)_{(PQ) \times (PQ)} \text{ are submatrix of Jacobian matrix.}$$

Now, the Submatrices of diagonal element are calculated by differentiating, equation (13) and (14) with respect to δ and $|V|$.

Procedure of Transmission Line Parameter Calculation

Length calculation of the transmission line between Bus-1 to Bus-2 is shown.

$$x = 0.05917, R = 0.01938, \frac{B}{2} = 0.0264 \Leftrightarrow B = 0.0264 \times 2$$

$$\text{Length of transmission Line} = \left(\frac{\sqrt{x} \times \sqrt{B}}{2\pi f} \right) \times (\text{velocity of light in km/sec})$$

$$\text{Length of transmission line} = \frac{\sqrt{x} \times \sqrt{B}}{2\pi f} \times v = \frac{\sqrt{0.05917} \times \sqrt{0.02640 \times 2}}{2 \times \pi \times 50} \times 3 \times 10^5 = 53.375 \text{ Km}$$

Transmission Line Parameter Calculation

The value specified in datasheet are in per unit (*pu*). In Simulink model, we enter the actual value/km and also enter the length of the line.

Transmission Line length Calculation.

For Line connecting between Bus-1 and Bus-2 with the base value –

$$v_b = 230 \text{ kV}, s_b = 100 \text{ MVA}, R = 0.01938, x = 0.05917, \frac{B}{2} = 0.02640, \Leftrightarrow B = 0.02640 \times 2$$

$$\text{Length} = \left(\frac{\sqrt{x} \times \sqrt{B}}{2\pi f} \right) \times (\text{velocity of light in km/sec})$$

$$\text{Length} = \left(\frac{\sqrt{0.05917} \times \sqrt{0.02640 \times 2}}{2\pi \times 50} \right) \times (3 \times 10^5) = 53.375 \text{ Km}$$

Positive and Zero Sequence Resistance Calculation

$$Z_{base} = R_{base} = X_{base}, R_{actual} = R_{base} \times R$$

$$R_{base} = X_{base} = \left(\frac{v_b^2}{s_b} \right) = \left\{ \frac{(230 \times 10^3)^2}{100 \times 10^6} \right\} = 529$$

$$R_{actual} = 529 \times 0.01938 = 10.252 \Omega$$

$$R_{(\Omega/km)} = \frac{R_{actual}}{\text{Line Length}} = \frac{10.252}{53.375} \Omega/km = 0.19279 \Omega/km$$

$$R_0 = 3 \times R = 0.576 (\Omega/km)$$

Positive and Zero Sequence Inductance Calculation

$$x_{actual} = x_{base} \times x_{pu}, \quad x_{actual} = 529 \times 0.05917 = 31.3 \Omega$$

x_{actual} is actual Inductive reactor but we have to find

$$L_{actual} = \frac{x_{actual}}{2\pi f} = \frac{31.3}{2\pi \times 50} = 0.0996$$

$$L(H/km) = \frac{L_{actual}}{Length} = \frac{0.0996}{53.375} = 1.868 \times 10^{-3} H/km, L_0 = 3 \times L_1 = 3 \times 1.868 \times 10^{-3} H/km$$

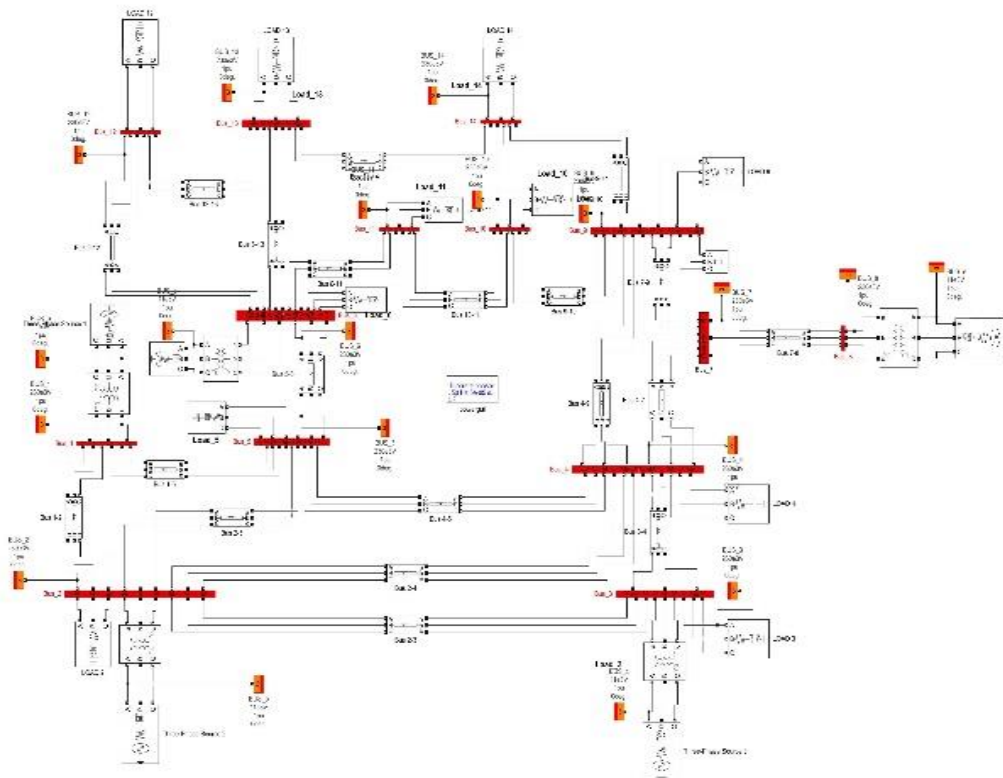


Fig 2. MATLAB Simulink of IEEE 14 bus system

Table 1. : - Line Data – IEEE 14 bus system

Line Number	From Bus	To Bus	Line impedance(p.u)		Half Line Charging Susceptance (pu)
			Resistance(pu)	Reactance(pu)	
1	1	2	0.01938	0.05917	0.02640
2	1	5	0.05403	0.22304	0.02190
3	2	3	0.05811	0.19797	0.01870
4	2	4	0.05695	0.17632	0.02460
5	2	5	0.04699	0.17389	0.01710
6	4	5	0.01337	0.04213	0.00650
7	3	4	0.06703	0.17105	0.01740
8	4	7	0.12711	0.27038	0.02500
9	4	9	0.08205	0.19207	0.02200
10	5	6	0.00010	0.0059	0.00260
11	6	11	0.09498	0.1989	0.02000
12	6	12	0.12291	0.25581	0.01880
13	6	13	0.06615	0.13027	0.01920

14	7	8	0.00011	0.0059	0.00260
15	7	9	0.00054	0.0078	0.00290
16	9	10	0.03181	0.0845	0.02300
17	9	14	0.12711	0.27038	0.02500
18	10	11	0.08205	0.19207	0.02200
19	12	13	0.12092	0.19988	0.01700
20	13	14	0.07093	0.14802	0.01650

Positive and Zero Sequence Capacitance Calculation

$$B_{actual} = B_{base} \times B_{pu}$$

$$B_{base} = \left(\frac{s_b}{v_b^2} \right) = \frac{100 \times 10^6}{(230 \times 10^3)^2} = 1.890 \times 10^{-3}$$

$$B_{actual} = 1.890 \times 10^{-3} \times 0.02640 \times 2 = 9.863 \times 10^{-5}$$

$$C_{actual} = \frac{B_{actual}}{2\pi f} = \frac{9.863 \times 10^{-5}}{2\pi \times 50} = 3.139 \times 10^{-7} F$$

$$(F/km) = \frac{C_{actual}}{LineLength} = \frac{3.139 \times 10^{-7}}{53.375} F/km = 5.8819 \times 10^{-9} F/km$$

$$C_0 = 3 \times 5.8819 \times 10^{-9} F/km = 1.76 \times 10^{-8} F/km$$

Similarly, all buses values are calculated by same process, which is shown in below table 2.

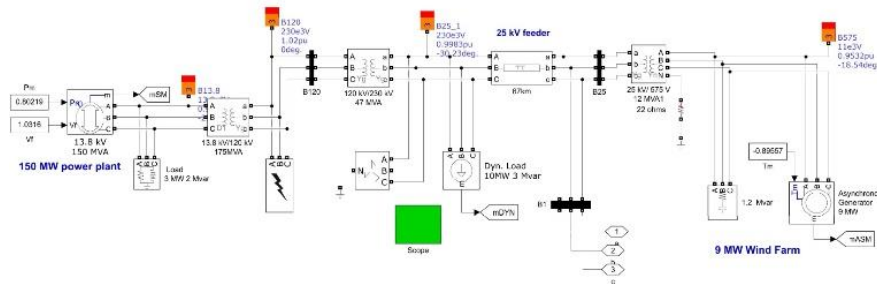


Fig 3. MATLAB Simulink of Wind Farm System at anyone bus of IEEE 14 bus Transmission System

Table 2. Line Data (in actual value) – IEEE 14 bus system

Line No.	From Bus	To Bus	R _{actual} /Km	X _{actual} /Km	C _{actual} /Km
1	1	2	0.19200	1.868e-3	5.881e-9
2	1	5	0.30280	3.979e-3	2.790e-9
3	2	3	0.33860	3.988e-3	2.734e-9
4	2	4	0.34560	3.360e-3	3.350e-9
5	2	5	0.33860	3.988e-3	3.017e-9
6	3	4	0.48250	3.920e-3	2.830e-9
7	4	5	0.31854	3.190e-3	3.470e-9
8	4	7	0.60550	4.120e-3	2.710e-9
9	4	9	0.4944	3.680e-3	3.100e-9
10	5	6	0.0001	4.198e-3	2.780e-9
11	6	11	0.58980	3.932e-3	2.825e-9
12	6	12	0.98180	6.500e-3	3.416e-9
13	6	13	0.51810	3.248e-3	3.420e-9
14	7	8	0.01100	1.878e-3	2.957e-9

15	7	9	0.04440	2.045e-3	5.435e-9
16	9	10	0.28260	2.380e-3	4.648e-9
17	9	14	0.60560	4.100e-3	2.700e-9
18	10	11	0.49440	3.684e-3	3.015e-9
19	12	13	0.81258	4.280e-3	2.598e-9
20	13	14	0.56225	3.734e-3	2.974e-9

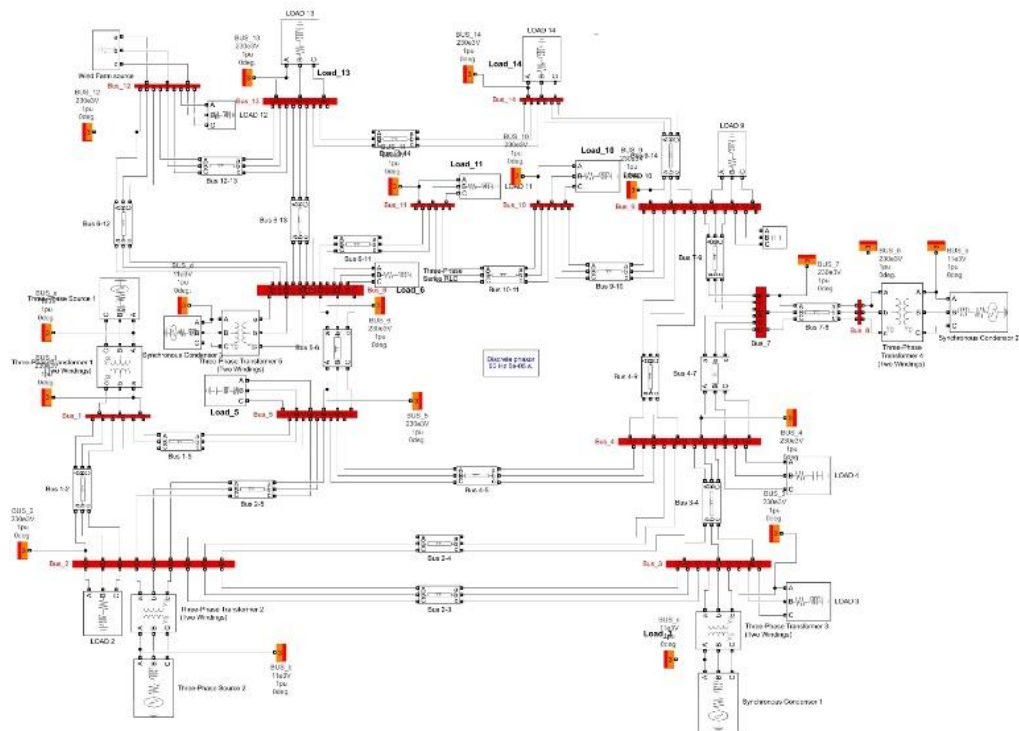


Fig 4. MATLAB Simulink of IEEE 14 bus transmission system using Wind Farm at anyone bus of I IEEE 14 bus Transmission System

Table 3. Comparison table of IEEE 14 bus system and Enhanced IEEE 14 bus system

	Load Flow Analysis without Wind Farm		Load Flow Analysis with Wind Farm	
	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
Total generation	330.5498	185.3961	458.5912	458.5346
Total PQ load	269.9993	71.99796	302.9976	84.99559
Total Z shunt	36.40307	-5.00075	135.3494	93.11721
Total ASM	0	0	-8.916	4.134228
Total losses	24.14739	118.3988	29.16029	276.2876

IV. CONCLUSION

In this paper, firstly we have calculated the value of power generation on 14 bus system. For this calculation, we use Newton Raphson method because Newton Raphson method is the best method for solving quadratic equations for large system. This method is fast convergence and calculation time is less than other method. After this for enhancing the value of power generation of IEEE 14 bus system we connect the wind farm on this system because wind farm plays an important role in electric power generation. After calculating the value with wind farm using synchronous generator and asynchronous generator. We can

see the above value with and without wind farm power generation value. We can say that after connecting the wind farm power generation value is increased and loss is very low respect to without wind farm, so our system performance is enhanced after using Wind farm on IEEE 14 bus system.

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