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# ENHANCEMENT OF TRANSIENT STABILITY OF IEEE 14 BUS USING SHUNT FACTS CONTROLLER

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## ABSTRACT

*The simulation is done on PSAT in MATLAB. Transient stability analysis is done for an IEEE 14 bus system with a three phase fault created at a bus. It has been found from time domain simulation that Statcom enhance the transient performance of the system by damping out the power oscillations under large disturbance conditions with less settling time. In this paper three cases are considered i) steady state system ii) faulty system iii) transient stability enhanced system ( with Statcom) the study demonstrates that STATCOM can enhance the transient stability.*

***Index Terms: IEEE-14 Bus System, PSAT (Power System Analysis Toolbox, STATCOM, Transient Stability***

## I.INTRODUCTION

The power system is a highly nonlinear system that operates in a continuously changing environment. When a transient disturbance occurs, the stability of the power system depends on the nature of the disturbance as well as on the initial operating condition. By the development and use of FACTS devices it becomes possible to enhance the power system transient stability [1]. Some of the advantages of the utilization of FACTS devices in transmission systems are increasing in maximum transmissible power in transmission lines, improving in the stability of transmission systems especially when a fault occurs, and decreasing in line losses. These advantages are not achievable with traditional mechanical switches based approaches because of lack of continuous control and the necessity of large stability margin with them.

### Structure and Behavior of Statcom

The static synchronous compensator (STATCOM) is one of the key FACTS devices. Based on a voltage source convertor, the STATCOM regulates system voltage by absorbing or generating reactive power [9]. A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The equivalent circuit of a Synchronous

Condenser (SC) is shown in Fig.1, which shows a variable AC voltage source (E) whose magnitude is controlled by adjusting the field current. Neglecting losses, the phase angle (ẟ)

difference between the generated voltage (E) and the bus voltage (V) can be assumed to be zero. By varying the magnitude of E, the reactive current supplied by SC can be varied. When E = V, the reactive current output is zero. When E > V, the SC acts as a capacitor whereas when E < V, the SC acts as an inductor. When ẟ = 0, the reactive current drawn ($I_r$) is given by

$$I_r = (V-E)/X'$$

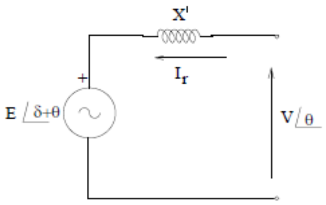


**Figure 1: A synchronous condenser**

There are certain assumptions have to be taken in order to reduce the complexity of transient stability analysis. Each synchronous machine is represented by a constant voltage source behind the direct axis transient reactance. This representation neglects the effects of saliency and assumes constant flux linkages. The actions of the governor are neglected and the input powers are assumed to remain constant during the entire period of simulation. Using the prefault bus voltages, all loads are converted to equivalent admittance to ground and are assumed to remain constant. Damping and asynchronous powers are ignored. The mechanical rotor angle of each machine coincides with the angle of the voltage behind the machine reactance. Machine belonging to the same station swing together and are said to be coherent. A group of coherent machines are represented by one equivalent machine. IEEE-14 bus systems have loads with constant impedance and all generators with constant excitation and constant mechanical input power. Five synchronous machine with IEEE type1 excitation three of which are synchronous compensators. Generator1 is taken as reference generator. Power system analysis tool box (PSAT) software is used for the simulation of the result. The main features of PSAT are power flow, continuation power flow, optimal power flow, small signal stability analysis, time domain simulation, phasor measurement unit placement, complete graphical user interface, CAD for network design, user define models, command line usage etc.. The contents of this paper are given as follows: First the STATCOM unit and modeling, second the single line diagram of IEEE-14 bus standard system, third the transient stability enhancement of multimachine system using STATCOM during prefault, fault and post fault condition. The power flow analysis is done using Newton-Raphson method.

By varying the inverter firing angle **α** the reactive power variation can be instantly achieved and hence improving the transient stability.

## II. SINGLE LINE DIAGRAM OF IEEE 14 BUS SYSTEM

A single line diagram of IEEE14 bus system is shown in Fig. 2 having loads assumes to be having constant impedance and all generators are operate with constant mechanical input power and with constant excitation. It consists of five synchronous machine with IEEE type-1 exciters, three of which are synchronous compensators used only for reactive power support with generator1 taken as reference generator.

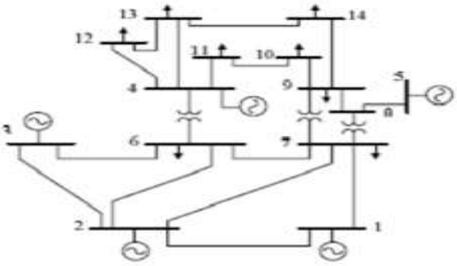


**Figure 2: Single Line Diagram of IEEE 14 Bus test system**

The best location for the reactive power compensation of transient stability margin is the weakest bus of the system. The bus nearest to experiencing a voltage collapse or the fault occurs is defined as the weakest bus.

## III. PSAT MODEL  IEEE 14 BUS SYSTEM PREFAULT

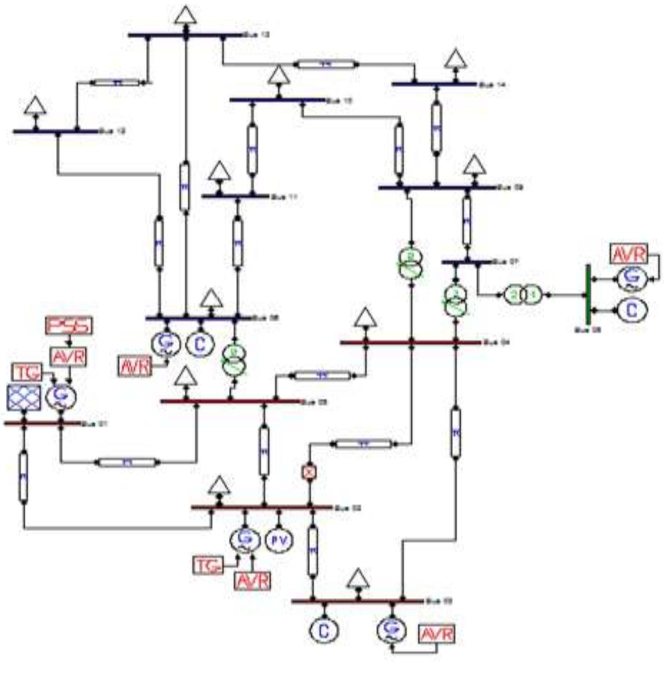


**Figure 3. PSAT model of IEEE 14 Bus system**

this is the steady state  condition that is the prefault condition. Transient stability is more in this condition. The IEEE 14 bus system built using PSAT library. Once defined in the simulink model then load the network in PSAT and solve for power flow. The power flow analysis is carried out for the IEEE 14 bus system using PSAT Software. Load flow study is the steady state condition of the power system network. The NR method for power flow computation using PSAT software as follows:

Newton-Raphson Method for Power Flow Computation
Datafile "C:\Users\dell\Desktop\psat\tests\d_014_pss_l14lokesh(mdl)"

```
Writing file "fm_call" ...
PF solver: Newton-Raphson method
Single slack bus model
Iteration = 1     Maximum Convergency Error = 0.40086
Iteration = 2     Maximum Convergency Error = 0.015935
Iteration = 3     Maximum Convergency Error = 0.00024325
Iteration = 4    Maximum Convergency Error = 5.7396e-008
Initialization of Synchronous Machines completed.
Initialization of Automatic Voltage Regulators completed.
Initialization of Turbine Gorvernors completed.
Initialization of Power System Stabilizers completed.
Power Flow completed in 1.01 s
```

From the above iteration it is clear that the maximum convergence error is 5.7396e-008. Voltage time, rotor angle and time graph are plotted for IEEE 14 bus system using PSAT software.

## IV. PSAT MODEL IEEE 14 BUS FOR FAULT CONDITION

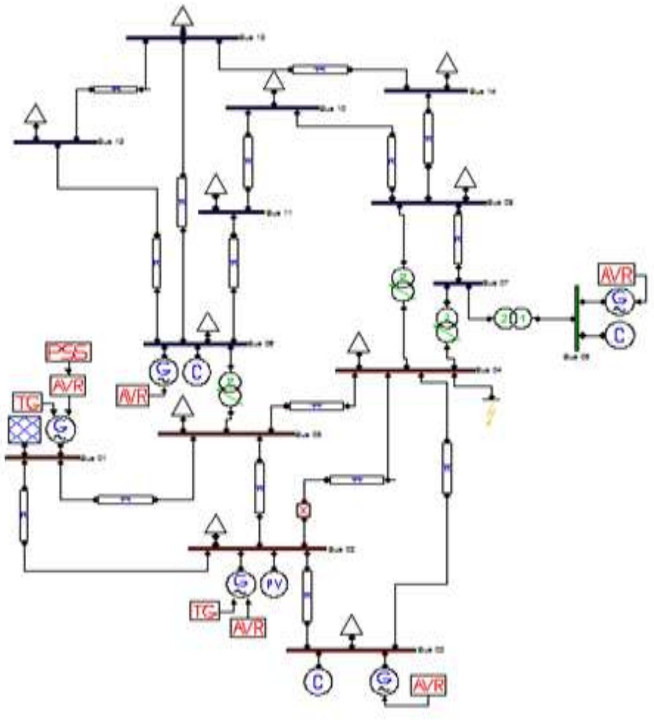


**Figure: 4 IEEE 14 bus system during fault condition**

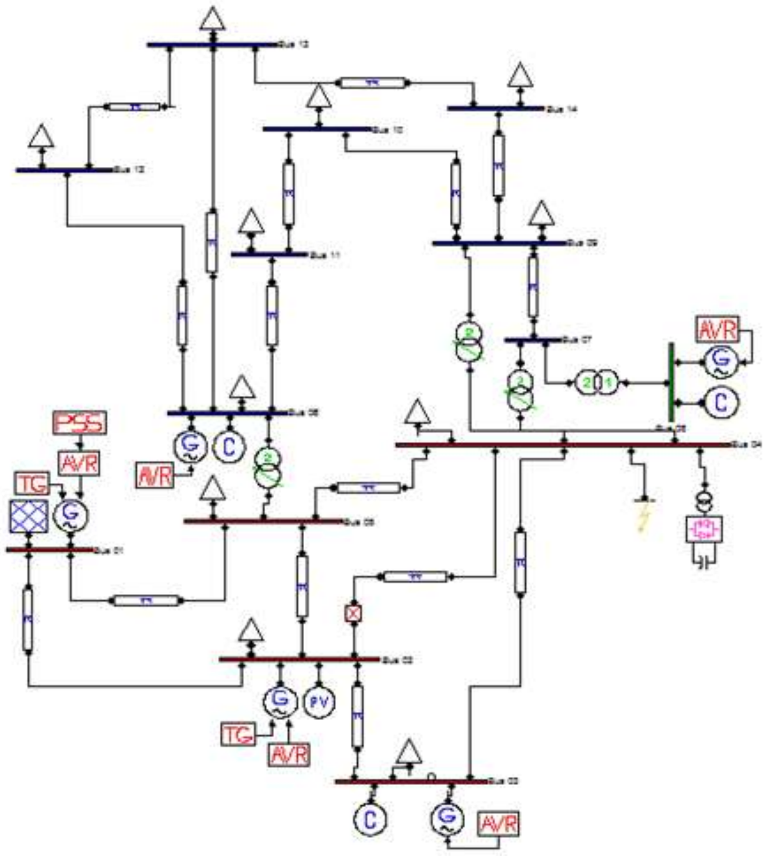
To create a transient instability a three phase fault occurs at bus no. 4. The introduced fault is a transient fault. The introduced fault time is 0.1 sec and fault clearing time is 0.2 sec

```
Newton-Raphson Method for Power Flow Computation
Datafile "C:\Users\dell\Desktop\psat\tests\d_014_pss_l14lokeshFault(mdl)"
```

```
Voltage rate of Fault #1 at Bus Bus 04 differs more than 10% from Bus voltage rate
Writing file "fm_call" ...
PF solver: Newton-Raphson method
Single slack bus model
Iteration = 1     Maximum Convergency Error = 0.423086
Iteration = 2     Maximum Convergency Error = 0.017635
Iteration = 3     Maximum Convergency Error = 0.00034125
Iteration = 4    Maximum Convergency Error = 3.2396e-008
Initialization of Synchronous Machines completed.
Initialization of Automatic Voltage Regulators completed.
Initialization of Turbine Gorvernors completed.
Initialization of Power System Stabilizers completed.
Power Flow completed in 0.04 s
```

Voltage time, rotor angle and time graph are plotted for IEEE 14 bus system under faulty condition using PSAT software. The fault is cleared at 0.2 sec.

## V. PSAT MODEL OF IEEE 14 BUS WITH STATCOM



```
Writing Data File
Construction of Data File <d_014_pss_l14lokeshpostFault_mdl.m> completed.
```

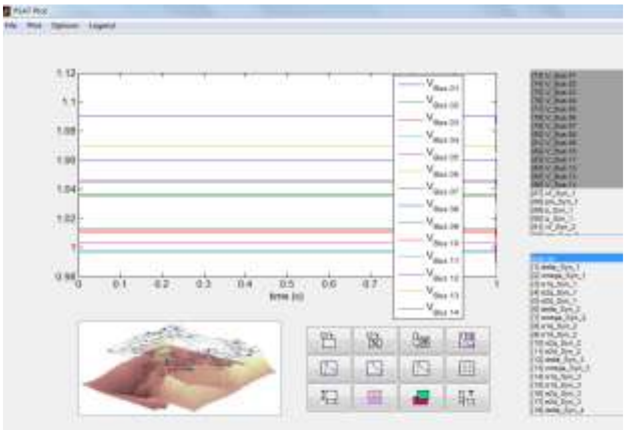
```
Data file "C:\Users\dell\Desktop\psat\tests\d_014_pss_l14lokeshpostFault(mdl)" set
 Newton-Raphson Method for Power Flow Computation
Data file "C:\Users\dell\Desktop\psat\tests\d_014_pss_l14lokeshpostFault(mdl)"
Voltage rate of Fault #1 at Bus Bus 04 differs more than 10% from Bus voltage rate
Voltage rate of Statcom #1 at Bus Bus 04 differs more than 10% from Bus voltage rate
Writing file "fm_call" ...
PF solver: Newton-Raphson method
Single slack bus model
Iteration = 1     Maximum Convergency Error = 0.400031
Iteration = 2     Maximum Convergency Error = 0.014935
Iteration = 3     Maximum Convergency Error = 0.00021025
Iteration = 4     Maximum Convergency Error = 7.604e-008
Initialization of Synchronous Machines completed.
Initialization of Automatic Voltage Regulators completed.
Initialization of Turbine Gorvernors completed.
Initialization of Power System Stabilizers completed.
Warning: STATCOM #1 at bus <Bus 04>: no PV generator
found at the bus.
Warning: STATCOM #1 at bus <Bus 04>: Ish is under its
min limit.
Initialization of STATCOMs completed.
   Power Flow completed in 0.53 s
```

The error is less than IEEE 14 bus system having three phase fault. The maximum convergence error is 7.6046e-008

## VI. SIMULATION RESULTS

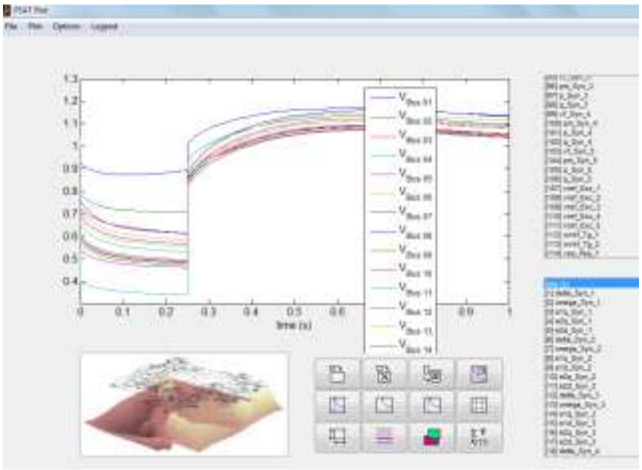
The output of generators during prefault, fault and post fault conditions is plotted using PSAT software. Using PSAT software we obtained the voltage time graph, synchronous generator active power graph with time. From simulation results we can see that before prefault system is stable and after fault system becomes unstable. During the fault the transmitted electrical power decreases significantly while the mechanical input power to the generator remains constant, as a result the generator continuously accelerate and the rotor angle when the fault is cleared at 0.2s the speed is continuously increasing and the system is not able to gain stability due to the lack of damping. During the fault, the generator terminal experiences voltage sag of 90% without the Statcom. This voltage is not recovered after the fault is clearance due to lack of reactive power support. The transient instability is more in case of faulty condition. This instability can be overcome by introducing FACTS device in the unstable bus. After post fault using FACTS device i.e. Statcom the system again stable.

## VII. PREFAULT CONDITION



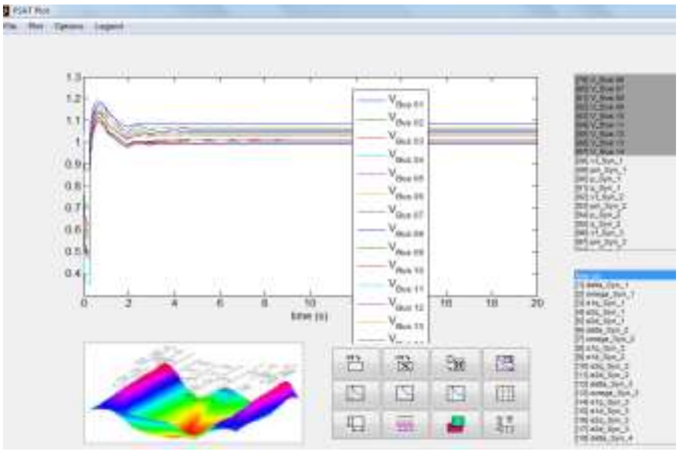
VOLTAGE TIME CURVE PREFAULT CONDITION

## VIII. FAULT CONDITION



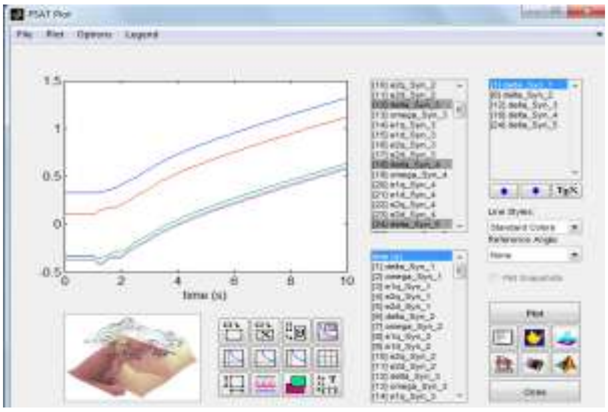
VOLTAGE TIME CURVE FAULT CONDITION

## IX. POST FACULT CONDITION



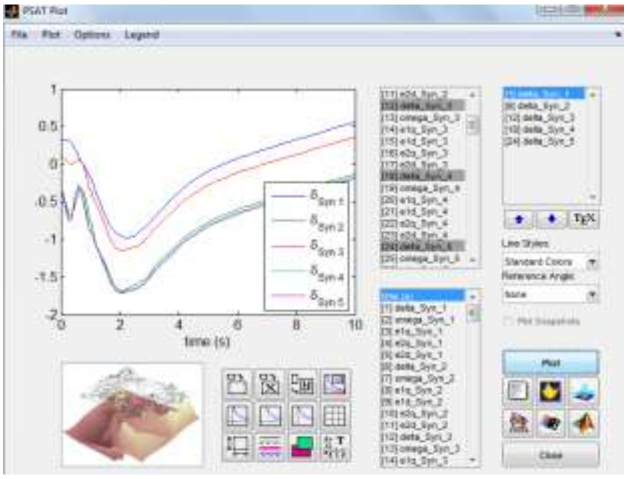
VOLTAGE TIME CURVE WITH STATCOM IN BUS 4

## X. PREFAULT CONDITION



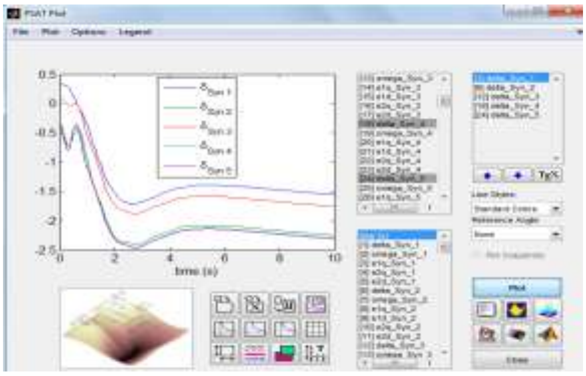
SWING CURVE FOR GENERATOR

## XI. FAULT CONDITION



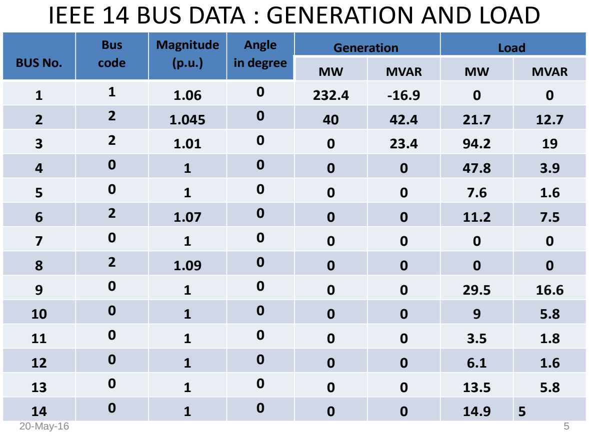
SWING CURVE WITH FAULT CONDITION

## XII. POST FAULT CONDITION



SWING CURVE WITH STATCOM IN BUS 4

## XIII. CONCLUSION


IEEE 14 BUS DATA : GENERATION AND LOAD

| BUS No. | Bus code | Magnitude (p.u.) | Angle in degree | Generation | | Load | |
|---|---|---|---|---|---|---|---|
| | | | | MW | MVAR | MW | MVAR |
| 1 | 1 | 1.06 | 0 | 232.4 | -16.9 | 0 | 0 |
| 2 | 2 | 1.045 | 0 | 40 | 42.4 | 21.7 | 12.7 |
| 3 | 2 | 1.01 | 0 | 0 | 23.4 | 94.2 | 19 |
| 4 | 0 | 1 | 0 | 0 | 0 | 47.8 | 3.9 |
| 5 | 0 | 1 | 0 | 0 | 0 | 7.6 | 1.6 |
| 6 | 2 | 1.07 | 0 | 0 | 0 | 11.2 | 7.5 |
| 7 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 8 | 2 | 1.09 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 1 | 0 | 0 | 0 | 29.5 | 16.6 |
| 10 | 0 | 1 | 0 | 0 | 0 | 9 | 5.8 |
| 11 | 0 | 1 | 0 | 0 | 0 | 3.5 | 1.8 |
| 12 | 0 | 1 | 0 | 0 | 0 | 6.1 | 1.6 |
| 13 | 0 | 1 | 0 | 0 | 0 | 13.5 | 5.8 |
| 14 | 0 | 1 | 0 | 0 | 0 | 14.9 | 5 |

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The simulation results using PSAT software shows clearly the impact of STATCOM in enhancing the transient stability of multimachine system. In this paper the transient stability enhancement of multimachine system is analyzed. The stability has determined by plotting the voltage time curve and the swing curves. The single line to ground fault is cleared by introducing the STATCOM in the faulty system. It is therefore recommended that the power system engineers must do proper care in enhancing the transient stability. Thus it is concluded that STATCOM helps in enhancing the transient stability of multimachine system.

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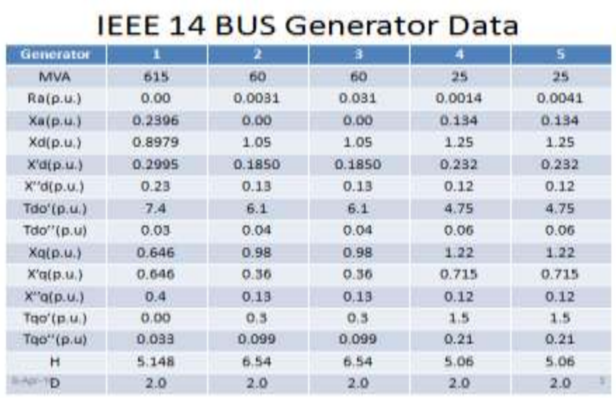
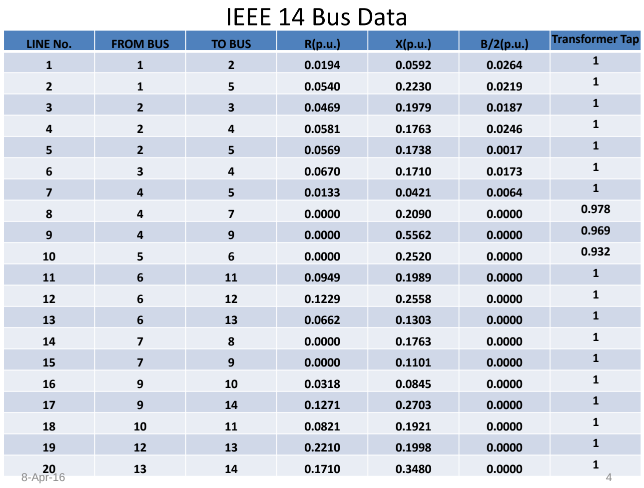
# APPENDIX



IEEE 14 BUS Generator Data

| Generator | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| MVA | 615 | 60 | 60 | 25 | 25 |
| Ra(p.u.) | 0.00 | 0.0031 | 0.031 | 0.0014 | 0.0041 |
| Xa(p.u.) | 0.2396 | 0.00 | 0.00 | 0.134 | 0.134 |
| Xd(p.u.) | 0.8979 | 1.05 | 1.05 | 1.25 | 1.25 |
| X'd(p.u.) | 0.2995 | 0.1850 | 0.1850 | 0.232 | 0.232 |
| X''d(p.u.) | 0.23 | 0.13 | 0.13 | 0.12 | 0.12 |
| Tdo'(p.u.) | 7.4 | 6.1 | 6.1 | 4.75 | 4.75 |
| Tdo''(p.u) | 0.03 | 0.04 | 0.04 | 0.06 | 0.06 |
| Xq(p.u.) | 0.646 | 0.98 | 0.98 | 1.22 | 1.22 |
| X'q(p.u.) | 0.646 | 0.36 | 0.36 | 0.715 | 0.715 |
| X''q(p.u.) | 0.4 | 0.13 | 0.13 | 0.12 | 0.12 |
| Tqo'(p.u.) | 0.00 | 0.3 | 0.3 | 1.5 | 1.5 |
| Tqo''(p.u) | 0.033 | 0.099 | 0.099 | 0.21 | 0.21 |
| H | 5.148 | 6.54 | 6.54 | 5.06 | 5.06 |
| D | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |



IEEE 14 Bus Data

| LINE No. | FROM BUS | TO BUS | R(p.u.) | X(p.u.) | B/2(p.u.) | Transformer Tap |
|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 0.0194 | 0.0592 | 0.0264 | 1 |
| 2 | 1 | 5 | 0.0540 | 0.2230 | 0.0219 | 1 |
| 3 | 2 | 3 | 0.0469 | 0.1979 | 0.0187 | 1 |
| 4 | 2 | 4 | 0.0581 | 0.1763 | 0.0246 | 1 |
| 5 | 2 | 5 | 0.0569 | 0.1738 | 0.0017 | 1 |
| 6 | 3 | 4 | 0.0670 | 0.1710 | 0.0173 | 1 |
| 7 | 4 | 5 | 0.0133 | 0.0421 | 0.0064 | 1 |
| 8 | 4 | 7 | 0.0000 | 0.2090 | 0.0000 | 0.978 |
| 9 | 4 | 9 | 0.0000 | 0.5562 | 0.0000 | 0.969 |
| 10 | 5 | 6 | 0.0000 | 0.2520 | 0.0000 | 0.932 |
| 11 | 6 | 11 | 0.0949 | 0.1989 | 0.0000 | 1 |
| 12 | 6 | 12 | 0.1229 | 0.2558 | 0.0000 | 1 |
| 13 | 6 | 13 | 0.0662 | 0.1303 | 0.0000 | 1 |
| 14 | 7 | 8 | 0.0000 | 0.1763 | 0.0000 | 1 |
| 15 | 7 | 9 | 0.0000 | 0.1101 | 0.0000 | 1 |
| 16 | 9 | 10 | 0.0318 | 0.0845 | 0.0000 | 1 |
| 17 | 9 | 14 | 0.1271 | 0.2703 | 0.0000 | 1 |
| 18 | 10 | 11 | 0.0821 | 0.1921 | 0.0000 | 1 |
| 19 | 12 | 13 | 0.2210 | 0.1998 | 0.0000 | 1 |
| 20 | 13 | 14 | 0.1710 | 0.3480 | 0.0000 | 1 |

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