

# Modeling and Simulation of Static Synchronous Series Compensator and It's Applications in IEEE 14-Bus System

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## Abstract:

The growing demand for electricity has been a main reason for many blackouts. The way we transmit electricity now can't support the high need for power. This is making the voltage, which is like the electric pressure, unstable, which results in a big problem when managing the power grid. So, it's really important to understand how much load, or demand, the system can handle without getting messed up. Stability is a key concept, especially voltage stability. This means the power system's ability to keep the voltage at good levels at all points, both when things are normal and when there are problems or malfunctions. The unstable voltage happens because of higher demand for power, changes in the way the system works, and when the voltage drops in overloaded power grids. Checking voltage stability is a basic way to figure out if a system is safe. In order to make the system healthy there is a need of a series FACTS device to maintain certain power and voltage profile even though it's subjected to practical disturbances.

**Keywords:** SSSC, FACTS, Stability, Compensation.

## 1. INTRODUCTION

The primary responsibility of every Electrical Power Authority or Corporation is to ensure the consistent provision of high-quality and reliable power throughout the year. However, certain disturbances, such as voltage drops and the effects of inductance and capacitance, can disrupt the proper functioning of the system. To address these challenges, we utilize a specialized device called a Static Synchronous Series Compensator (SSSC). This device incorporates FACTS technology, an innovative integrated approach designed to enhance system efficiency, power transmission capacity, and overall stability.

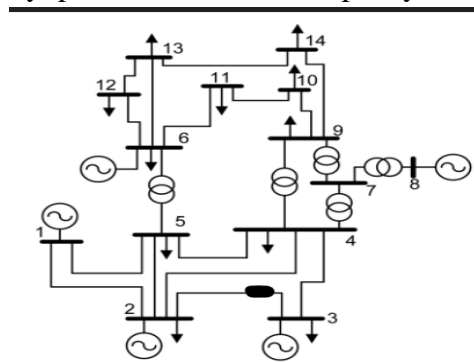


Figure 1. Typical IEEE 14 Bus System with SSSC

## 2. FUNCTIONING OF STATIC SYNCHRONOUS SERIES COMPENSATOR

The Static Synchronous Series Compensator (SSSC) is a FACTS device designed to enhance power quality. It incorporates a Voltage Source Converter (VSC) and connects in series to a transmission line through a transformer or multilayer inverters. In contrast to the STATCOM, the SSSC employs voltage control techniques but distinguishes itself by utilizing a series connection instead of a shunt connection. By generating a series-injected voltage capable of simulating controlled inductive or capacitive reactance, depending on the lag or lead of the line current, the SSSC effectively alters the equivalent line impedance. This modification contributes to enhancing the active power transfer capacity of the line

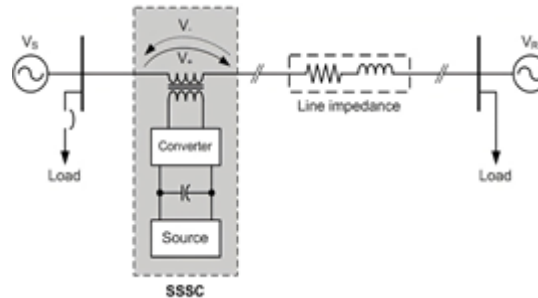


Fig2. Block diagram of SSSC

## 3. MODELING OF STATIC SYNCHRONOUS SERIES COMPENSATOR

In this paper we took a case study of a regional power utility company where there is a challenge to meet the power demand at peak demand periods. These challenges are mainly due to voltage drop at buses and increase in load impedance. Hence, deployment of SSSC is the possibly solutions to retain the system's healthy function.

There are three parts in analysing this system:

- MATLAB Code for IEEE 14-Bus System at normal conditions.
- MATLAB Code for IEEE 14-Bus System without SSSC at peak demand period.
- MATLAB Code for IEEE 14-Bus System with SSSC at peak demand period.

### A. MATLAB Code for IEEE 14-Bus System at normal conditions

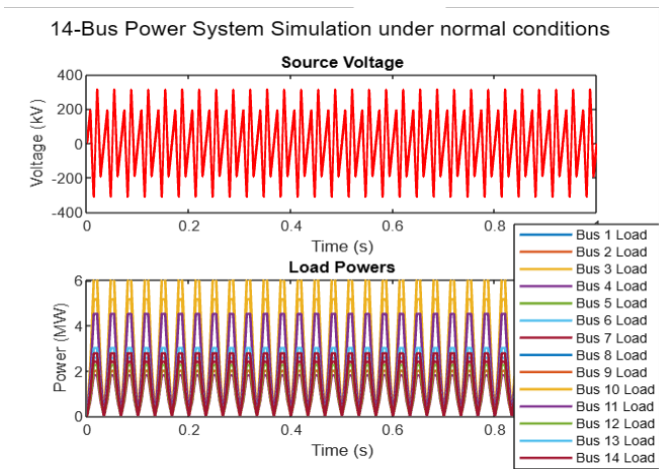
```
Vbase = 230;
Sbase = 1000;
Zbase = Vbase^2 / Sbase;
Zload = [0.8 0.6 0.35 1.0 0.6 0.7 0.75 0.8 0.9 0.3 0.4 0.8 0.6 0.65] * Zbase;
f = 60;
t = 0:1/(10*f):1;
Vsource = Vbase * sqrt(2) * sin(2*pi*f*t);
Iload = zeros(length(t), 14);
Pload = zeros(length(t), 14);
for i = 1:2
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 3:4
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
```

```
end
for i = 4:5
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 5:6
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 6:7
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 7:8
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
End
for i = 8:9
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 9:10
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 10:11
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 11:12
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 13:14
Iload(:, i) = Vsource' ./ Zload(i);
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
subplot(2, 1, 1);
plot(t, Vsource, 'r', 'LineWidth', 1.5);
ylabel('Voltage (kV)'); xlabel('Time (s)');
title('Source Voltage');
subplot(2, 1, 2);
plot(t, Pload, 'LineWidth', 1.5);
```

```
title('Source Voltage'); subplot(2, 1, 2);
```

```
plot(t, Pload, 'LineWidth', 1.5);
ylabel('Power (MW)'); xlabel('Time (s)');
```

```
legend('Bus 1 Load', 'Bus 2 Load', 'Bus 3 Load', 'Bus 4 Load','Bus 5 Load', 'Bus 6
Load', 'Bus 7 Load', 'Bus 8 Load','Bus 9 Load', 'Bus 10 Load','Bus 11 Load', 'Bus 12 Load', 'Bus 13
Load', 'Bus 14 Load');
title('Load Powers'); sgtitle('14-Bus Power System Simulation');
```



**Fig.3.1. Output waveforms for IEEE 14-Bus system under normal conditions**

**B. MATLAB Code for IEEE 14-Bus System without SSSC subjected to fault**

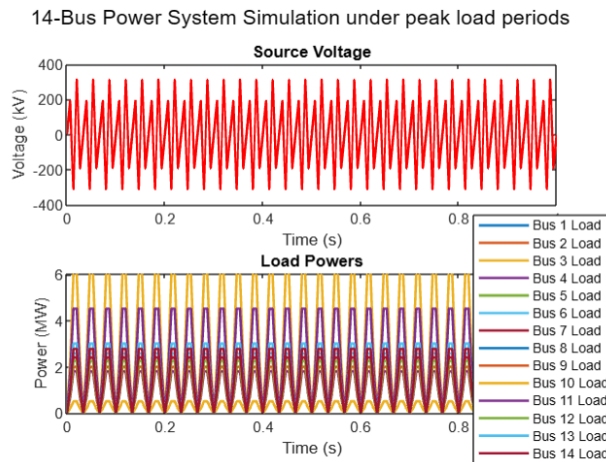
```
Vbase = 230;
Sbase = 1000;
Zbase = Vbase^2 / Sbase;
Zload = [0.8 0.6 3.5 1.0 0.6 0.7 0.75 0.8 0.9 0.3 0.4 0.8 0.6 0.65] * Zbase;
f = 60;
t = 0:1/(10*f):1;
Vsource = Vbase * sqrt(2) * sin(2*pi*f*t);
Iload = zeros(length(t), 14);
Pload = zeros(length(t), 14);
for i = 1:2
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 3:4
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 4:5
    Iload(:, i) = Vsource' ./ Zload(i);
```

```
Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 5:6
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 6:7
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 7:8
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 8:9
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 9:10
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 10:11
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 11:12
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
for i = 13:14
    Iload(:, i) = Vsource' ./ Zload(i);
    Pload(:, i) = real(Vsource' .* conj(Iload(:, i))) / 1000;
end
subplot(2, 1, 1);
plot(t, Vsource, 'r', 'LineWidth', 1.5);
ylabel('Voltage (kV)'); xlabel('Time (s)');
title('Source Voltage');
subplot(2, 1, 2);
plot(t, Pload, 'LineWidth', 1.5);
title('Source Voltage'); subplot(2, 1, 2);

plot(t, Pload, 'LineWidth', 1.5);
```

```
ylabel('Power (MW)'); xlabel('Time (s)');
```

```
legend('Bus 1 Load', 'Bus 2 Load', 'Bus 3 Load', 'Bus 4 Load','Bus 5 Load', 'Bus 6 Load', 'Bus 7 Load', 'Bus 8 Load','Bus 9 Load', 'Bus 10 Load','Bus 11 Load', 'Bus 12 Load', 'Bus 13 Load', 'Bus 14 Load');
title('Load Powers'); sgtitle('14-Bus Power System Simulation');
```



**Fig.3.2. Output waveforms for IEEE 14-Bus system without SSSC under peak load period**

### C. Modeling Equations of SSSC

$$P = (V_s \cdot V_r) \sin \delta / X_L = V^2 \cdot \sin \delta / X_L \text{-----(1)}$$

$$Q = (V_s \cdot V_r) (1 - \cos \delta) / X_L = V^2 \cdot (1 - \cos \delta) / X_L \text{-----(2)}$$

$$P = V_q \cdot I_q + V_d \cdot I_d \text{-----(3)}$$

$$Q = V_q \cdot I_d + V_d \cdot I_q \text{-----(4)}$$

Where ;

$V_s$  = Sending end voltage;

$V_r$  = Receiving end voltage;

$V_q$  = Compensation voltage;

$X_q$  = Injected reactance ;

### D. MATLAB Code for IEEE 14-Bus System with SSSC

```
%SSSC modelling for IEEE 14 Bus power system
```

```
Vb= 230;
```

```
Sb = 1000;
```

```
fb = 60;
```

```
Zb = Vb*Vb / Sb;
```

```
Vcomp = 1.1 * Vb;
```

```
Xcomp = 0.2 * Zb;
```

```
Zload = 0.8 * Zb;
```

```
f = 60;
```

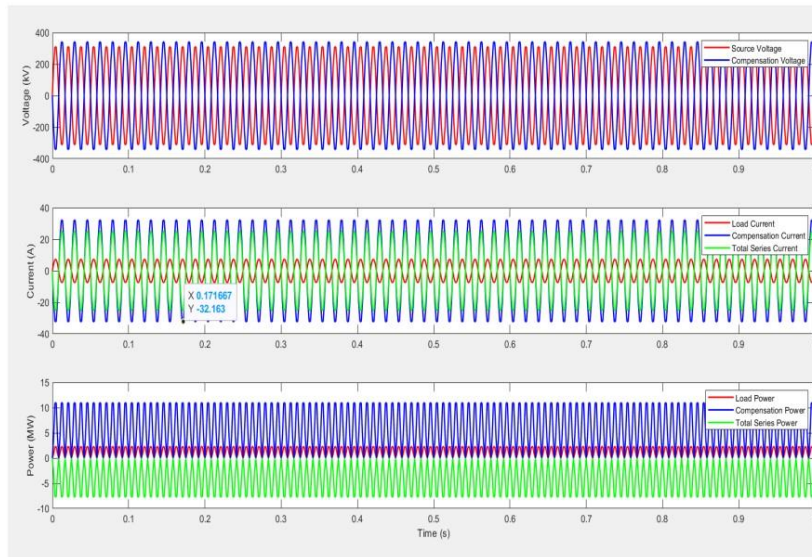
```
t = 0:1/(10*f):1;
```

```
Vs = Vb * sqrt(2) * sin(2*pi*f*t);
```

```

Vcompensator = Vcomp * sqrt(2) * sin(2*pi*f*t + pi);
Iload = Vs ./ Zload;
Icompensator = Vcompensator ./ Xcomp;
Iseries = Iload + Icompensator;
Pcompensator = real(Vcompensator .* conj(Icompensator)) / 1000;
subplot(3, 1, 1);
plot(t, Vs, 'r', 'LineWidth', 1.5);
hold on;
plot(t, Vcompensator, 'b', 'LineWidth', 1.5);
hold off;
ylabel('Voltage (kV)');
legend('Source Voltage', 'Compensation Voltage');
plot(t, Iseries, 'g', 'LineWidth', 1.5);
ylabel('Current (A)');
legend('Load Current', 'Compensation Current', 'Total Series Current');
subplot(3, 1, 3);
plot(t, Pload, 'r', 'LineWidth', 1.5);
hold on;
plot(t, Pcompensator, 'b', 'LineWidth', 1.5);
plot(t, Pseries, 'g', 'LineWidth', 1.5);
hold off;
ylabel('Power (MW)');
xlabel('Time (s)');

```



**Fig.3.3 Output waveforms for IEEE 14-Bus system with SSSC**

E. Line and Bus data

**Line Data**

Line	From Bus	To Bus	Resistance (p.u.)	Reactance (p.u.)	Charging (p.u.)
1	1	2	0.02	0.06	0.03
2	2	3	0.01	0.03	0.02
3	3	4	0.03	0.09	0.04
4	4	5	0.04	0.12	0.05
5	5	6	0.02	0.06	0.03
6	6	7	0.01	0.03	0.02
7	7	8	0.02	0.06	0.03
8	8	9	0.01	0.03	0.02
9	9	10	0.03	0.09	0.04
10	10	11	0.02	0.06	0.03
11	11	12	0.01	0.03	0.02
12	12	13	0.02	0.06	0.03
13	13	14	0.03	0.09	0.04

**Bus Data:**

Bus	Type	Voltage (p.u.)	Angle (deg)	Gen. Active Power (MW)	Gen. Reactive Power (MVAR)	Load Active Power (MW)	Load Reactive Power (MVAR)	Load Impedance (MVAR)
1	1	1.05	0.0	50	20	30	10	5
2	2	1.05	0.0	0	0	0	0	0
3	2	1.07	0.0	0	0	0	0	0
4	1	1.0	0.0	30	10	20	5	2
5	1	1.0	0.0	0	0	0	0	0
6	2	1.07	0.0	0	0	0	0	0
7	1	1.0	0.0	40	15	25	8	4
8	2	1.06	0.0	0	0	0	0	0
9	1	1.0	0.0	0	0	0	0	0
10	2	1.09	0.0	25	8	15	4	2
11	1	1.0	0.0	0	0	0	0	0
12	2	1.09	0.0	0	0	0	0	0
13	2	1.06	0.0	35	12	18	6	3
14	1	1.0	0.0	0	0	0	0	0

**APPLICATIONS OF SSSC**

**F. Power Factor Improvement Using SSSC**

The power factor plays a vital role in the power system .It’s desired to have the higher power factor because it enables in saving electricity bills, increment in available power, reduction installation size, reduction in voltage drops.

%MATLAB code for power factor improvement using SSSC

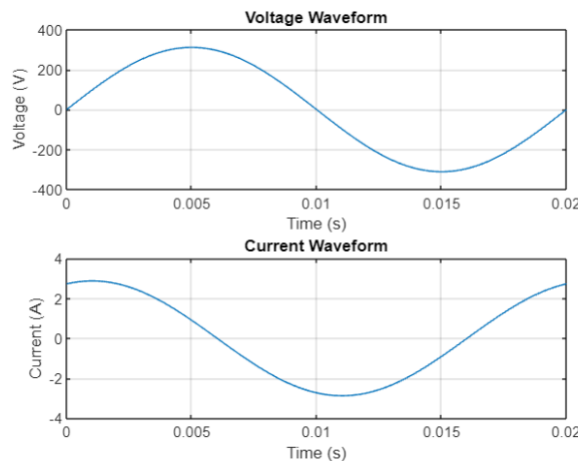
```
Vt = 230;
Zt = 1 + 1i*1;
Pload = 500;
Qload = -200;
St = Pload + 1i*Qload;
Iload = conj(St/Vt);
Zload = Vt/Iload;
```



```

Zc = (Zload - Zt)/Zt;
Qc = -imag(conj(St) * Zc);
Qc_required = -0.9 * abs(Pload);
Qc_correction = Qc_required - Qc;
Ic_correction = Qc_correction/Vt;
disp(['Load Current: ', num2str(abs(Iload)), ' A']); disp(['Compensation
Current:num2str(abs(Ic_correction)), ' A']);
subplot(2,1,1);
plot(t, Vwaveform);
xlabel('Time (s)');
ylabel('Voltage (V)');
title('Voltage Waveform');
grid on;
% Plot current waveform
subplot(2,1,2);
ylabel('Current (A)');
title('Current Waveform');
grid on;
% Display power factor
disp(['Power Factor: ', num2str(pf)])
disp(['CorrectionRequired: ',num2str(abs(Qc_correction)), ' vars'])

```



**Fig.4.1 Output waveforms power factor correction using SSSC**

**G. Reactive power Compensation using SSSC**

```

%MATLAB code for reactive power compensation using SSSC
% Define system parameters
V = 230;
f = 60;
R = 0.05;
L = 0.5;
C = 2e-6
P_load = [50 80 70 90];

```

```
Q_load = [30 60 50 70];
V_inj = -1i * Q_load / conj(Z);
Q_compensation = imag(V_inj * conj(I_inj));
disp('SSSC Injection Voltage (kV):');
disp(V_inj);
disp('SSSC Injection Current (A):');
disp(I_inj);
disp('Reactive Power Compensation by SSSC (MVAR):');
disp(Q_compensation);
```

**Output:**

```
SSSC Injection Voltage (kV):
0.1592 - 0.0000i 0.3183 - 0.0001i 0.2653 - 0.0001i 0.3714 - 0.0001i
```

```
SSSC Injection Current (A):
2.5497e+02 - 1.8856e+02i
```

```
Reactive Power Compensation by SSSC (MVAR):
30.0000 60.0000 50.0000 70.0000
```

**H. Load Balancing using SSSC**

```
% MATLAB Code Load Balancing using SSSC
V = 230;
f = 60;
R = 0.05;
L = 0.5;
C = 2e-6;
P_load = [50 80 70 90];
Q_load = [30 60 50 70];
LF = sum(P_load) / V;
Z = R + 1i * 2 * pi * f * L;
V_inj = -1i * (P_load - LF * V) / conj(Z);
I_inj = (P_load - LF * V - 1i * Q_load) / conj(V_inj);
disp(['Load Balancing Factor: ' num2str(LF)]);
disp('SSSC Injection Voltage (kV):');
disp(V_inj); disp('SSSC Injection Current (A):'); disp(I_inj)
```

**Output:**

```
Load Balancing Factor: 1.2609
SSSC Injection Voltage (kV):
-1.2732 + 0.0003i -1.1141 + 0.0003i -1.1671 + 0.0003i -1.0610 + 0.0003i
```

```
SSSC Injection Current (A):
1.8851e+02 + 4.4372e+01i
```

## CONCLUSION

The following are the simulation results obtained using MATLAB code for a 14- bus system, When the system is simulated using MATLAB programme, with standard test system ratings and under abnormal conditions, the voltage (p.u.) are within safe limits ensuring that the system is in healthy condition and safe to transmit the power from source to load.

When the system undergone large increase in load impedance, it has created a drop in voltage (p.u.) at each bus and the total power loss is high. The bus voltages are unstable, making the system lose its voltage stability and reduced performance in the overall system.

When the system undergoes a compensation technique i.e., series FACTS device, for weak buses, there is a significant rise in p.u. voltage levels of that bus making the system reliable to transmit the power flow one from end to another end and relatively losses are also reduced.

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