# Power Quality Improvement in Power System by Using Static Synchronous Series Compensator

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***Abstract* – This paper presents the performance of SSSC for power quality improvement. As nonlinear loads causes the harmonics in the system and therefore the power quality gets reduce because of these non linear load. Hence power quality is study with case I. Non linear load without SSSC & case II. Non linear load with SSSC in IEEE 9 bus system. The diode bridge rectifier is used here as non linear load. Series FACTS devices are most powerful controllers used for power flow, power quality, power oscillation damping and improving transient stability of the power system. Power quality study is carried out with Fast Fourier Transform analysis and Total Harmonic Distortions are obtained which shows the harmonics present in the system.Results are validated by using MATLAB.**

***Keywords–SSSC, Non linear load, Total Harmonic Distortion (THD)., Fast Fourier Transform (FFT), FACTS.***

## I. INTRODUCTION

Increasing non-linear loads cause various undesirable effects and power quality problems. The use of power electronic converters and equipments and other non-linear loads are rapidly increasing in industry and also by commercials. These equipments draw non-linear currents from the AC mains as compare to normal loads such as motors and resistive heating elements, these non linear current causes the distortions in the power system voltage and current. These currents result in distorted voltages and currents that can directly impact the system performance in different ways, as the number of harmonic producing loads has increased over the years it has become increasingly necessary to reduce these harmonic current.

Hence to overcome these power quality problems and improve the power quality, Flexible AC Transmission System (FACTS) device plays a very important role. There are various types of FACTS devices out of these series FACTS devices are used for controlling power flow in transmission lines, damping the oscillations present in power system, and power quality improvement. Static synchronous series compensator (SSSC) injects the voltages or absorbs voltages from transmission line where it is connected. SSSC can damp oscillations by changing the compensated reactance of the transmission line. Synchronous voltage source implemented by an Insulated Gate Bipolar Transistor (IGBT) based voltage sourced inverter for providing the controllable series compensation.SSSC also provides controllable compensating voltage over an identical compensating voltage over identical capacitive and inductive range independent of the magnitude of the transmission line current. External dc power supply compensates the voltage drop across the resistive component of the line impedance. For harmonic reduction phase shifting transformer with multiple pulses for multilevel inverter is used. This multilevel inverter produces sinusoidal voltages and controls the power flow in transmission lines. Diode bridge rectifier is one of the responsible cause for reducing the power quality in the distribution network, by introducing harmonics, propagating voltage flickers and causes unbalance in voltage and current.

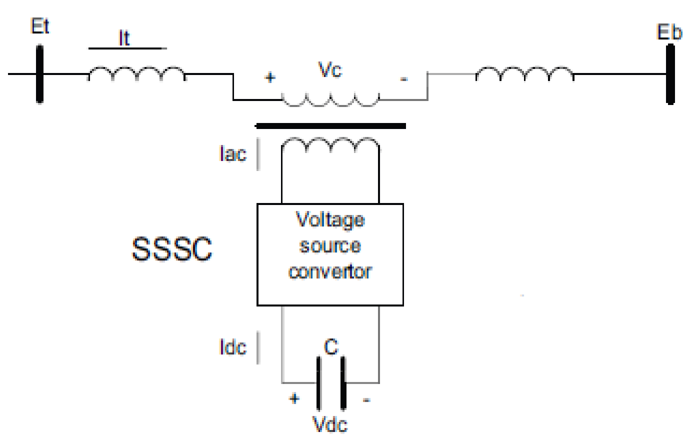


Fig.1. Static synchronous series compensator

The SSSC is a series FACTS device having voltage source converter (VSC) to control the power flow in transmission lines and improve the transient stability in power system as shown in fig.1. The SSSC controls the power flow in transmission lines where it is connected by controlling the magnitude of injected voltage and also the phase angle of injected voltage (Vse ) in series with the transmission line. It consist of three basic components that are I) voltage source converter as a main component II) transformer for coupling the SSSC to the transmission line and III) energy storage device to provides the voltage across dc capacitor and compensate for device losses.

This paper shows performance of static synchronous series compensator for the power quality improvement in electrical power system.

## II. MATHEMATICAL MODELLING OF SSSC

The Static synchronous series compensator is a FACTS device which injects the voltage in series with transmission line for the compensation of system voltage. Hence, SSSC plays a very important role for the power system stability. The controller of SSSC controls the injection of voltages in transmission line. Hence, the system could effects because of changing control signals.

The generator equations of rotor motion can be represented as-

$$\delta^1 = \omega_1 - \omega_{01} \quad (1)$$

$$\omega^1 = \frac{\omega_{01}}{M}\left(P_m - \frac{D}{\omega_{01}}(\omega_1 - \omega_{01}) - P_e\right) \quad (2)$$

Let, excitation system is neglected for simplicity the voltage equations becomes-

$$E_q = V_{1q} + V_{ssscq} + I_{1d}x_{1d'\Sigma} \quad (3)$$

$$0 = V_{1d} + V_{ssscd} + I_{1q}x_{1q\Sigma} \quad (4)$$

Where,

$\delta^1$ – generator rotor motion angle
$\omega^1$ – rotational speed
M – moment of inertia
D – damping coefficient
$P_e$ – Electromagnetic power
$P_m$ – Mechanical power
$V_{ssscd}$ – direct axis voltage component of SSSC
$V_{ssscq}$ – quadrature axis voltage component of SSSC
$V_{1d}$ – direct axix voltage component of infinite bus
$V_{1q}$ – quadrature axix voltage component of infinite bus
$I_{1d}$ – direct axis current component of transmission line
$I_{1q}$ – quadrature aixs current component of transmission line

$$x_{1d'\Sigma} = x_{1d'} + x_t + x_l \quad (5)$$

$$x_{1q'\Sigma} = x_{1q} + x_t + x_l \quad (6)$$

Equation (5) & (6) shows the impedance of the system Therefore $I_{1d}$ & $I_{1q}$ becomes –

$$I_{1d} = \frac{(E_q - V_{1q} - V_{ssscq})}{x_{1d'\Sigma}} \quad (7)$$

$$I_{1q} = \frac{V_{1d} + V_{ssscd}}{x_{1q\Sigma}} \quad (8)$$

The electromagnetic power of the generator can be written as-

$$P_e = E_q I_{1q} + (x_{1q} - x_{1d'})I_{1d}I_{1q} \quad (9)$$

The mathematical model of system with SSSC is given from equation (1) as follows-

$$\delta^1 = \omega_1 - \omega_{01}$$

$$\omega^1 = \frac{\omega_{01}}{M}\left[\begin{array}{c} P_m - \frac{D}{\omega_{01}}(\omega_1 - \omega_{01}) - \frac{E_q V_s \sin\delta}{x_{1d'\Sigma}} \\ + \frac{V^2{}_s(x_{1q\Sigma} - x_{1d'\Sigma})\sin 2\delta}{2x_{1d'\Sigma}x_{1q\Sigma}} \\ - \frac{V_s V_{ssscq}\sin\delta}{x_{1d'\Sigma}} + \frac{V_s V_{ssscd}\cos\delta}{x_{1q\Sigma}} \end{array}\right] \quad (10)$$

$$E_q = \frac{1}{T_{do}}\left[\begin{array}{c} E_{q0} - \frac{x_{1d'}E_{q0}}{x_{1d'\Sigma}} + \\ \frac{(x_{1d'} - x_{1d})(V_{ssscq} + V_s\cos\delta)}{x_{1q\Sigma}} \end{array}\right] \quad (11)$$

$E_{q0}$ – no load electromotive force
$T_{d0}$ – transient time constant

## III. CONTROL SCHEME OF SSSC

The control scheme for the static synchronous series compensator is shown in fig.2.in which all the blocks of the control scheme of the SSSC is given in that.

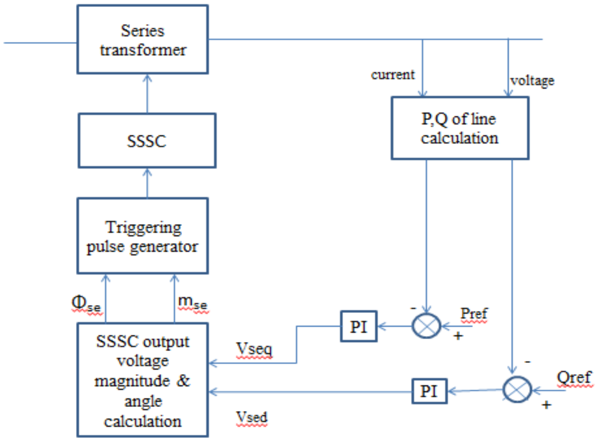


Fig.2. Control scheme for SSSC

From the control scheme it is clear that the SSSC injects voltage in series with the transmission line for series compensation and it gives the superior voltage stability and ultimately improves the voltage profile and power quality too.

The power quality study is done with the IEEE 9 bus system with 3 machines and 9 buses as shown in fig.3. Overall power quality is studied in MATLAB environment.

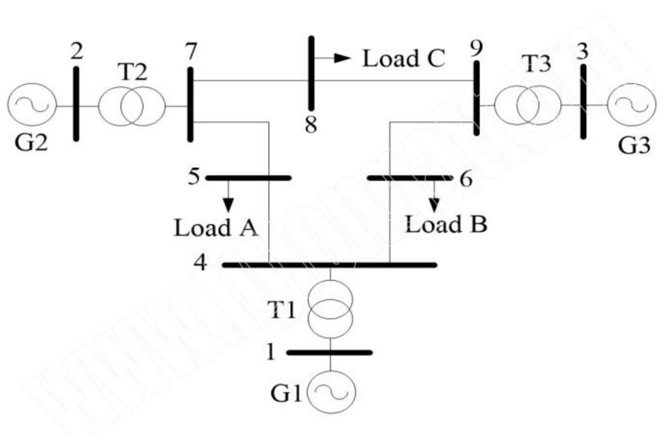


Fig.3. Single line diagram of IEEE 9 bus system

The power quality study is done as in the following sequence :-

Case (I) **:-** In this case there is a change in the load at bus 5.At this bus 5 the non linear load diode bridge rectifier is connected and by using FFT analysis the total harmonic distortions in voltage and current are measured.

Case (II) **:-** In this case the study is with the non linear load and by connecting the Static Synchronous Series Compensator in series with the transmission line as shown in fig.4. SSSC is connected in series with transmission line between the bus 5 and bus 7. In this case the diode bridge rectifier is kept connected at bus 5. Finally, with the SSSC and with the Non linear load the total Harmonic Distortions in voltage and current are measured by using the FFT analysis.

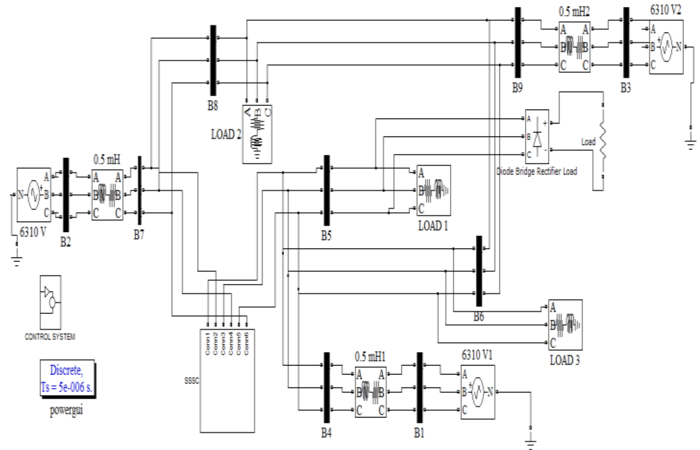


Fig.4. IEEE 9 Bus System with SSSC

## IV. SIMULATION RESULTS

Multi machine system with 9 bus system is tested in MATLAB under various cases and the simulation results are taken out and these simulation results are given as follows-

Case (I) System with Non linear load at Bus 5 without SSSC

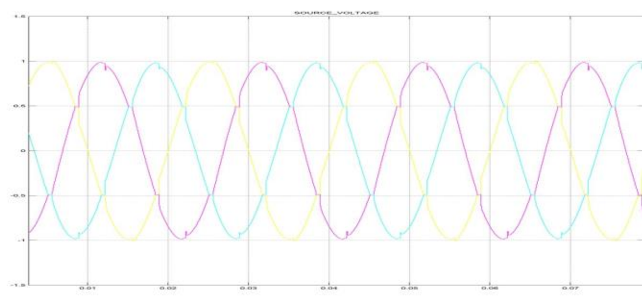

Fig.5. Source side voltage for non linear load without SSSC

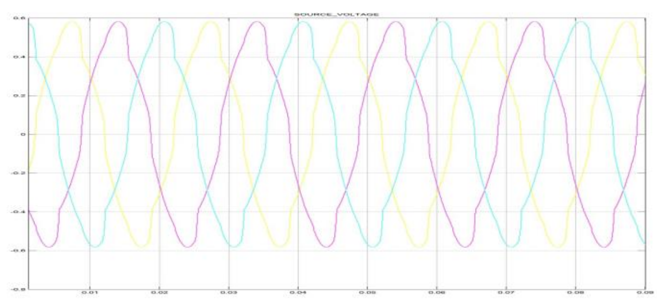

Fig.6. Source side current for non linear load without SSSC

From the fig.5.and fig.6.it is clear that source side voltage waveform and source side current waveforms gets distorted because of non linear load which shows that there is a presence of harmonics in the source side voltage and current.

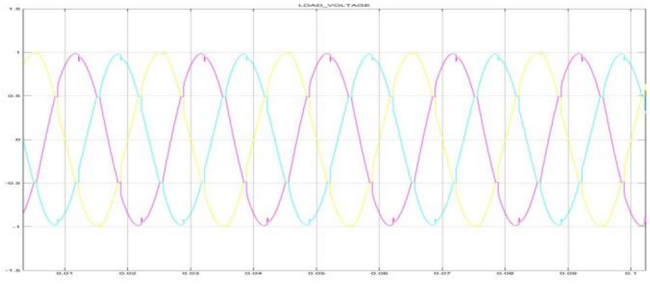

Fig.7.Load side voltage for non linear load without SSSC

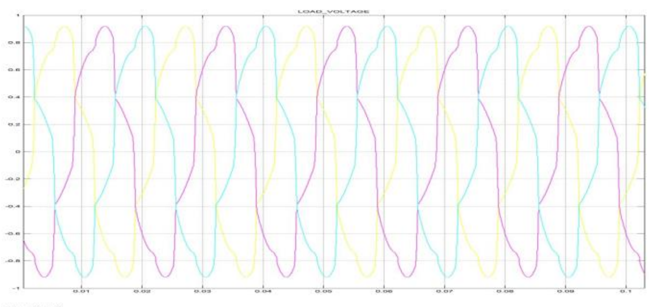

Fig.8.Load side current for non linear load without SSSC

The fig.7. and fig.8. shows the load side voltage and load side current waveforms gets distorted more because of non linear load as compared to source side voltage and source side current waveforms. It shows that waveforms at the load side contain more harmonics.

Case (II) System with non linear load and with SSSC at Bus 5

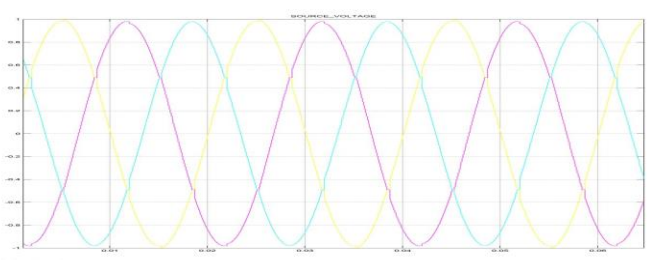

Fig.9.Source side voltage for non linear load with SSSC

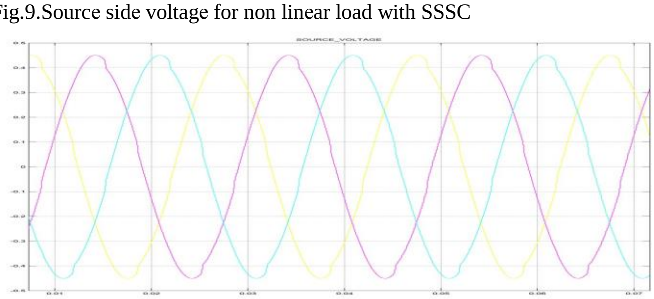

Fig.10.Source side current for non linear load with SSSC

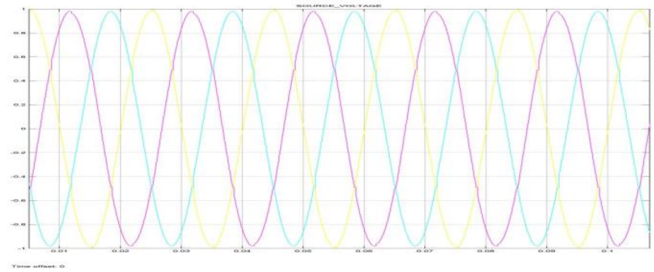

Fig.11.Load side voltage for non linear load with SSSC

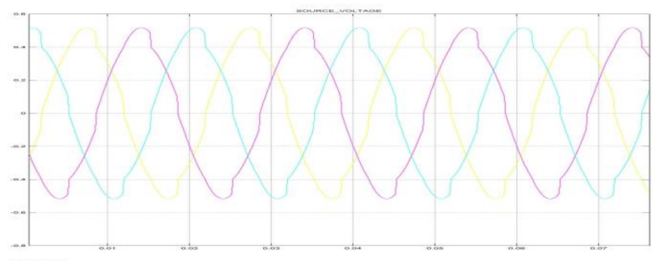

Fig.12.Load side current for non linear load with SSSC

The above simulation results fig.9 and fig.10 shows the source side voltage and current waveform respectively with SSSC. Similarly fig.11.and fig.12. shows the load side voltage and current respectively with SSSC. It is clear from the above simulation results after placing SSSC in the system, distortion in the source side and load side voltage and current respectively gets reduced as compared to the system without SSSC.

## V. TOTAL HARMONIC DISTORTION ANALYSIS BY USING FFT

Case (I) FFT analysis for system with non linear load without SSSC

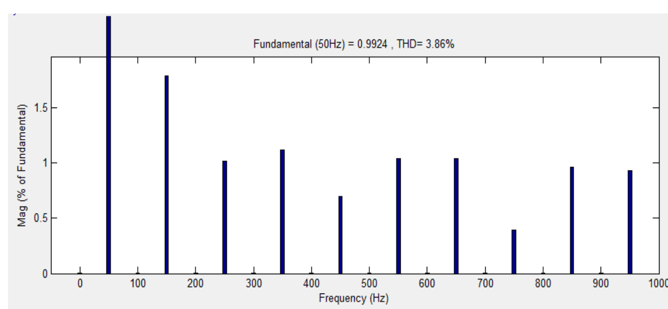


Fig.13.Source voltage THD results for non linear load without SSSC

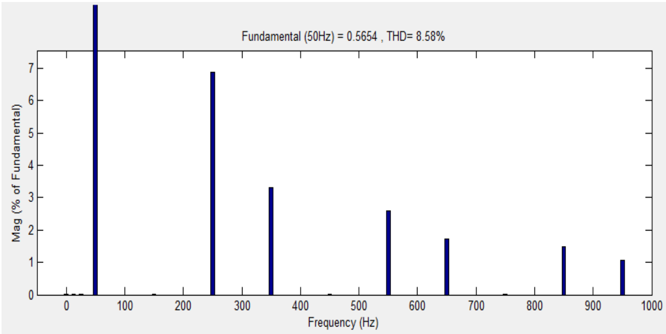


Fig.14.Source current THD results for non linear load without SSSC

The fig.13.and fig.14.shows the results for the source voltage and source current THDs for the system without SSSC with non linear load which are 3.86% and 8.58% respectively.

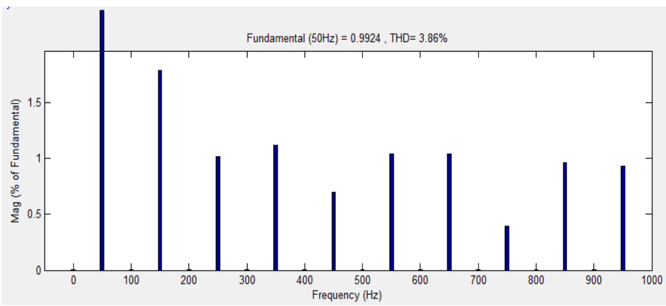


Fig.15.Load voltage THD results for non linear load without SSSC

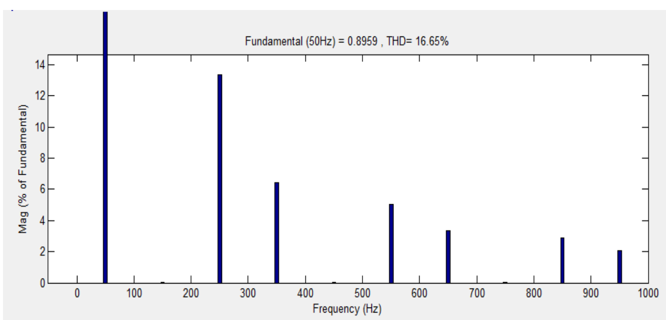


Fig.16.Load current THD for non linear load without SSSC

The fig.15.andfig.16.shows the results for load side voltage and current THDs for the system without SSSC with non linear load which are 3.86% and 16.66%

Case (II) FFT analysis for system with non linear load and with SSSC

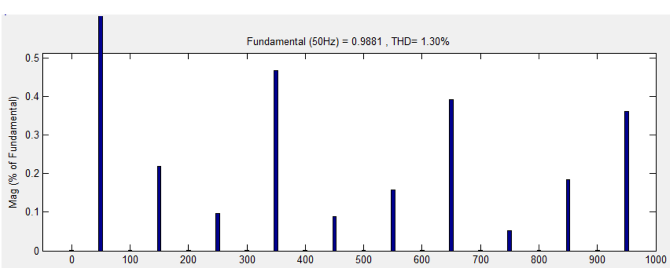


Fig.17.Source voltage THD for non linear load with SSSC

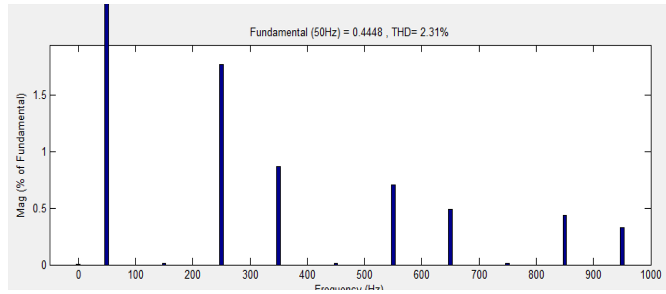


Fig.18.Source current THD for non linear load with SSSC

The fig.17.and fig.18.shows the results for the source side voltage and current THDs for the system with non linear load and with SSSC which are obtained by FFT analysis are 1.30% and 2.31%. Which show that by applying the SSSC in the system the THDs gets reduced in source side voltage and current gets reduced.

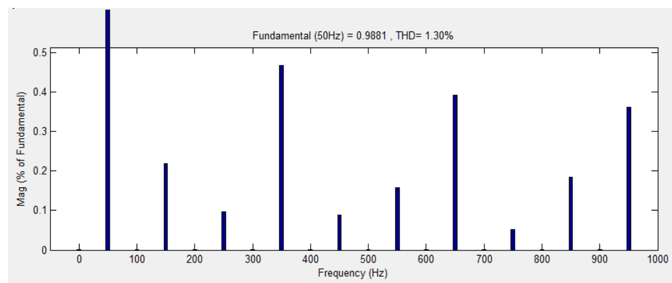


Fig.19.Load voltage THD for non linear load with SSSC

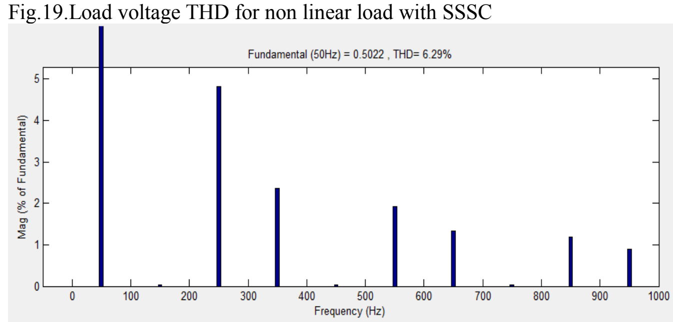


Fig.20.Load current THD for non linear load with SSSC

The fig.19.andfig.20.shows the results for load side voltage and current THDs for the system with SSSC in the system with non linear load.Which shows that by implementing the SSSC in the system the THDs gets reduced in source side and load side voltage and current gets reduced.

TABLE I

INDIVIDUAL HARMONIC DISTORTION (IHD) AT BUS 5 WITH NON LINEAR LOAD WITHOUT SSSC

| Harmonic | Source voltage IHD in % | Source current IHD in % | Load voltage IHD in % | Load current IHD in % |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Fundamental | 100 | 100 | 100 | 100 |
| 2nd Harmonic | 0.00 | 0.00 | 0.00 | 0.00 |
| 3rd Harmonic | 1.79 | 0.01 | 1.79 | 0.03 |
| 4th Harmonic | 0.00 | 0.00 | 0.00 | 0.00 |
| 5th Harmonic | 1.02 | 6.87 | 1.02 | 13.34 |
| 6th Harmonic | 0.00 | 0.00 | 0.00 | 0.00 |
| 7th Harmonic | 1.12 | 3.31 | 1.12 | 6.43 |

TABLE II

INDIVIDUAL HARMONIC DISTORTION (IHD) AT BUS 5 WITH NON LINEAR LOAD WITH SSSC

| **Harmonic** | **Source voltage IHD in %** | **Source current IHD in %** | **Load voltage IHD in %** | **Load current IHD in %** |
|---|---|---|---|---|
| Fundamental | 100 | 100 | 100 | 100 |
| 2nd Harmonic | 0.00 | 0.00 | 0.00 | 0.00 |
| 3rd Harmonic | 0.22 | 0.01 | 0.22 | 0.04 |
| 4th Harmonic | 0.00 | 0.00 | 0.00 | 0.00 |
| 5th Harmonic | 0.10 | 1.77 | 0.10 | 4.81 |
| 6th Harmonic | 0.00 | 0.00 | 0.00 | 0.00 |
| 7th Harmonic | 0.47 | 0.87 | 0.47 | 2.37 |

Above TableI and TableII show the individual harmonic distortion (IHD) upto the 7th harmonics in the system for the source side & load side voltage and current with and without SSSC respectively. From the tables it is clear that only harmonics present in the system are the odd harmonics because of these odd harmonics there is a harmonics present in the system. IHDs and THDs for the source side voltage and for the load side voltage without SSSC and with SSSC remains same. Only change in the source side and load side current which gets distorted and contain more harmonics, also the load side current contain more harmonics as compared to source side current.

From the FFT analysis and from the TableI and TableII table of Total Harmonic Distortion can be obtained with and without SSSC as follows shown below in TableIII.

TABLE III

TOTAL HARMONIC DISTORTION ANALYSIS AT BUS 5 WITH NON LINEAR LOAD

| | **Without SSSC** | **With SSSC** |
|---|---|---|
| **Signals** | **THD %** | **THD %** |
| 1) Source voltage | 3.86 | 1.30 |
| 2) Source current | 8.58 | 2.31 |
| 3) Load voltage | 3.86 | 1.30 |
| 4) Load current | 16.65 | 6.29 |

From the above TableIII of total harmonic distortion it is clear that without SSSC the source side voltage, current and load side voltage and current have distortion with non linear load that means there is presence of harmonics in the system because of the non linear load. TheTHDs which are observed without SSSC on source side are 3.86% and 8.58% in voltage and current respectively where as on load side 3.86% and 16.65% respectively. It is clear that because of non linear load there is not much change in the source and load side voltage but the current on the load side gets more distorted than that of the source side. After placing the SSSC in the system the THDs on the source side are 1.30% and 2.31% respectively in voltage and current where as on load side 1.30% and 6.29% respectively. It is cleared that with SSSC harmonics in the current are reduced on the source sides reduced by 73.07% that of without SSSC and on load side current harmonics reduced by 62.22 % that of without SSSC. However,the harmonics on the load side and source side voltage with SSSC are reduced by 66.32% that of without SSSC. It shows that there is not a change in the source side and load side voltage harmonics with SSSC but the harmonics in the current are reduced to a certain extent.

## VI. CONCLUSIONS

From the above simulation results, tables of Individual Harmonic Distortion and Total Harmonic Distortion it is clear that by using series FACTS device Static Synchronous Series Compensator (SSSC) the power quality can be improved very well as SSSC helps to reduce the harmonics present in the system voltages and currents. Hence, power quality in power system can be improved by using series FACTS device static synchronous series compensator (SSSC).

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