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SSSC Controller a Pro-defensive and Preventive Approach for Power System Optimisation

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ABSTRACT

The conventional and modern controlling practices used in power technology contradict each other. This is due to their operational and observational outcome while mitigating with a power system. The modern quality power culture requirements in terms of daily usage have been revised drastically in the recent past. The traditional systems use a non-dynamic type controller device, whereas modern power system require dynamic one. The dynamic controller are designed by using power electronic components such as SCR, MOSFET, IGBT, GTO, Power BJT etc. Due Moreover, dynamic controllers can operate in either absorbing or delivering power modes to/from a system. The modern Power Systems being dynamic can utilise reactive power to useful energy. The present work is an effort to emphasize the usefulness of reactive power in order to minimize power loss. SSSC controller of FACTS device have been utilised to estimate reactive paper usage during loading. The results were very much encouraging. The parameters enhanced with this technique were found to be Bus Voltage, flow of Real Power and Reactive Power.

Keywords: FACTS devices; WLS Technique; SSSC; Deregulated power Systems.

INTRODUCTION

The electrical power network of India as well as of World is complex in nature. The several components of the Power technology play a important role in effective operation of the power network. The system consists of multiple components of dissimilar rating with diverse characteristics. The Single Line Diagram of the power network may give a brief idea of entire power system. But actual role of the power network is not that simple rather very complex. There being multiple components, numerous possibilities of disturbances of varied nature may occur during operation of a system. Apart from smooth operation of a system Reliability, Sensitivity, and Stability towards society is equally significant. These parameters are very much affected due to their varied nature as well as manifold operations of power system components.

The entire power network consists generation, distribution, and transmission of electric power to the load end users. The demand of power and its generation many a times have vast gap. It results into unequal distribution of load on transmission lines. The transmission lines therefore remain either under-loaded or over-loaded. This makes the system congested with low stability, less reliability and lower sensitivity. The FACTS controllers are power electronic based device, which help in reducing the congestion of transmission lines during peak hours. It has the capability to provide a stable and continuous supply of power to the consumer during peak hours.

(Anwar S. Siddiqui and Tanmoy Deb. 2014) discussed the different type of FACTS controllers to minimise congestion in critically loaded transmission lines. This was used in order to diminish system loss and enhance stability and hence minimise delivery cost of energy. The multiple combinations of individual TCSC, STATCOM, and UPFC controller were work on IEEE 14 bus network. The system argued with various parameters on the different combination as a single, double and triple combination of FACTS devices on the same bus system in comparison with no FACTS device at loaded conditions. (Bone Gorazd & Mihalic Rafael. 2015) investigated the vector mismatch the vector mismatch during power flow among the buses. The implementation of SSSC is conferred and identified the power injection impact on controlling of vector mismatch. (Esmaeil Ghahremani & Innocent Kamwa. 2013) used GUI technique work on a genetic algorithm in shorting the position of multiple type FACTS device for a large power system. The GA helped in identifying the location and size of FACTS device to rectify the system loadability. It also improved security & stability with fewer transmission line losses, finally, added an energy-efficient transmission system. The controllers tested in their work were SVC, TCPST, TCVR, TCSC, and UPFC on IEEE 300 buses system. They used FACTS placement toolbox which contained all abovementioned controllers. It was found to be flexible and effective for analysing a large scenario, mixed and multiple types of FACTS devices at multi-point locations. (Garg Lokesh et al. 2018) suggested the operation of TCSC, SSSC, and UPFC for transient state stability. The time-domain simulator was used on PSAT box for IEEE 9 bus network. The eigen-value analysis was opted to determine identified pre-fault and fault condition of a system. The researcher suggested that power system analysis with FACTS devices for transient system improvement UPFC are more effective controller as compared with TCSC and SSSC. (Gupta Anju & Sharma P.R. 2012) conferred on FACTS controller device for static voltage stability with an increase in loadability margin of the power system. They used bus based P-V curve and eigen values analysis along with stability indices. They also used PSAT software with continuation power flow setting and UPFC on IEEE 14 bus system. They suggested that UPFC will help in increasing the loadability and stability margin of a power system.

(Jiang Xia et al. 2010) used FACTS devices as Voltage source Inverter for dynamic stability of the power system. They worked on linear and nonlinear examination for power network dynamics. The FACTS controllers i.e. UPFC, STATCOM, and SSSC were used to damped out oscillations of a region. It was also tested for Supplementary plan of damping controller for time-domain based simulation. This concept was originally announced by N. G. Hingorani (N. G. Hingorani & L. Gyugyi. 1999).

(Jitender Kumar & Narendra Kumar. 2020) model designed of IEEE 14 bus network by using Matlab/Simulink platform. They recommended PMU technique in cooperation of WLS technique for identifying the location of an additional device, which may be used to compensate power system. The technique was used to achieve an optimal location for setting up enhancement devices to realize power quality norms. (Jitender Kumar. 2016 & Jitender Kumar et al. 2012) investigated Weighted Least Square Technique for identifying the status a system in identifying optimal allocation device placement in big power network system. (Kumar Jitender & Kumar Narendra. 2018) investigated different parameters of IEEE Bus system by using TCSC and STATCOM controller. The parameters discussed were voltage profile and reactive power flow during loading condition. They also discussed impact of effective utilisation of FACTS device on sizing and its allocation in IEEE 14 Bus system. (Kumar Sahoo Ashwin, et al. 2007) discussed FACTS devices operation for control of voltage and power angle for each bus on 5 bus system. The STATCOM and UPFC model was designed for IEEE bus network at a different level of voltage with a variation of power angle on the same system. The model also investigated benefits of FACTS controller at steady state conditions. The progression of the power system by means of FACTS controllers is the most appealing work. (M. Vural A. & Tumay M. 2003) was discussed FACTS mathematical modeling and analysis on a steady state operation. The model of UPFC was worked on IEEE 14 & 30 bus network. The system adapted on user-defined modelling technique by use of Newton raphson method. The parameters tested for modelling operation were real and reactive power with or without UPFC. They also compared its advantages on IEEE bus system. (Parvathy S et al. 2015) worked on FACTs functioning for control of voltage profile; line impedance and power angle in manage power transfer on transmission line. They suggested a decoupled control scheme with a PI controller. The system operated on varied power factors and at different load The FACTS controller helps in reducing losses as well as enhancing system reliability and stability. It also assist in mitigation on flow of power through overloaded transmission lines improve system loadability, enhance system security and improve system efficiency, etc. Due to these benefits transmission of power over an existing line are enhanced by a specific value which compensate increased load and re-regulate power supply. The compensation for the varied demand/supply options of power, there is a need to investigate ways to reduce losses and exploit the transfer capability on power transmission lines. The researcher concentrated on a specific limit of the system with respect to system reliability and stability. To achieve a high performance to control power system operation, the power electronic components are more efficient with lower switching losses.

The power system analysis needs to be conducted on the Static model of Static Synchronous Series Compensator. The FACTS controllers are mainly applicable to Reactive Power Compensation, compensate transmission losses, and maintain line voltage with power flow capability within their specified limit.

The FACTS device controller provides line compensation over the transmission line within a specified limit. In this case, the combination of a capacitor is varied during charging and discharging combinations by adjusting their firing angle. So that it provides a control over apparent power flow with voltage magnitude. The SSSC (Anwar S. Siddiqui & Tanmoy Deb 2014) (Kumar Jitender & Kumar Narendra. 2018) were connected in series with the flow over transmission line which helps in control line impedance and enhancement in power handling capability of transmission lines. The SSSC provides a bi-directional flow of both powers between two buses.

The present work uses a model of IEEE 14 Bus system (Anwar S. Siddiqui & Tanmoy Deb 2014) (Jitender Kumar & Narendra Kumar. 2020) with SSSC controller in order to be simulated on Matlab/ Simulink platform. The system analysis process is concentrated on system parameters i.e. Voltage magnitude and Real Power Compensation, with and without implementation of FACTS devices on a power system.

MODELING OF SSSC

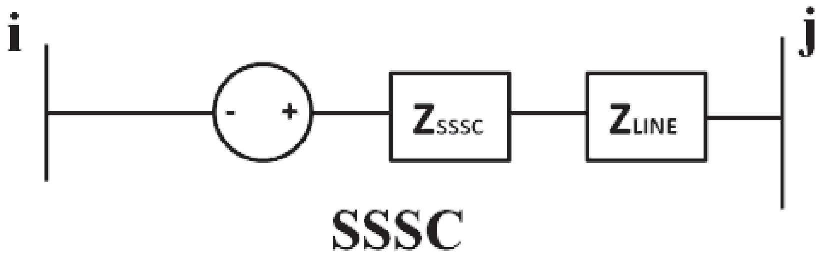

Figure 1. SSSC Model

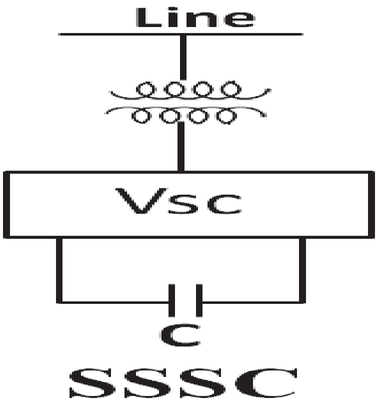

Figure 2. SSSC Model

The most widely used series FACTS device is Static Synchronous Series Compensator (Kumar Sahoo Ashwin, et al. 2007) (M. Vural A. & Tumay M. 2003), which also act as a static phase shifter. It will help in injects of quadrature voltage to one sideline end voltages and regulate active power flow of respective bus. The SSSC consist a Power Capacitor which operates Reactive Power absorption or delivering on a comparison of power angle of buses. So that SSSC is more competent to recompense not only Voltage magnitude but also help in the control of Real and Reactive power of power network.

The SSSC phase angle and magnitude are accustomed by any appropriate technique so that it gratifies the flow of real and reactive power during operation of SSSC on transmission line (Kumar Sahoo Ashwin, et al. 2007) (S. Amara & Hasan H.A. 2012).

$$L\frac{di}{dt} + Ri = v_s - v_C - v_R \tag{1}$$

$$i = i_1 + ji_2, \quad v_s = v_{s1} + jv_{s2} \tag{2}$$

$$v_C = v_{C1} + jv_{C2}, \quad v_R = v_{R1} + jv_{R2} \tag{3}$$

The transforming of above equation into 1, 2 to D – Q components which related to

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} \text{Cos}\,\theta & \text{Sin}\,\theta \\ -\text{Sin}\,\theta & \text{Cos}\,\theta \end{bmatrix} \begin{bmatrix} i_D \\ i_Q \end{bmatrix} \tag{4}$$

Where $\theta = \omega_0 t + \theta_0$. In this case there is no loss of generality in assuming $\theta_0 = 0$. Similarly, the transformation as given above applies to the variables v_{s1}, v_{s2} and v_{sD}, v_{sQ} & so on

$$(i_2 + ji_1) = (i_Q + ji_D)\, e^{j\omega_0 t} = Ie^{j\omega_0 t} \tag{5}$$

$$L\frac{d(Ie^{j\omega_0 t})}{dt} + R(Ie^{j\omega_0 t}) = (V_s - V_C - V_R)e^{j\omega_0 t} \tag{6}$$

On simplifying the equation, we get

$$(R + j\omega_0 L)I = (V_s - V_C - V_R) \tag{7}$$

The power flow (Garg Lokesh et al. 2018)(N. G. Hingorani & L. Gyugyi. 1999) between buses are as follows

$$S_{ij} = V_i I_{ij}^* \tag{8}$$

$$P_{ij} = V_i^2 G_{ii} - V_i V_j (G_{ij}\,\text{Cos}\,\theta_{ij} + B_{ij}\text{Sin}\,\theta_{ij})$$
$$- V_i V_{CR}(G_{ij}\,\text{Cos}\,(\theta_i - \delta_{CR}) + B_{ij}\text{Sin}(\theta_i - \delta_{CR})) \tag{9}$$

$$Q_{ij} = -V_i^2 B_{ii} - V_i V_j (G_{ij}\,\text{Sin}\,\theta_{ij} - B_{ij}\,\text{Cos}\,\theta_{ij})$$
$$- V_i V_{CR}(G_{ij}\,\text{Sin}\,(\theta_i - \delta_{CR}) + B_{ij}\text{Cos}(\theta_i - \delta_{CR})) \tag{10}$$

$$P_{ji} = V_j^2 G_{jj} - V_i V_j (G_{ij}\,\text{Cos}\,\theta_{ji} + B_{ij}\text{Sin}\,\theta_{ji})$$
$$+ V_j V_{CR}(G_{ij}\,\text{Cos}\,(\theta_j - \delta_{CR}) + B_{ij}\text{Sin}(\theta_j - \delta_{CR})) \tag{11}$$

$$Q_{ji} = -V_j^2 B_{jj} - V_i V_j (G_{ij}\,\text{Sin}\,\theta_{ji} - B_{ij}\,\text{Cos}\,\theta_{ji})$$
$$+ V_j V_{CR}(G_{ij}\,\text{Sin}\,(\theta_j - \delta_{CR}) - B_{ij}\text{Cos}(\theta_j - \delta_{CR})) \tag{12}$$

So that the power flow constraints are given as

$$\text{Re}\,(V_{CR} I_{ji}^*) = 0 \tag{13}$$

WLS STATE ESTIMATION TECHNIQUE

$$z = h(x) + e \tag{14}$$

Where:

$$h^T = [h_1(x), h_2(x), h_3(x), ...h_m(x)] \tag{15}$$

hi (x) is the non-linear function relating to ith measurement for the state vector x

$x^T = [x_1, x_2, x_3 .... x_n]$ is the system state vector

$e^T = [e_1\ e_2\ e_3 .... e_m]$ is the state vector for error measurement.

The full weighted least square estimator (Jitender Kumar. 2016) (Jitender Kumar et al. 2012) will help in diminishing the objective function:

$$J(x) = \sum_{i=1}^{m} \frac{(z_i - h_i(x))^2}{R_{ii}} = [z - h(x)]^T R^{-1} [z - h(x)] \tag{16}$$

At a minimal value of the objective function, the first-order optimal condition is to be satisfied. It can be expressed by:

$$g(x) = \frac{\partial J(x)}{\partial x} = -H^T(x) R^{-1} [z - h(x)] = 0 \tag{17}$$

The Taylor series of non-linear function g(x) can be expanded for the state vector xk by neglecting the higher order terms (Jitender Kumar & Narendra Kumar. 2020) (Jitender Kumar et al. 2012) will be as

$$g(x) = g(x^k) + G(x^k)(x - x^k) + ... = 0 \tag{18}$$

The above equation may be resolved with the help of the GN method:

$$x^{k+1} = x^k - [G(x^k)]-1 . g(x^k) \tag{19}$$

where k is the iteration index, x^k is the state vector at iteration k and G(x) is called the gain matrix and expressed as:

$$G(x) = \frac{\partial g(x^k)}{\partial x} = H^T(x^k) R^{-1} H(x^k) \tag{20}$$

$$g(x^k) = -H^T(x^k) R^{-1} [z - h(x^k)] \tag{21}$$

Normally, the gain matrix is now decomposed into triangular factors. At each iteration k, the gain matrix is solved by using forward / backward substitutions, where $\Delta x^{k+1} = x^{k+1} - x^k$ and

$$[G(x^k)] \Delta x^{k+1} = H^T(x^k) R^{-1} [z - h(x^k)] = H^T(x^k) . R^{-1} \Delta z^k \tag{22}$$

All the iterations to be performed until we get the maximum variable difference will satisfy the condition, ' Max $|\Delta x^k| \le \varepsilon$ '.

WLS Technique along with facts devices:

1. Study input data of the network system;
2. When FACTS device implement to node k then analyse Modified admittance matrix (Y bus).
3. Merge both network equation and power equations.
4. The inclusion of facts devices with conventional Jacobian matrix then these parameters amplify their Jacobian matrix dimensions.
5. Then WLS state estimation technique pursues from equation 14 to 22.

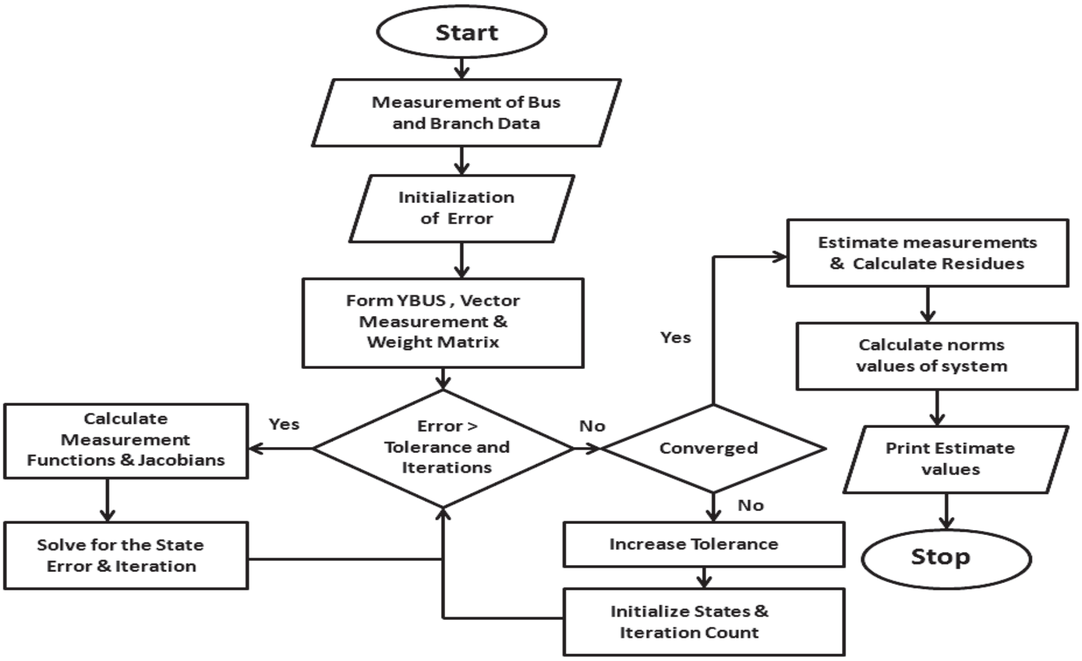

Figure 3. WLS Technique

SIMULATION RESULT AND DISCUSSION

The standard result obtained by operation of the IEEE 14 Bus network (Jitender Kumar & Narendra Kumar. 2020) (Jitender Kumar et al. 2012) on loading conditions are shown in Table 1:-

Table 1. IEEE 14 Bus System Base Values

Bus No.	Bus Voltage (pu)	Voltage Angle (deg.) (pu)	P MW	Q MVAr
1	1.7012	1.039	0.0123	0.0803
2	1.4328	0.961	-0.0157	0.0153
3	1.1047	0.835	0.0141	0.00569
4	1.0110	0.791	-0.00194	-0.00510
5	0.9979	0.784	-0.0499	-0.0447
6	1.3807	0.944	0.00959	0.0734
7	1.0881	0.828	-0.00111	-0.00266
8	1.6916	1.037	-0.00151	-0.0322
9	0.9584	0.764	0.0172	0.0114
10	0.9464	0.758	1.30E-05	8.56E-06
11	0.9696	0.770	-0.00282	0.00570
12	0.9696	0.770	0.00186	0.00671
13	0.9659	0.768	0.0127	0.0165
14	0.9439	0.757	-9.33E-05	3.92E-04

The system is operating on standard condition without implementation of any additional device which may improve system performance of a under loading conditions. The parameter considers for system performances are system Voltage; flow of Real Power and Reactive Power of each bus of IEEE 14 Bus system (Jitender Kumar & Narendra Kumar. 2020) (Jitender Kumar et al. 2012) in Table 1.

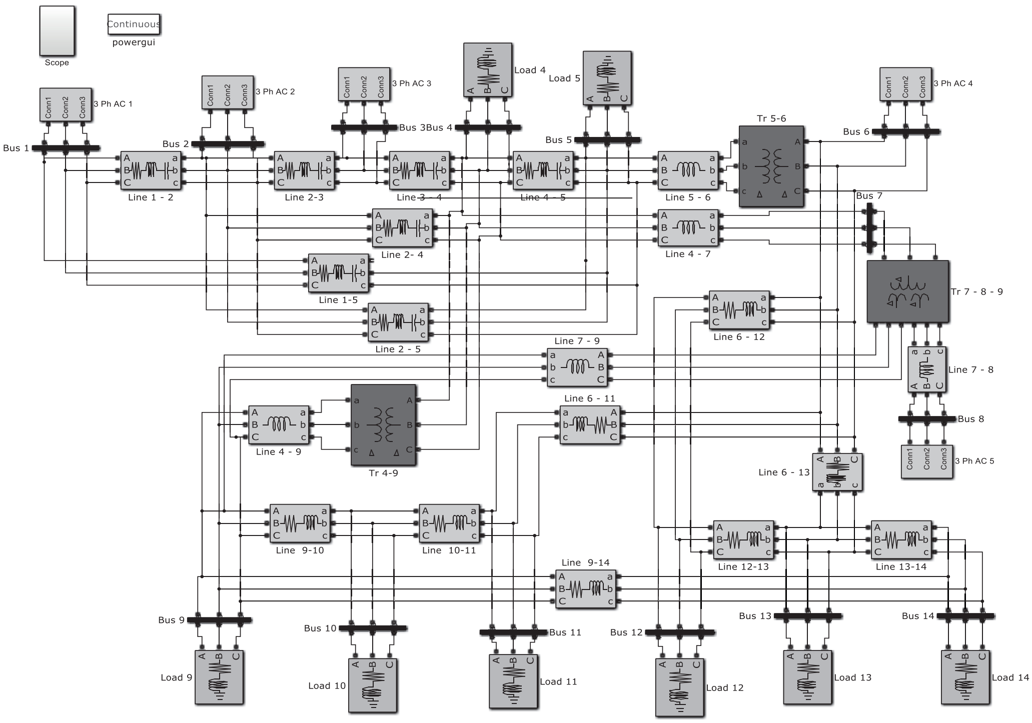

Figure 4. IEEE 14 BUS SYSTEMS

The SSSC are power electronic devices which are enhancement of network voltage profile and the real power of the power system to the desired level as per the requirement for electric power quality norms. As per the Table 1, the values of voltage on multiple buses are lying below the unity value which must be equal/above the unity values. So that we needed an additional device which enhanced the voltage values on buses above the unity values as per the requirement of a system. The equipment required for such conditions must be dynamic in nature and mitigate system efficiently. This paper proposed SSSC device to mitigate parameters of buses which descend below a precise value of the network system in IEEE 14 Bus system.

The SSSC are dynamic controlling devices which implemented on IEEE system to enhanced the system parameters and improve its performance. The network voltage profile of some buses in IEEE 14 bus system is less than unity and required a dynamic controller to improve their parameters in the minimum time period. Table 1 exemplifies that the voltage parameter of some buses in the power system is not satisfactory as per the power quality issues. The values of bus 9 to 14 are as 0.9584 pu, 0.9464 pu, 0.9696 pu, 0.9696 pu, 0.9659 pu, and 0.9439 pu. All such buses needed an additional device, which is capable to enhance these parameters to a specific value as per power quality norms.

The realization of SSSC on specified under-voltage buses of Table 1 in IEEE 14 Bus system illustrates that SSSC controller enhances the performance parameter of buses on power system as per result is shown in Table 2 and their graphical representation in Figure. 5 - 16.

Table 2. Effect of SSSC implementation on bus voltage, bus real power flow and bus reactive power flow

Bus No.	Bus Voltage with SSSC					Bus Real Power Flow with SSSC				Bus Reactive Power Flow with SSSC			
	Without	**9 - 10**	**10 - 11**	**12 - 13**	**13 – 14**	**9 - 10**	**10 - 11**	**12 - 13**	**13 - 14**	**9 - 10**	**10 - 11**	**12 - 13**	**13 - 14**
1	1.7012	1.7009	1.7010	1.7011	1.7011	0.0130	0.0127	1.25E-02	0.0126	0.0821	0.0811	0.0807	0.0809
2	1.4328	1.4321	1.4325	1.4326	1.4325	-0.0133	-0.0143	-1.53E-02	-0.0150	0.0195	0.0173	0.0163	0.0171
3	1.1047	1.1042	1.1045	1.1046	1.1045	0.0155	0.0148	1.42E-02	0.0145	0.00796	0.00675	0.00615	0.00661
4	1.0110	1.0294	1.0219	1.0110	1.0139	-0.00153	-0.00175	-1.85E-03	-0.00179	-0.00449	-0.00479	-0.00498	-0.00476
5	0.9979	1.0023	1.0013	0.9977	0.9978	-0.0453	-0.0475	-4.88E-02	-0.0476	-0.0409	-0.0428	-0.0438	-0.0428
6	1.3807	1.3815	1.3856	1.3844	1.3798	0.0209	0.0218	2.88E-02	0.0148	0.0900	0.0841	0.110	0.0856
7	1.0881	1.1842	1.1404	1.0905	1.1063	0.00202	5.37E-04	-7.05E-04	-1.54E-04	0.00197	-5.19E-04	-0.00178	-4.41E-04
8	1.6916	1.6907	1.6914	1.6912	1.6911	0.00515	0.00230	9.36E-06	0.00269	-0.0355	-0.0332	-0.0326	-0.0332
9	0.9584	1.2997	1.1392	0.9808	1.0430	0.0324	0.0245	1.81E-02	0.0207	0.0216	0.0163	0.0121	0.0138
10	0.9464	1.6934	1.1334	0.9622	1.0019	4.27E-05	1.87E-05	1.35E-05	1.48E-05	2.83E-05	1.24E-05	8.89E-06	9.80E-06
11	0.9696	1.2013	1.7130	0.9748	0.9822	-4.60E-04	0.00173	-2.37E-03	-0.00214	0.00898	0.0173	0.00577	0.00590
12	0.9696	0.9717	0.9973	1.0851	0.9844	0.00187	0.00197	2.58E-03	0.00192	0.00675	0.00712	0.00851	0.00695
13	0.9659	0.9800	1.0479	1.3058	1.0153	0.0131	0.0150	2.33E-02	0.0142	0.0170	0.0195	0.0316	0.0185
14	0.9439	1.1232	1.7123	1.0958	1.5384	-4.13E-06	2.16E-04	-1.78E-06	1.09E-04	5.57E-04	0.00124	5.30E-04	9.50E-04

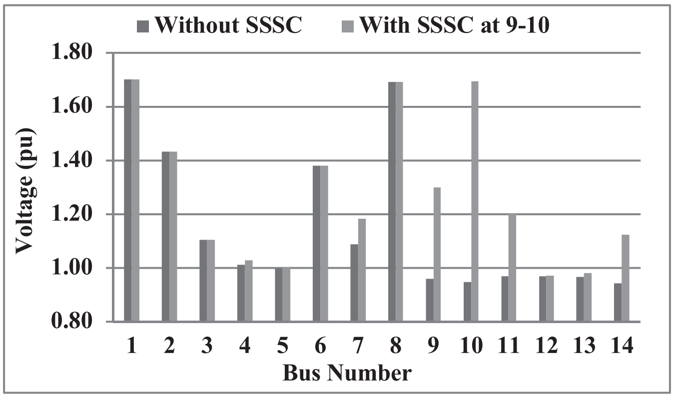

Figure 5. Performance Curve of Voltage with SSSC at 9-10

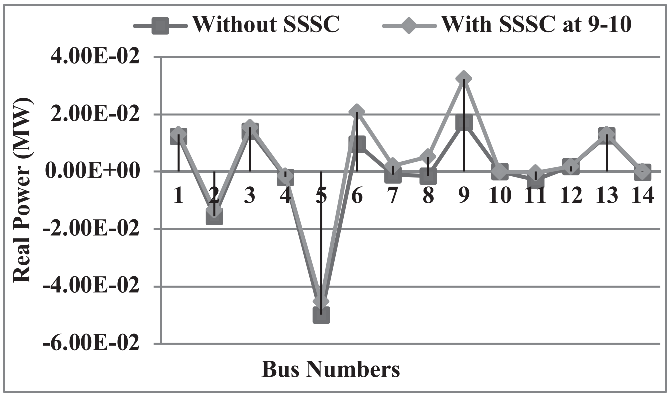

Figure 6. Performance Curve of Voltage with SSSC at 10-11

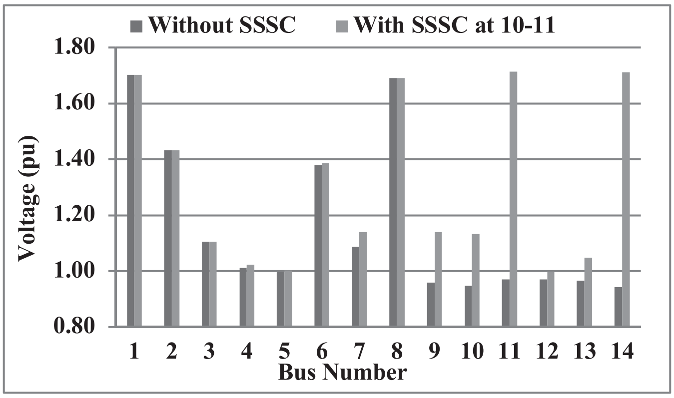

Figure 7. Performance Curve of Voltage with SSSC at 12-13

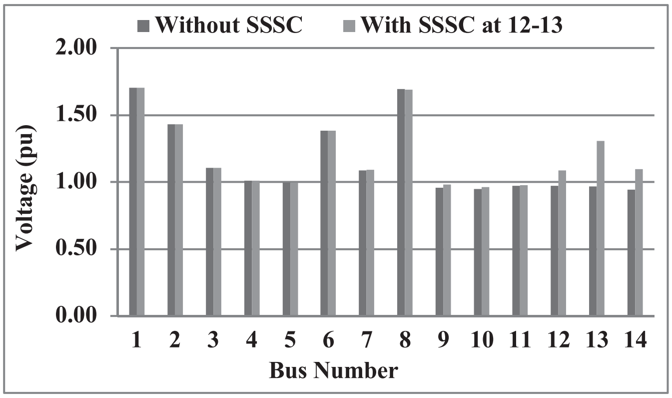

Figure 8. Performance Curve of Voltage with SSSC at 13-14

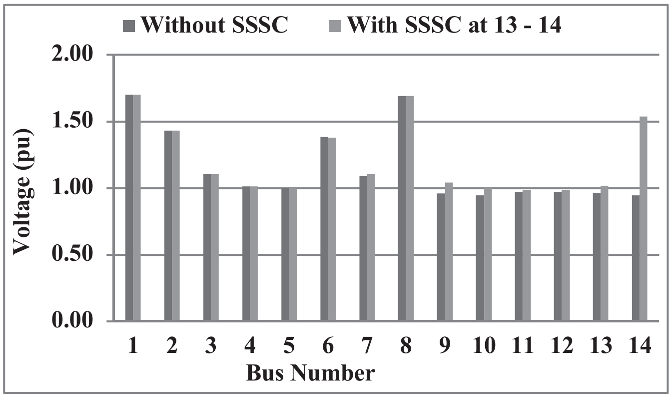

Figure 9. Performance Curve of Real Power Flow with SSSC at 9-10

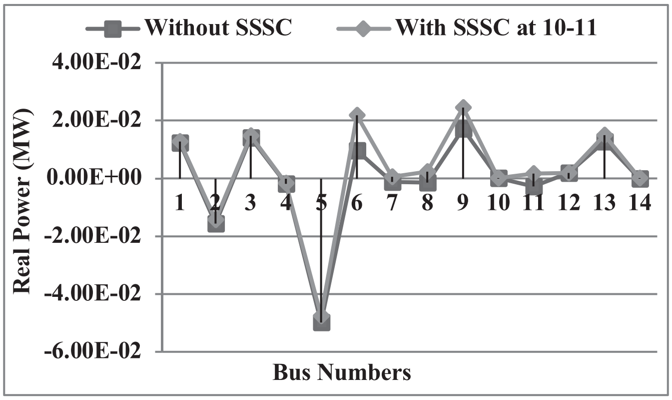

Figure 10. Performance Curve of Real Power Flow with SSSC at 10-11

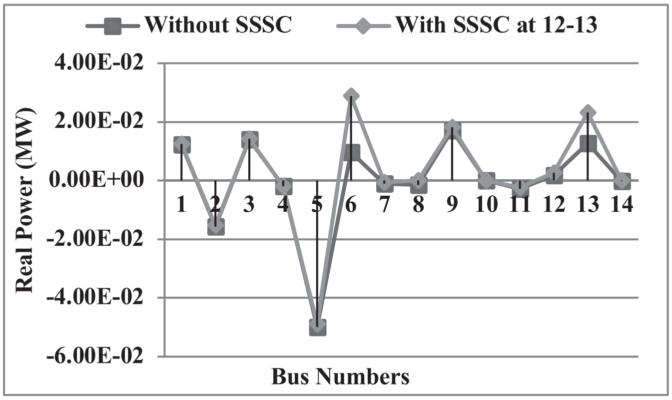

Figure 11. Performance Curve of Real Power Flow with SSSC at 12-13

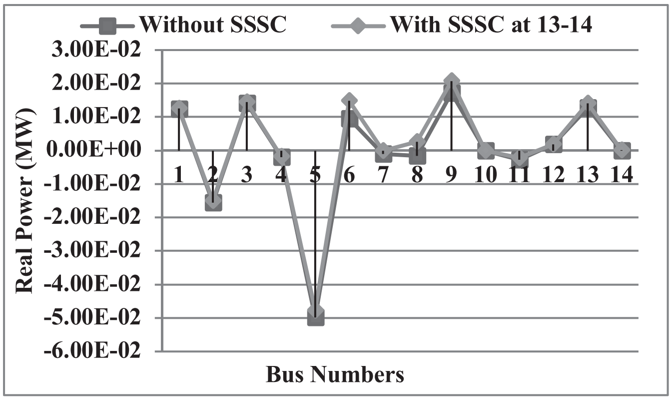

Figure 12. Performance Curve of Real Power Flow with SSSC at 13-14

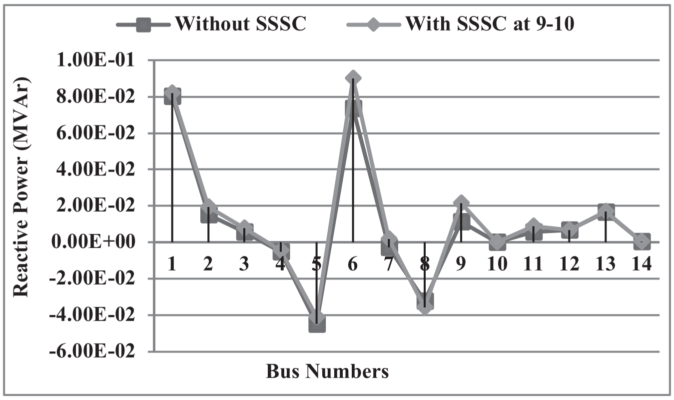

Figure 13. Performance Curve of Reactive Power Flow with SSSC at 9-10

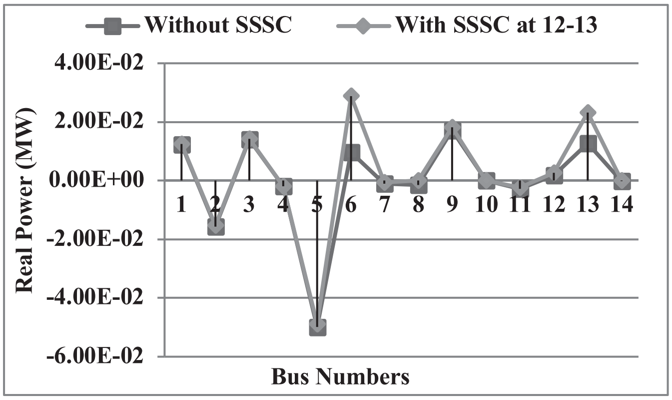

Figure 14. Performance Curve of Reactive Power Flow with SSSC at 10-11

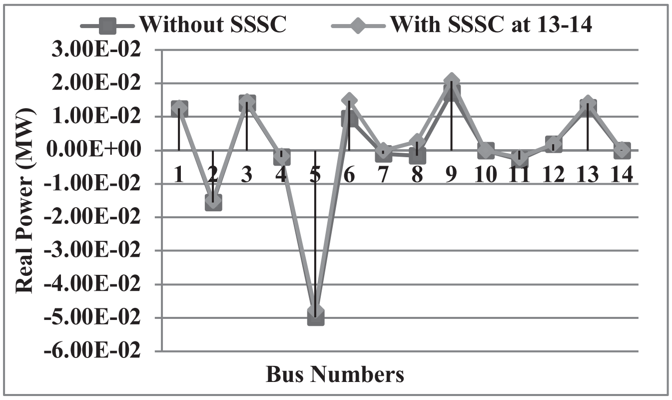

Figure 15. Performance Curve of Reactive Power Flow with SSSC at 12-13

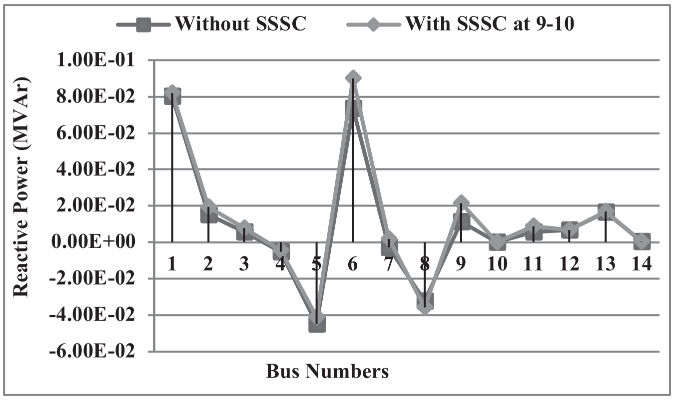

Figure 16. Performance Curve of Reactive Power Flow with SSSC at 13-14

The graphical representation of results obtained related to Bus Voltage, and Apparent Power (Real and Reactive) Flow is shown in Figures 5 – 16, with and without implementing of SSSC controller on IEEE 14 bus network. Also, the power system parameter variations are recognized in tabular form in Table 1 - 2.

CONCLUSION

In this paper, the load congestions in power network have been discussed in cooperation with FACTS controller devices. The purpose of this paper is to initially identify the location and then finalize the size of the FACTS controller device to enhanced system performance. The other papers are focused either on voltage or reactive power flow and analysis their paper without analysing its impact on real power flow. The paper also includes the impact of controller on Real Power Flow with enhancement of System Voltage and Reactive Power Flow on network buses. The IEEE 14 Bus networks are operated with multiple location of dynamic SSSC controller. The controllers are very fast, most efficient, and capable to divert or absorb their load to other buses. The main objective of all of the above operation is to sustain network parameters to a precise value and achieve a more reliable power system as per power quality norms on loading conditions.

The result achieved with or without implementation of FACTS controller provides evidence that the whole system becomes more reliable and stable. The implementation of SSSC on network proves that the Voltage profile of respective bus is improved at Bus 9 from 0.9584 to 1.2997 and at Bus 10 from 0.9464 to 1.6934. The implementation of SSSC also shows the improvement in Real Power Flow and Reactive Power Flow on load buses. The results obtained with or without SSSC are depicted in the tabular and graphical form on different identified buses. The final conclusion achieved with SSSC that it will dynamically improve Voltage Profile, Real Power Flow, Reactive Power Flow, minimize Load Congestion, minimize System Losses and improve System Efficiency, for the identical type of IEEE 14 bus system.

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