International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-3, February 2020

Enhancement of Power Transfer Capacity and Transmission Efficiency using SSSC

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Abstract*: The power demand is increasing globally at a higher rate than the possible increase in the generation. The increased demand requierements put additional burdon on the existing transmission lines and sometimes burdoned beyond their power carrying capacities. Increase in power demand either due modernization of power system, industrialization leads to congestion problem and abruptly affects the stable and reliable operation of power system. Redesign and reconstruction of power system according to load requirements everytime is not an economical and viable solution. Other possible solution to the problem is use of FACTS devices. The use of FACTS devices the problems like increase in load demand, high losses in transmission line and dip in receiving end voltage can be eliminated or easily tackeled. In this paper, Static Synchronous Series Compensator as one of FACTS device has been used for improvement of voltage profile of different buses and power carrying capacity of the transmission lines. The main objective of this paper is to make a comparative investigation between compensated and uncompensated power system in terms of enhancement of power carrying capacity with low losses and improvement of voltage profiles of buses in the transmission network. The performance of uncompensated power system has been compared with compensated power system with the use of MATLAB/ Simulink software.

Index Terms*: Flexible alternating current transmission system, static synchronous series compensator, power carrying capacity, available transfer capacity.

I. INTRODUCTION

The modernization of world makes the power system operation more complex. Power system is a combination of generating stations, transmission system networks, and the distribution networks with consumers. The increased demand puts unnecessary burden on the generating stations to generate more power which then transmitted to different consumers through transmission and distribution networks working on different voltage level. The increase in the generation and transmission capacities from existing to new capacities is not an easy task. The generation capacities cannot increase proportionally to the power demand [1]**.** As a result, problems like low receiving end voltage, frequency and power quality issues occurs in receiving end. So there are two possible methods to eliminate these problems. First one is redesign of new power system and second one is use of already existing power system with FACTS (Flexible AC Transmission System) devices which eliminates the need of redesign and reconstruct of new power system to some extent with an advantage of improved power quality.

FACTS technology is integrated technology based on power electronics configuration devices and power converters for improvement of power system stability, power carrying capacity, reliability of interconnected system and quality of power transmitted [2]. FACTS devices are very useful for satisfying power system constraints like Voltage stability limits, Steady state power transfer limit, Short circuit current limit, Power transfer capacity and transient stability limit by controlling the parameters of transmission line [3]. FACTS devices also help in the improvements in transient and dynamic limits, power quality issues, by reducing the pollution generated from the power generation from convention sources by utilizing the existing power system infrastructure. Series FACTS device vary the reactance of transmission line through their different configurations. Series FACTS device are of two types. One of them is Static Synchronous Series Compensator (SSSC), which based on voltage technology (SSSC) and other is Thyristor Control Series Compensator (TCSC), which based on thyristor technology**.** Series FACTS device gives beneficial result by increasing power transfer capacity of transmission line, improving voltage profile and voltage stability of power system. Increase in power generation from the renewable energy resources makes the power system operation complex. Due to mismatch in generation and demand consumers had to face different problems such as low receiving end voltage and bad quality of power supply [2]**.** The supply-demand mismatches produce fluctuations in receiving end voltages at various buses in the operating network. To overcome the voltage fluctuations in network, the capacity of transmission line should be enhanced to fulfill the power demanded by the system at the desired location.

In [4],[5] authors used the split search space management to improve the capacity of the power transmission using TCSC along with optimal location of the TCSC in transmission line network. The split search management minimizes the range of operating interval of FACTS controllers.

Revised Manuscript Received on February 15, 2020.
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Partial swarm optimization (PSO) and genetic algorithm (GA) techniques used to enhance available transfer capacity (ATC) [6]. PSO reduce the cycles per unit execution time as compare to GA. Furthermore, author used an optimizing kit which combines the feature of GA and regularized global approximation (RGA) in order to enhance ATC by calculating the excellent location and parameters of TCSC in [6]. Differential evolutionary (DE) and GA is also used for determine the excellent location and optimal setting of TCSC.

In [7] repeated power flow (RPF) used to perform probabilistic analysis for increasing TTC using TCSC. This algorithm was not supported by IEEE reliability test system. With the help of this algorithm there was booming in TTC. Analogous to control the line parameters with the use of TCSC in [8]. Optimization of parameter has been done using fuzzy logic and hybrid heuristic approach of analytical Hierarchy process.

The use of SSSC to avoid the overloading of transmission line and to maximize the ATC at the selected network bus is studied in [9]. The harmony search (HS) algorithm has been applied to limit the number of lines and improves the rate of convergence in [10]. In literature PSO and HS based optimization techniques are used and results shows that the HS technique give better results for sizing and location of SSSC as compared to the PSO technique. SSSC placement using HS algorithm improves the available transmission capacity of the system and reduces the expansion cost of the transmission network.

An improved power injecting SSSC model has been studied to analyze the power flow incorporating charging suspectance of transmission line and complex impedance of series transformer in [11]. The DC load flow method in order to maximize ATC and to find better location of SSSC has been studied using the merit order list in [12]. In the present study, SSSC has been used to analyze the effect of SSSC on power carrying capacity, voltage profile of different buses and losses of power system using simulink model in MATLAB.

II. SYSTEM DESCRIPTION

In present model utility grid under study consisting of two generating substations (GS) having capacities 2100 MVA and 1400 MVA respectively. First and second generating station has six and four generating units with capacity of 350MVA each are shown in Fig.1.

Four buses of the transmission network Bus 1 (B-1), Bus 2 (B-2), Bus 3 (B-3) and Bus 4 (B-4) connects two generating substations through double transmission line. Two generating stations are connected with the transmission network through two step-up transformers represented by T1 and T2 respectively.

Transmission line lengths between Bus 1- Bus 3, Bus 3-Bus 4, Bus 2- Bus 4 and transformer T2 to Bus 4 are 150Km, 150Km, 280Km and 50 Km respectively. The copensation in the transmission network through SSSC is provided by connceting between Bus 1 and Bus 2. Different loads are conncted to Bus 1, Bus 3 and Bus 4 respectively. A load of 2200 MW is connected at Bus 4.

A. Static synchronous series compensator

SSSC is voltage based converter, controls the voltage injected into the transmission line. The injected voltage determines the type of compensation. Positive voltage injected for capacitive compensation and negative voltage injected for inductive compensation by the SSSC compensator. Phase angle of the SSSC determines the reactive power absorb or deliver [6]. $+90^0$ phase angle of SSSC operation deliver reactive power to the system and -90^0 phase angle for absorb reactive power from the system. Other than 90^0 phase angle operation of SSSC will deliver or absorb both active and reactive power in the system. The resonance condition eliminated in the SSSC operation makes it superior than the TCSC [2]. The current actually flowing in the transmission lines are directly controlled by the SSSC. The SSSC used in the present work has the following parameters and characteristics:

SSSC Rating**:** Series converter rating = 100 MVA, Nominal voltage = 500 KV, Frequency = 60 Hz. Maximum injected voltage = 0.10 per unit. Series converter impedance R = (0.16/30) per unit, L = 0.16 per unit. DC link voltage = 40 KV and DC link total equivalent capacitance = $375*10^{-6}$ F. Injected voltage regular gains k_p = (0.03/8), k_i = (1.5/8) Dc voltage regular gains k_p = (1/10000), k_i = (2/100).

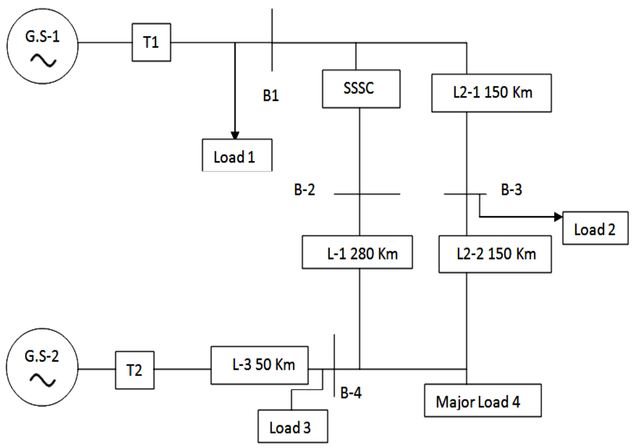

Fig.1. Block diagram of compensated system

The generalized compensated system is as shown in Fig. 2.

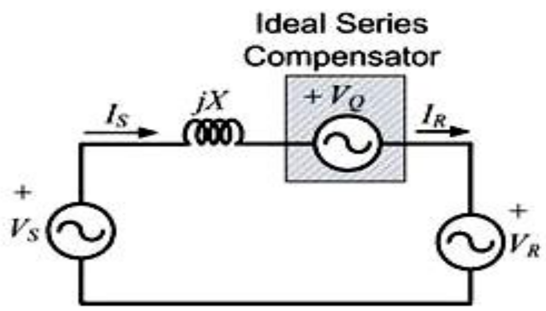

Fig. 2. Ideal series compensated system.

Power flow equations of the system with and without SSSC compensation are represented in (1) and (2) in capacitive mode:

$$P_S = P_R = \frac{V_S.V_R.Sin\delta}{X} + \frac{V_R.V_Q.Cos(\frac{\delta}{2})}{(X)} \quad (1)$$

Without FACTS device ($V_Q = 0$), it becomes

$$P_S = P_R = \frac{V_S V_R Sin\delta}{X} \quad (2)$$

Where, V_S, V_R, P_S and P_R are representing the sending end voltage, receiving end voltage, sending end power and receiving end power respectively while V_q represents the injected voltage in line. Compensation enhances the power flow in the system as compared to the system without compensation.

B. SSSC controller

SSSC controller can be classified into internal controller and external controller. The function of internal controller is fed a signal into internal circuit of power converter to generate an output voltage. The output voltage magnitude should be in limits and its phase angle should be in synchronism with ac power system. The functional operational of SSSC is determine with the help of external signal. It helps to modify the reference signal and achieve the performance as per requirement as shown in Fig.3. The calculation of injected reactance is achieving by a ratio of injected voltage to line current and then injected reactance is compared with modified reactance (sum of supplementary controller reactance and reference reactance). Furthermore, difference between injected reactance and modified reactance is fed to proportional and integral (PI) controller for controlling the action or magnitude of net reactance. PI controller's output forms modulation index which helps to calculate the amplitude of controlling signal. PI controller is used to reduce the steady state error between input and output. The primary reason to use this controller that output at steady state which can become a non zero constant value, even if error signal is zero at input terminal. The reason behind is to specified lowest and highest limits on the output of PI controller to prevent from unwanted output values [12]. The PI controllers are the combination of proportional and integral controller. The PI controller parameters are tuned-up by changing the gain of proportional and integral controllers in small increments with the use of trial and error technique.

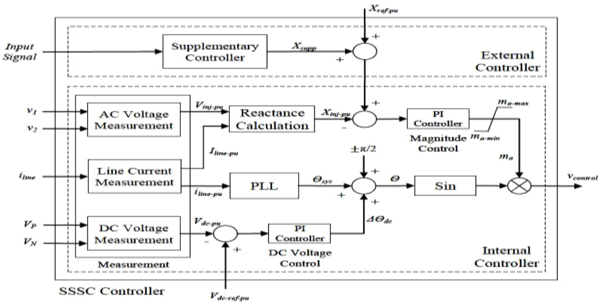

Fig. 3. SSSC controller block diagram.

Phase locked loop (PLL) is used to measure the phase of sinusoidal signal and modified it. It is used in SSSC controller to check the phase of line current. A shift of $\pm\pi/2$ is added in line current, according to need of operation of system. If $+\pi/2$ is added in system, it means current leads the voltage by 90^0 and mode of compensation is capacitive, while If $-\pi/2$ is added in system, it means current lags the voltage by 90^0 and mode of compensation is inductive.

Injection of sinusoidal voltage and its phase synchronism with power system is very important parameter for SSSC. The important feature of PLL is to generating a sinusoidal signal of same frequency as well as phase of input signal. The PLL is a combination of low pass filter (LPF), phase detector and voltage controlled oscillator (VCO). Phase detector is one type of conventional multiplier while VCO helps to generating an output sinusoidal signal whose phase signal coincides with as input signal. The subtraction of VCO signal from input signal produces an error signal. And this error signal is multiplied by output of VCO and provided to LPF. The purpose of using the dc voltage controller is to measure and maintain dc voltage constant. After measure dc capacitor voltage, compare with dc reference value. The difference between them is fed to PI controller that creates a small angle displacement, which is added to the sum of θ_{sys} and $\pm\pi/2$. This small angle displacement tells about the operation of SSSC. The summation of all the signals θ_{sys}, $\pm\pi/2$ and $\Delta\theta_{dc}$ are sent to sine block which produce a sinusoidal waveform whose amplitude is one and frequency is 60 hertz. Furthermore, this sinusoidal wave form is multiplied by modulation index and it gives voltage control.

III. PROBLEM FORMULATION

The system under investigated has two generating stations having six and four generating units along with three loads connected to different buses of the transmission network. The system investigates under compensated and uncompensated scenarios to find the improvements in various defining operational constraints and issues of the operating system.

Case 1: System without any compensation

Case 2: System with SSSC compensator.

Case 1: The MATLAB simulink model of the uncompensated system under investigation is as shown in Fig. 4. The six and four generating units at two generating stations are by total capacity of 2100 MVA and 1400 MVA respectively. The generating stations are connected through double transmission lines. The various transmission line parameters are presented in table 1. Specifications of the different loads connected to the buses at different locations are presented in table 2.

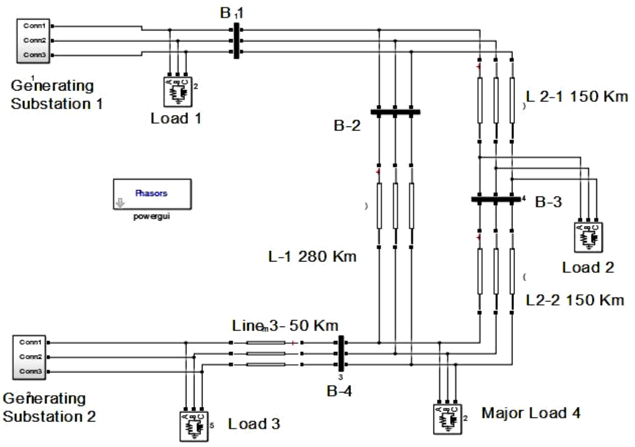

Fig. 4. Uncompensated power system.

Case 2: The uncompensated system in case 1 is modified as case 2 by connecting a SSSC compensation in the transmission line network between the Bus 1 and Bus 2 as shown in Fig. 5. The specifications of the SSSC compensator are already presented in section II. The Simulink model of the system analyzes for the voltage profiles of system buses with the power transfer capacity of transmission lines.

Table-I: Data of transmission line used under simulink model

S. No	Line	Length (KM)	$R_{p.u.}$	$L_{p.u.}$ Magnitude	p.u
1	Line 1	280	0.162	0.9337	2.
2	Line 2-1	150	0.162	0.9337	2
3	Line 2-2	150	0.162	0.9337	2
4	Line 3	50	0.162	0.9337	2.

Table-II: Data of load used under simulink model

S. No.	Load	MW	MVAR
1	Load-1	250	10
2	Load-2	50	10
3	Load-3	100	50
4	(Load-4) Major	2200	100

IV. RESULTS AND DISCUSSIONS

The system under investigation consists of two generating substation (G.S 1 and G.S 2). Both G.S 1 and G.S 2 are connected through their step up transformer (13.8/500 kV) T1 and T2 respectively in Figure 1. The variations of power carrying capacity of bus 2 with and without increasing compensation of the SSSC compensator are shown in Fig.6. In the uncompensated system the power carrying capacity will remain same but for the SSSC compensated line the power transfer capacity increases with the increase in compensation from two to ten percent. The power transfer capacity of the compensated bus 2 enhances from the 640 MW to 750 MW in the system. The increase in power carrying capacity is 110 MW which is 12.95%. The reason behind enhancement of power carrying capacity in bus 2 is due to SSSC virtual capacitance between bus 1 and bus 2, due to which more current will flow from bus 1 to 2. More current will flow from Bus 1 to Bus 2 as compared to Bus 1 and Bus 4.

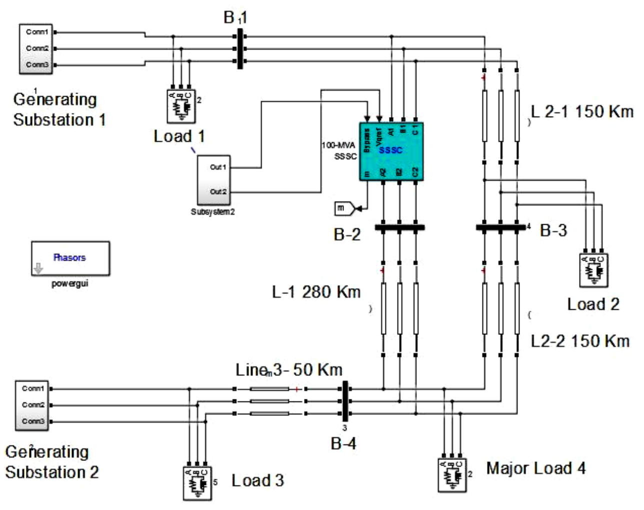

Fig.5. Compensated power system.

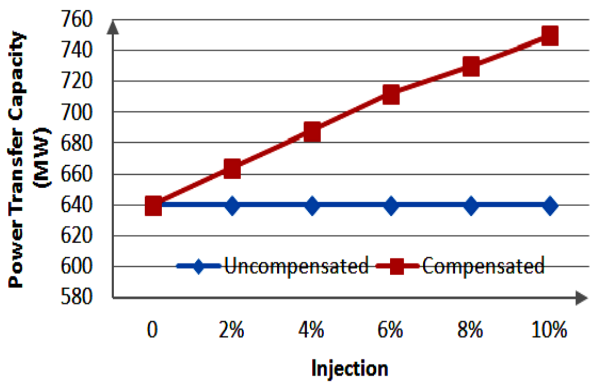

Fig.6. Comparison of PCC of uncompensated and compensated system.

The variation of voltage profile of bus 1 with increasing injection from two to ten percent of SSSC compensator has been shown in Fig.7. As SSSC compensator is connected between bus 1 and 2 provides the injected voltage at Bus 1. Due to injection of voltage at Bus 1 the voltage profile of bus 1 improves. Bus 3 is also connected to Bus 1 through transmission line of 150 Km and its voltage profile also enhances from its previous state. With the use of SSSC in power system at different injection (2%, 4%, 6%, 8% and 10%), voltage profile of bus 1 (0.94, 0.96, 0.98, 1.0 and 1.02) and bus 4 (0.92, 0.94, 0.96, 0.98 and 1.0) improved respectively. After SSSC implementation between bus1 and bus2, the voltage drop reduces between bus 1 and 4. The increase in voltage profile of bus 1 is 0.095 p.u.

Fig.8 shows the variation of inductive losses with increasing voltage injection. The inductive losses are decreases with increase in compensation. With the use of SSSC between bus 1 and bus 2, the decrease in inductive losses is 0.10 p.u or 35 MW based on 350 MVA power bases which improve the transmission efficiency.

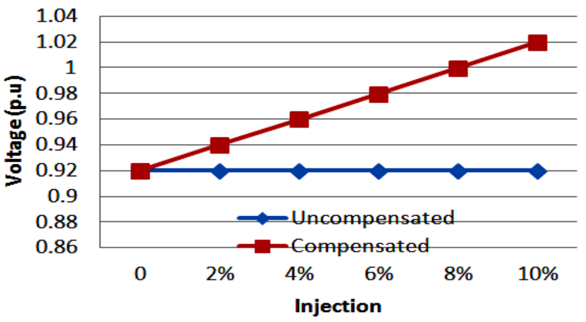

Fig.7. Comparison of voltage profile between uncompensated and compensated system.

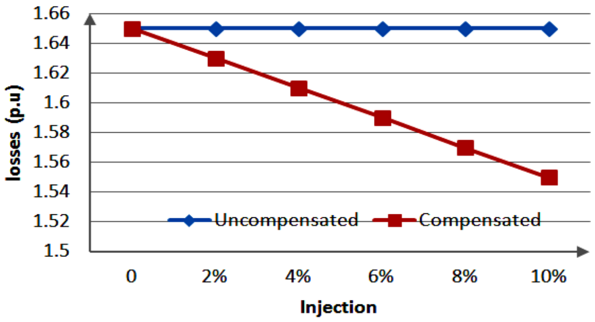

Fig.8. Comparison of losses between uncompensated system and compensated system.

V. CONCLUSIONS

In this paper, the problem under investigation constitutes of a grid, which is a combination of two generating substation. Two generating substations have six and four generating machines are connected through different buses. Furthermore, buses are connected through each other with the arrangement of double circuit transmission line. In this paper, two constraints steady state power transfer limit as well as voltage profile limit are selected and these two constraints are investigated on system without compensation and with compensation. With the use of MATLAB/SIMULINK, uncompensated power system has been compared with compensated power system. After connecting SSSC between two buses, Steady state power transfer limit, reduction in losses and voltage profile limit can be enhanced by using the SSSC positive injection voltage mode. Power carrying capacity of transmission line 1 of uncompensated model is 640 MW. With the use of SSSC in power system, at different injection, Power carrying capacity of transmission line increased from 640 to 750 at 10% injection. Improvement of power carrying capacity of bus 2 is 17.18%. Voltage profile of Bus 1 and Bus 4 of uncompensated model has been compared with compensated model at different injection. The net increase in voltage profile of bus 1 is 0.095 p.u. Improvement of voltage profile is 9.5%. With the use of SSSC, losses are decreases from 1.65 p.u to 1.55 p.u. The study reveals that SSSC is very efficient to enhance the power carrying capacity, voltage profile and improvement in efficiency of transmission lines.

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