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Enhancement on Power Transfer Capability in Long Transmission Line using Shunt FACTS Device

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Abstract – **Reactive Power Compensation plays a vital role to minimize the losses, to control the voltage and to improve the power transfer capability in a long transmission line. This paper employs the shunt connected FACTS device such as Static Var compensation (SVC) to control voltage and the power flow and also to minimize the losses in a long distance transmission line about 100Km, 200Km, 300Km & 400Km. The proposed device was used in different locations such as sending end of the transmission line, middle and receiving end of the transmission line. The PWM control strategy was used to generate the firing pulses for the controller circuit. Simulations were carried out using MATLAB Simulink environment. The suitable location and the performance of the proposed model were examined. The results were obtained with and without compensation. The simulation results reveals that the reactive power generated and injected is better at the sending end of the transmission line and it was 62.03MVAr when compared with the other ends of the transmission line and also the voltage is controlled at the sending end of the line. The line losses and the power transfer capability of the line were obtained at the midway and receiving end of the line. The results show that the line losses are reduced and the power transfer capability is better when SVC is connected at the sending end of the line. These results were shown in table 1 and 2. Henceforth the location of SVC is optimum when connected at the sending end of the line.**

Keywords – **FACTS Device, SVC, PWM Technique, Power Transfer Capability, MATLAB Simulink.**

I. INTRODUCTION

To meet the power demand, the line losses in the transmission line will be reduced to improve the power transfer capability and also to control the power flow. To control the voltage and the power flow, reactive power compensation is very important. Wherever and whenever to control the voltage and power flow the reactive power is injected at the particular location by the use of the FACTS devices such as SSSC, STATCOM and SVC. It is an urgent need to control the power flow, in a long distance transmission line.

The FACTS devices are introduced in the power system transmission for the reduction of the transmission line losses and also to increase the transfer capability. SVC is an impedance based controller to regulate the voltage by varying the reactive power in a long transmission line. Karthikeyan M et al [1] have compared the Power transfer capability of a Long transmission line of Shunt Facts devices like STATCOM and SVC. Karthikeyan M et al [2] have briefly explained about the location of shunt FACTS Device to control the power flow in a long transmission line and also gave the location for the better transfer capability. Mithulananthan. N et al [3] have explained the comparison of different control techniques for damping undesirable inter area oscillation in power systems by means of PSS, SVC and STATCOM. Jong et al [4] have described the practical operation effect of KEPCO(Korea Electric Power Corporation) FACTS devices in the Korean power system. Le.C.D et al [5] have explained about the ride-through capability of a large Indiction Generator based wind park with different reactive power support solutions. Ding Lijie Liu et al [7] have compared STATCOM and SVC in voltage supporting, improving transient stability and transmission limit and damping low frequency oscillations. Musunuri.S et al [6] have presented a comparison of four FACTS Controllers, SVC, STATCOM, TCSC and SSSC on power system steady state voltage stability. Haue.M.H., [8] has fully exploited the features of STATCOM and SSSC to improve the stability limit of a simple power system. Arun Bhaskar.M., et al [9] have explained about the need for reactive shunt compensation to improve the voltage profile in the line by comparing SVC, TCSC and TCPST. Ugalde-Loo.C.E.,et al [10] have compared the series and shunt FACTS devices for using the frequency domain methods under the framework of individual channel analysis and design (ICAD). Albasri, F.A.et al[11] have investigated a comparative study of the performance of distance relays for transmission lines compensated by shunt connected flexible ac transmission system (FACTS) controllers. Tan Y.L.,et al[12] have demonstrated the effectiveness of SVC and STATCOM of same rating for the enhancement of power flow. Albasri, F.A.et al [13] have investigated the performance of distance protection of transmission lines with SVC and STATCOM compensation and also studied the different fault types and fault locations and system conditions. Kamarposhti.M.A., et al [14] have presented a study of series and shunt FACTS devices on steady state voltage and power stability. Phadke.A.R., et al [15] have compared several voltage stability indices in electric power system to identify the weakest bus of the system.

In this paper, performance strategy was conducted on SVC at different locations such as sending end, middle and the receiving end of the long distance transmission line. In a long transmission line about 100Km, 200Km, 300Km & 400Km, the power flow was tested with and without compensation strategy. A mathematical modeling approach and control design were presented in this proposed work. The simulink model of the standard system was developed and tested using MATLAB Simulink environment.

II. OPERATING PRINCIPLE

SVC is a variable impedance device where the current through a reactor is controlled using back to back connected thyristor valves. The application of thyristor valve technology to SVC is an overshoot of the developments in HVDC technology. The major difference is that thyristor valves used in SVC are rated for lower voltages as the SVC is connected to an EHV line through a step down transformer.

The application of SVC was initially for load compensation of fast changing loads such as steel mills and arc furnaces. Here the objective is to increase the power transfer capability in a long transmission lines and also to control the power flow in the line. SVC has no inertia compared to synchronous condensers and can be extremely fast in response. This enables the fast control of reactive power in the control range.There are two types of SVC:

1. Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR)
2. Thyristor Switched Capacitor - Thyristor Controlled Reactor (TSC-TCR).

The schematic diagram of a TSC-TCR type SVC is shown in figure 1. This shows that the TCR and TSC are connected on the secondary side of a step-down transformer. Tuned and high pass filters are also connected in parallel which provide capacitive reactive power at fundamental frequency. The voltage signal is taken from the high voltage SVC bus using a potential transformer.

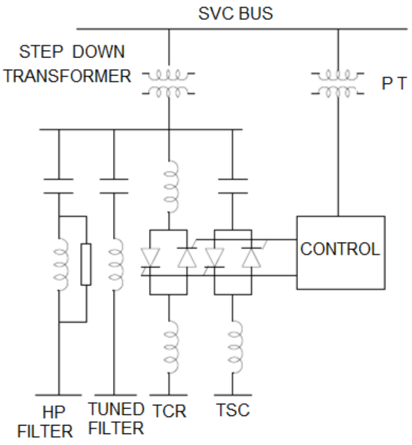

Fig.1. Schematic Diagram of SVC

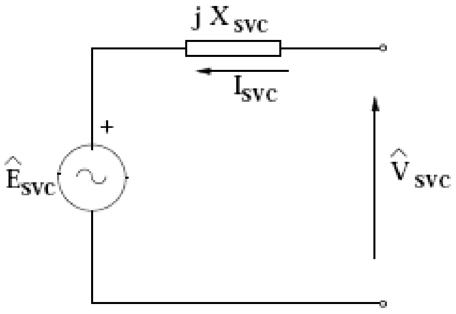

Fig.2. Equivalent Circuit of SVC

Figure 2 explains about the equivalent circuit of SVC. This shows a complex voltage source $\grave{E}_{svc}$ in series with a reactance X_{svc}. The losses in the SVC are neglected. The values of $\grave{E}_{svc}$ and X_{svc} are given below for the SVC operating in (i) the control range,(ii) capacitive control limit and (iii) inductive control limit.

III. CONTROL STRATEGY

The steady state control characteristics are modeled by using the equivalent circuit of SVC which is shown in figure2. The mathematical descriptions of the control functions are :

A. Control Range

$$E_{SVC}=V_{ref}\emptyset_{SVC} \quad (1)$$

$$X_{SVC}=X_S \quad (2)$$

where $\Phi_{SV\ C}$ is the angle of the SVC bus voltage. The control range applies when the SVC bus voltage lies in the range.

$$\frac{V_{ref}}{1+X_S B_{max}} < V_{SVC} < \frac{V_{ref}}{1+X_s B_{min}} \quad (3)$$

where B_{min} and B_{max} are the limits of B_{svc}. Note that B_{min} is, in general, negative (corresponding to the inductive limit) and $B_{max} = B_C$, where B_C is the total capacitive susceptance. (neglecting the transformer leakage reactance).

B. Capacitive Control Limit

$$X_{SVC} = -\frac{1}{B_{max}} \quad (4)$$

C. Inductive Control Limit

$$X_{SVC}= -\frac{1}{B_{min}} \quad (5)$$

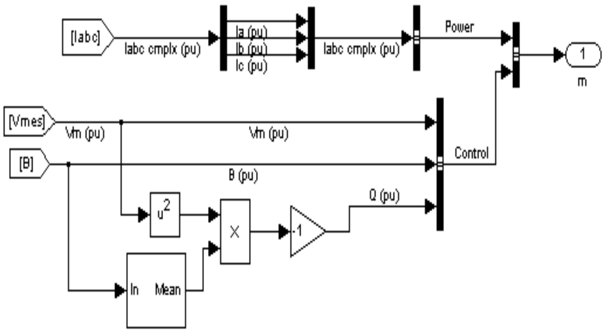

Fig.3. Control Circuit of SVC

In this control circuit the power can be obtained from the I_{abc} and also converted to per unit then the reactive power can be obtained in p.u and then in MVAr. Similarly the V_{ms} is obtained then it is converted into V_m p.u and then it is again converted in the form of volts.

This is clearly explained in the circuit diagram which is shown in the figure 3. Finally the power and the control is combined together and then given it to the modulation index m. From the modulation index itself the output reactive power Q_m and the voltage V_m can be obtained.

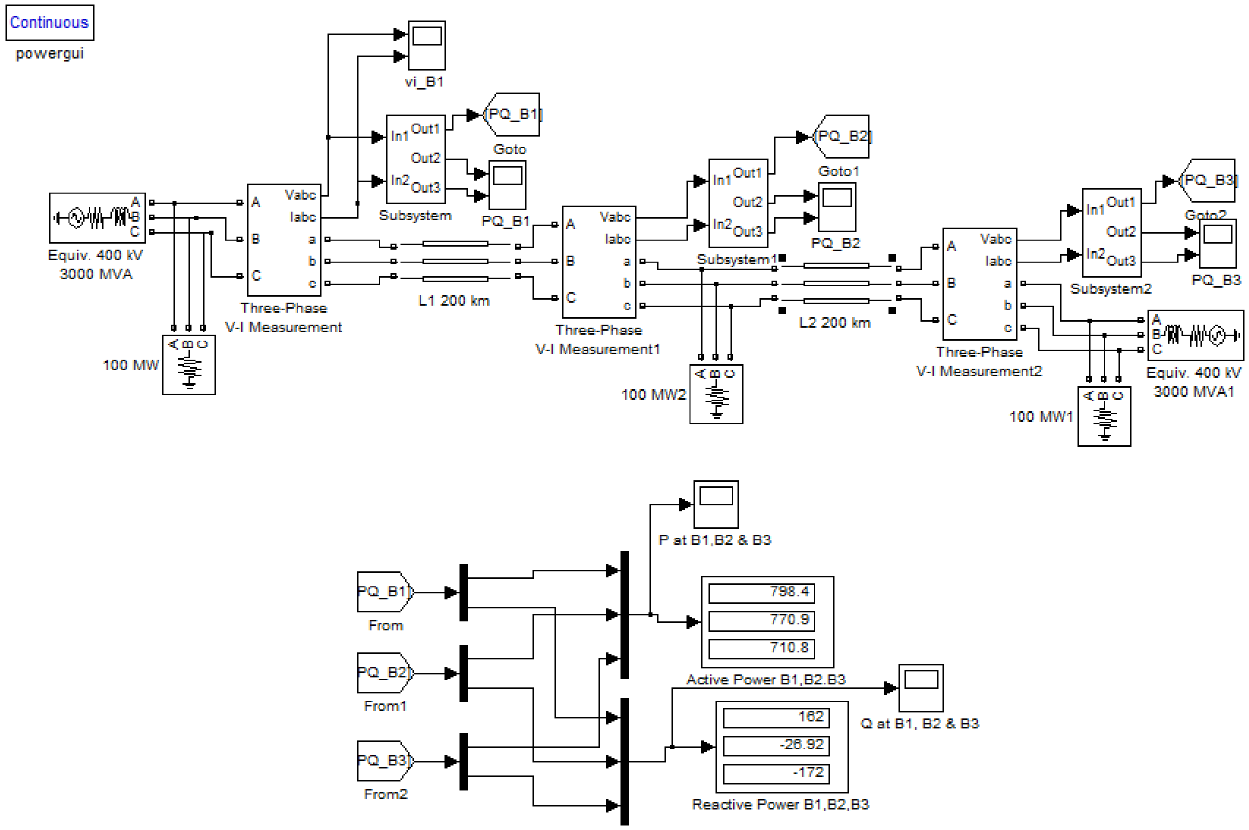

Fig.4. Circuit Diagram for without Compensation

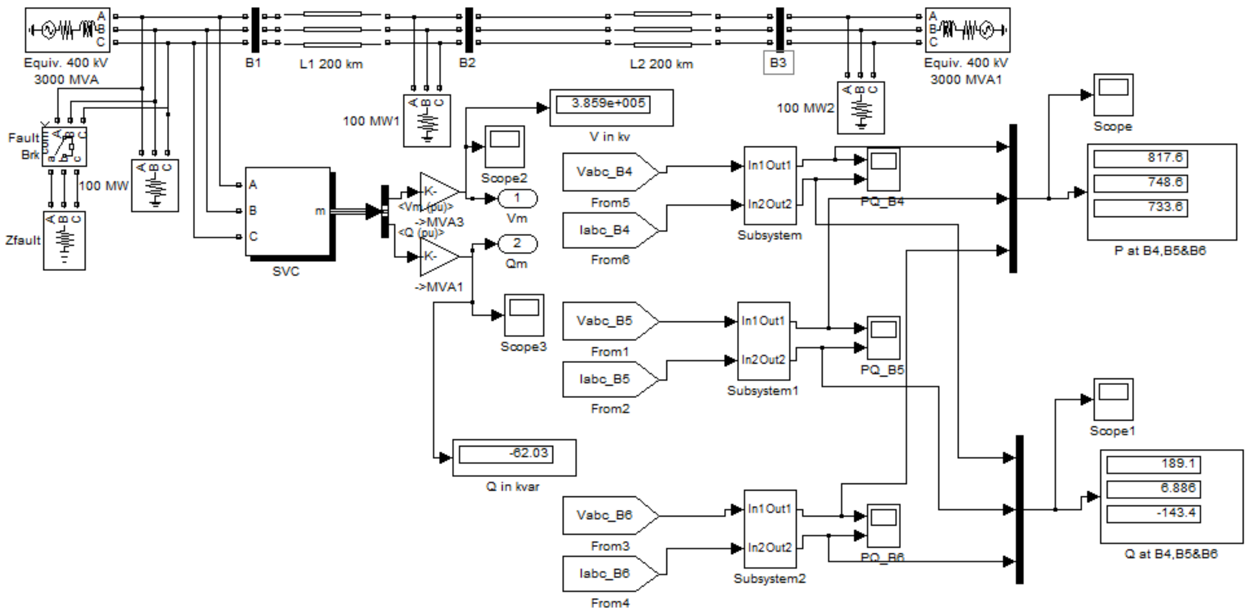

Fig.5. Circuit Diagram of SVC connected at Sending End of the Line

IV. SIMULATION OF SVC

A. Circuit Description

The power grid consists of two 400-KV and 3000 MVA equivalents, connected by a long transmission line of 100Km, 200Km, 300Km & 400Km respectively. The rating of SVC is selected as ±100MVAr. The average time delay due to thyrister valves firing Td is kept in the SVC as 4 msec. In the transmission line, the line resistance is selected as 0.0175 ohms per Km and inductance is 0.8737mH per Km and the capacitance is 13.3nF per Km. When the SVC is not in operation, the power loss in the transmission line is very high from bus B1 to B3. Figure 4 explains about the circuit diagram without compensation.

In this circuit the power is directly measured in the long transmission line at the three stages like B1,B2 and B3 and also tabulated the results in table1. Figure5 explains about the circuit diagram when SVC is connected at the sending end of the long transmission line. Similarly the connections are made when the SVC is connected at the middle and receiving end of the long transmission line.

V. SIMULATION RESULTS

A remote fault will be simulated on SVC using a fault breaker in series with a fault impedance. The value of the fault impedance is to produce a 30% voltage sag at bus B2 i.e. middle of the transmission line. Initially the breakers are closed and external control of switching time is selected. At the breakers the breaker resistance is selected as 0.001 ohm, the snubber resistance is as 1 mega ohm and snubber capacitance is selected as an infinity. When SVC is connected at the sending end of the line, the voltage observed is 385.9KV and the reactive power observed is 62.03MVAr. The results were obtained with and without compensation and also the numerical results were tabulated in table 1 & 2.

Figure 6, 7 & 8 shows the reactive power Q_m injected at the sending end, middle and receiving end of the long transmission line. When compared with all the three ends, the reactive power injected is better at the sending end of the line and the value is 62.03 MVAr.

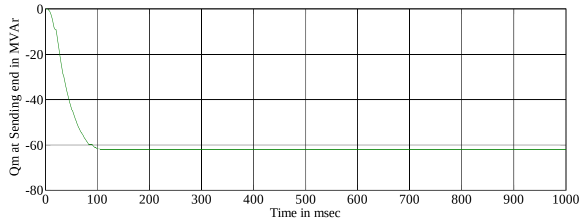

Fig.6. Reactive Power Q_m at the Sending End

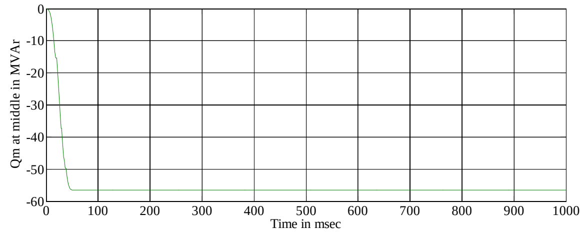

Fig.7. Reactive Power Qm at the Middle

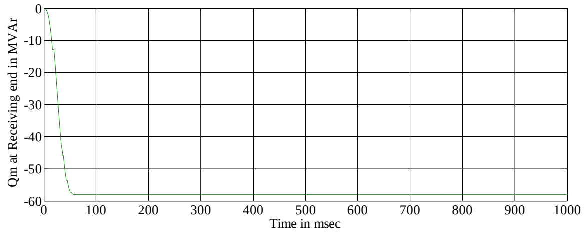

Fig.8. Reactive Power Qm at the Receiving End

Figure 9, Figure 10 and Figure 11 exhibits the active power at the three stages of the transmission line when SVC is connected at the sending end, middle and receiving end.

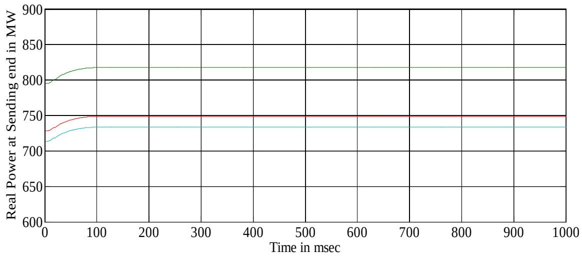

Fig.9. Real Power at B1, B2 & B3 when SVC is at Sending End of the Line

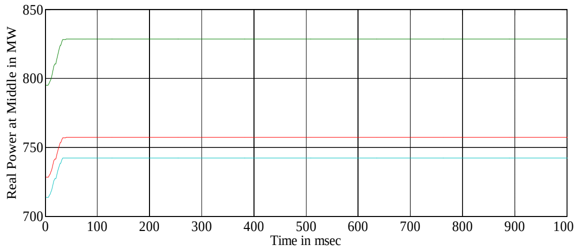

Fig.10. Real Power at B1,B2 & B3 when SVC is at Middle of the Line

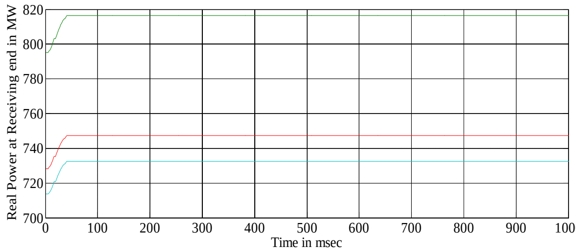

Fig.11. Real Power at B1,B2 & B3 when SVC is at Receiving End

Similarly the reactive power at the three stages B_1,B_2 and B_3 when SVC is connected to the sending end, middle and receiving end are shown in Figure12,13 and 14. The graph results show that the reactive power injected at the sending end is better when comparing with the other ends.

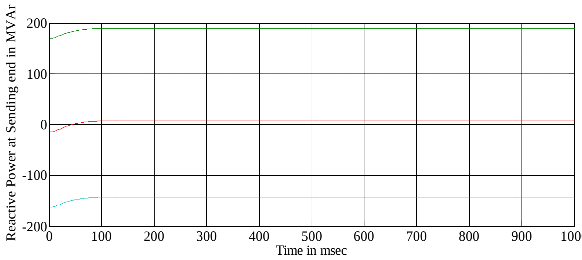

Fig.12. Reactive Power at B1,B2 & B3 when SVC is at Sending End

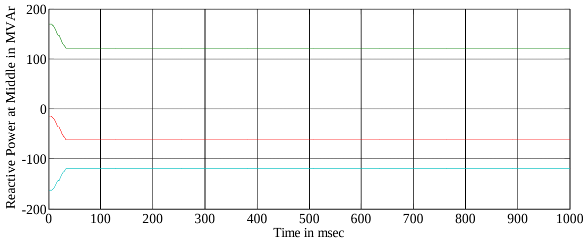

Fig.13. Reactive Power at B1, B2 & B3 when SVC is at Middle

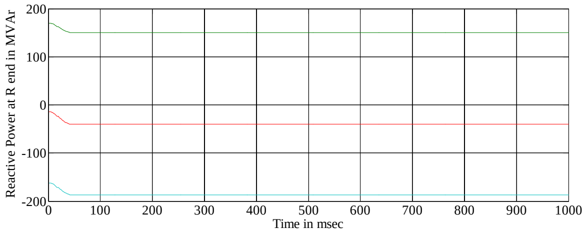

Fig.14. Reactive Power at B1, B2 & B3 when SVC is at Receiving End

Figure 15, 16 &17 show the voltage (V_m) when SVC is connected at the sending end, middle and receiving end of the long line. The graph results show that the voltage is controlled at the sending end of the line in both midway and end of the line.

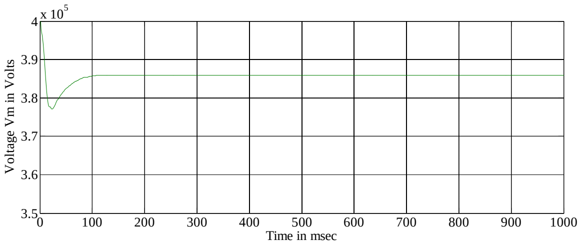

Fig.15. Voltage V_m when SVC is at Sending End of the Line

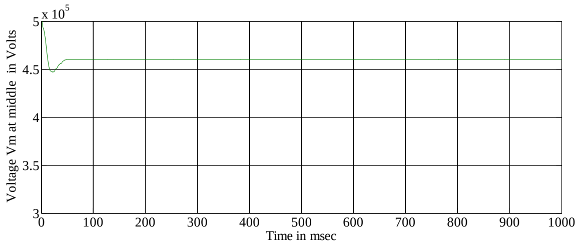

Fig.16. Voltage V_m when SVC is at Middle of the Line

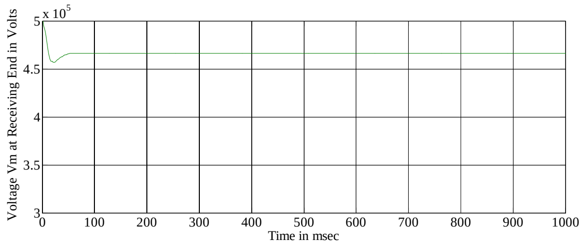

Fig.17. Voltage V_m when SVC is at Receiving End of the Line

VI. CONCLUSION

The vital role of reactive power compensation, in a long distance transmission lines, is to minimize the losses and to improve the power transfer capability in the transmission line and also to control the power flow in the power system network. In this proposed work SVC was employed as a shunt FACTS device. SVC was connected at the various locations such as sending end, middle and receiving end of the transmission lines of 100Km, 200Km, 300Km, and 400Km length. The results were obtained with and without compensation. The simulation results revealed that the reactive power injected is better at the sending end of the transmission line when compared with the other ends of the transmission line and also the voltage was controlled at the sending end of the line. The results show that the line losses are reduced and power transfer capability is better both the midway and receiving end of the line when SVC was connected at the sending end of the line of different lengths. So, the location of SVC is optimum when connected at the sending end of the line. The numerical results of the system analysis were elaborated in the table 1 and 2. The simulation results were carried in MATLAB Simulink environment.

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Table 1: Comparison of Real Power & Reactive Power

Length In KM	**At B1**		**At B2**		**At B3**	
	P in MW	***Q in MVAr***	***P in MW***	***Q in MVAr***	***P in MW***	***Q in MVAr***
SVC is at Sending End						
100	1230	180.2	1174	-9.464	1163	-183.8
200	1034	233.3	972	2.269	957.8	-204.8
300	905.4	224.6	839.6	6.257	824.6	-183.1
400	817.6	189.1	748.6	6.886	733.6	-143.4
SVC is at Middle						
100	1232	113.2	1175	-76.1	1164	-178.1
200	1038	166.1	975.3	-63.96	961.3	-192.6
300	912.8	157.1	845.5	-60.63	830.7	-164.9
400	828.4	120.8	757.1	-61.89	742.3	-119.2
SVC is at Receiving End						
100	1230	121	1173	-70.24	1162	-245.1
200	1033	181.9	971.2	-52.6	957	-259.4
300	904.4	180	838.7	-44.13	823.7	-231.8
400	816.4	150.4	747.5	-40.24	732.6	-186.8
Without SVC						
100	1367	--	1306	--	479.6	--
200	1129	219.8	915.5	-101.6	930	-113.6
300	882.4	183.2	862.6	-34.29	804.8	-215.1
400	798.4	162	770.9	-26.92	710.8	-172

Table 2: Line Losses & Power Transfer Capability

Position	Midway of the Line		End of the Line	
	Line Losses in MW	Power Transfer Capability in %	Line Losses in MW	Power Transfer Capability in %
Sending End	56	95.45	67	94.55
	62	94.00	76.2	92.63
	65.8	92.73	80.8	91.08
	69	91.56	84	89.73
Middle	57	95.37	68	94.48
	62.7	93.96	76.7	92.61
	67.3	92.63	82.1	91.00
	71.3	91.39	86.1	89.61
Receiving End	57	95.37	68	94.47
	61.8	94.02	76	92.64
	65.7	92.74	80.7	91.08
	68.9	91.56	83.8	89.74