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Optimal location of shunt FACT devices for Power flow control in power System

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***Abstract*— Power flow control, in an existing long transmission line, plays a vital role in Power System area. In this the shunt connected compensation (STATCOM) based FACTS device for the control of voltage and the power flow in long distance transmission line. The proposed device is used in different locations such as sending end of the transmission line, middle and receiving end of the transmission line. The PWM control strategy is used to generate the firing pulses of the controller circuit. Simulations were carried out using MATLAB Simulink environment. The suitable location and the performance of the proposed model were examined. Based on a voltage-sourced converter, the STATCOM regulates system voltage by absorbing or generating reactive power. The simulation results reveals that the reactive power generated is better at the middle of the transmission line when compared with the other ends of the transmission line and also the voltage is controlled at the middle of the line. Henceforth the location of STATCOM is optimum when connected at the middle of the line.**

***Keywords*— FACTS device, STATCOM, PWM technique, MATLAB Simulink.**

I. INTRODUCTION

In Present scenario the applications of the power electronics devices in power systems are very much augmented. 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, Increases Power System Stability and also to increase the transfer capability. STATCOM is VSC based controller to regulate the voltage by varying the reactive power in a long transmission line. Tan Y.L., et al[1] have demonstrated the effectiveness of SVC and STATCOM of same rating for the enhancement of power flow. Xia Jiang Xinghao Fang Chow et al [2] have focused on modelling converter-based controllers when two or more VSCs are coupled to a dc link (e.g., unified power-flow controller (UPFC), interline power-flow controller, and a generalized unified power-flow controller) and in their approach they allowed efficient implementation of various VSC operating limits, where one or more VSCs are loaded to their rated capacity. Chandrakar, V.K. et al [3] have investigated the optimal location of shunt FACTS devices in transmission line for highest possible benefit under normal condition and also they considered three different line models namely, line impedance model, reactance model and pi(π) model. Bebic, J.Z.[4] have presented two such topologies, the first one consists of a shunt connected controllable source of reactive power, and two series connected voltage-sourced converters - one on each side of the shunt device which is named as "hybrid power flow controllers", or HPFC. Johnson, B.K.[5] has presented an overview of how series connected and combined series/shunt connected FACTS controllers are studied in an AC system. Shankaralingappa, C.B.[6] has achieved the optimum required rating of series and shunt flexible ac transmission systems controllers for EHVAC long transmission lines by computing `optimum compensation requirement' (OCR) for different loading conditions. Shakib, A.D. [7] has defined a sensitivity analysis, which is used to determine the area on which the FACTS device has significant influence, for the detection of sensor nodes and then only this limited area is included in the Optimal Power Flow control. Salemnia, A. et al [8] have proposed the concept of using remote signals acquired through PMU to damp SSR. K.R. Padiyar et al[9] have considered a series passive compensation and shunt active compensation provided by a static synchronous compensator (STATCOM) connected at the electrical center of the transmission line to minimize the effects of SSR. Prabhu, N. et al [10] has investigated the sub synchronous resonance (SSR) characteristics of the system and proposed a novel method for the extraction of sub synchronous component of line current using filter. Zarghami, M.et al [11] has discussed a novel approach for damping interarea oscillations in a large power network using multiple STATCOMs. Yap, E.M. et al[12] have focused on the effective utilization of a flexible alternating current transmission system (FACTS) device called unified power flow controller (UPFC) for power flow control and also demonstrated the use of the latest power system analysis toolbox (PSAT) package for network analysis of alternative means of improving existing transmission capability. Y u Liu Bhattacharya, S. et al[13] have designed a controller in which an optimal combination modulation strategy is used, which leads to some challenges in designing the controller, such as extra switching and the balancing of individual dc capacitor voltages. Larki, F. et al [14] have presented a new approach for identification of optimal locations of STATCOM and SVC and also simulated case studies conducted on Kouzestan power networks in Iran based on the proposed techniques. Albasri, F.A.et al[15] have investigated a comparative study of the performance of distance relays for transmission lines compensated by shunt connected flexible ac transmission system (FACTS) controllers.

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In this paper performance strategy were conducted on STATCOM at different locations such as sending end, middle and the receiving end of the long distance transmission line. In every part of the location the power flow is tested with and without compensation strategy. In this paper also shows the effect of STATCOM on voltages of system buses and power flows in both steady state and abnormal conditions. The simulink model of the three bus system is developed and tested using MATLAB Simulink environment.

II. OPERATING PRINCIPLE

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The equivalent circuit of a Synchronous Condenser (SC) is shown in Fig.1, which shows a variable AC voltage source (E) whose magnitude is controlled by adjusting the field current. Neglecting losses, the phase angle (δ) difference between the generated voltage (E) and the bus voltage (V) can be assumed to be zero. By varying the magnitude of E, the reactive current supplied by SC can be varied. When E = V, the reactive current output is zero. When E > V, the SC acts as a capacitor whereas when E < V, the SC acts as an inductor. When δ= 0, the reactive current drawn (I_r) is given by

$$I_r = \frac{V - E}{X'} \qquad (1)$$

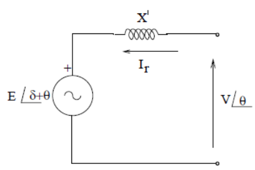

Fig.1 A Synchronous Condenser

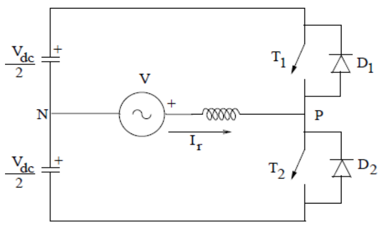

Fig.2 A Single Phase STATCOM

A STATCOM (previously called as static condenser (STATCON)) has a similar equivalent circuit as that of a SC. The AC voltage is directly proportional to the DC voltage (V_{dc}) across the capacitor (see Fig.2 which shows the circuit for a single phase STATCOM). If an energy source (a battery or a rectifier) is present on the DC side, the voltage V_{dc} can be held constant. The self-commutated switchesT1 and T2 (based on say GTOs) are switched on and off once in a cycle. The conduction period of each switch is 180˚ and care has to be taken to see that T_1 is off when T2 is on and vice versa. The diodes D1 and D2 enable the conduction of the current in the reverse direction. The charge on the capacitors ensures that the diodes are reverse biased. The voltage waveform across PN is shown in Fig.3. The voltage $V_{PN} = V_{dc}/2$ when T1 is conducting (T2 is off) and $V_{PN} = -V_{dc}/2$ when T2 is conducting (and T1 is off).

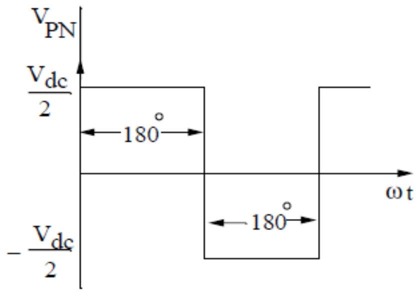

Fig.3 The waveform of V_{PN}

III. MODELING OF STATCOM

Based on the operating principle of the STATCOM, the equivalent circuit can be derived, which is given in Fig.4. In the derivation, it is assumed that (a) harmonics generated by the STATCOM are neglected; (b) the system as well as the STATCOM are three phase balanced.

Then the STATCOM can be equivalently represented by a controllable fundamental frequency positive sequence voltage source V_{sh}. In principle, the STATCOM output voltage can be regulated such that the reactive power of the STATCOM can be changed.

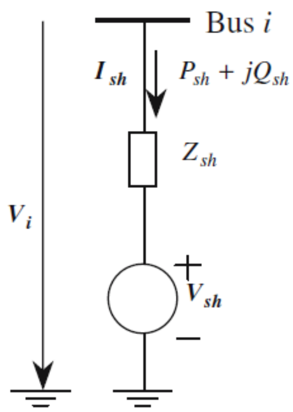

Fig.4 STATCOM Equivalent Circuit

According to the equivalent circuit of the STATCOM shown in Fig.4, suppose $V_{sh} = V_{sh}\angle\theta_{sh}$, $V_i = V_i \angle\theta_i$, then the power flow constraint of the STATCOM are:

$$P_{sh} = V_i^2 g_{sh} - V_i V_{sh}(g_{sh}\cos(\theta_i - \theta_{sh}) + b_{sh}\sin(\theta_i - \theta_{sh})) \qquad (2)$$

$$Q_{sh} = -V_i^2 b_{sh} - V_i V_{sh}(g_{sh}\sin(\theta_i - \theta_{sh}) - b_{sh}\cos(\theta_i - \theta_{sh})) \qquad (3)$$

Where

$$g_{sh} + jb_{sh} = \frac{1}{Z_{sh}}.$$

The operating constraint of the STATCOM is the active power exchange via the DC link as described by:

$$PE = \mathrm{Re}(V_{sh} I_{sh}^*) = 0 \qquad (4)$$

Where

$$\mathrm{Re}(V_{sh} I_{sh}^{*}) = V_{sh}^{2} g_{sh} - V_i V_{sh} (g_{sh} \cos(\theta_i - \theta_{sh}) - b_{sh} \sin(\theta_i - \theta_{sh})) \quad (5)$$

IV. SIMULATION MODEL

Here we considered a three bus Power system which consists of two 500-KV equivalents generators, respectively 3000 MVA and 2500 MVA, connected by a 600-km long transmission line. When the STATCOM is not in operation, the "natural" power flow on the transmission line is 951.4 MW from bus B1 to B3. STATCOM has a rating of +/- 100MVA. This STATCOM is a phasor model of a typical three-level PWM STATCOM.

Fig.5 explains about the circuit diagram without compensation. In this circuit the power is directly measured in the 600km long transmission line at the three stages like B1, B2 and B3 and also tabulated the result in table1. Fig.6 explains about the circuit diagram when STATCOM is connected at the Middle of the long transmission line. Similarly the connections are made when the STATCOM is connected at the sending end and receiving end of the long transmission line.

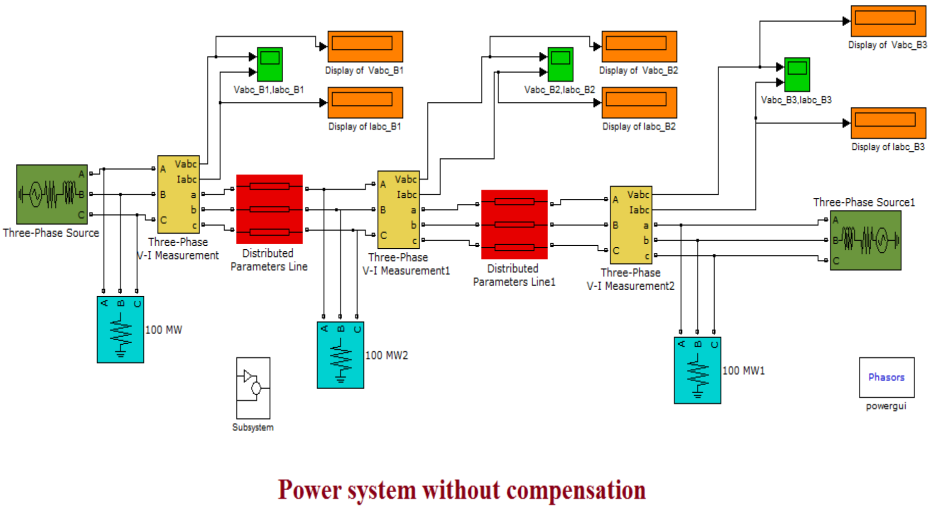

Fig.5 Simulink Model of Power System without compensation

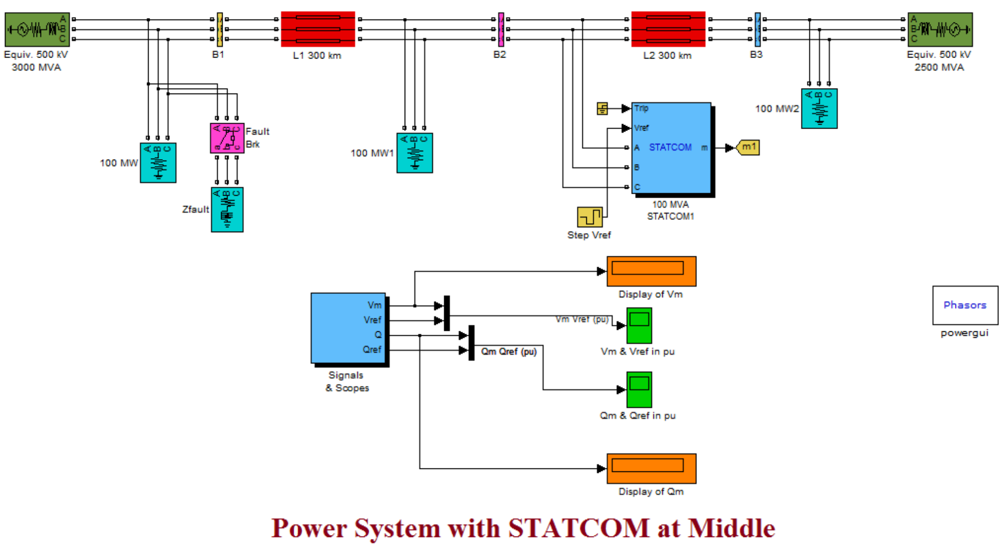

Fig.6 Simulink Model of Power System with STATCOM at Middle

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V. SIMULATION RESULTS

To understand the Effect of presence of STATCOM in system, on system parameters, typical cases we have carried out by simulation analysis of the system. The results are generated by MATLAB outputs shown on respective cases. The results of cases are tabulated, analyzed and compared which clearly shows the Effect of the STATCOM under various conditions. The cases are as under.

1. Effect on Power flows at B1, B2 and B3 in Steady State Operation (Case-1)
2. Effect on Power flows at B1, B2 and B3 in HV and LV Condition (Case-2)
3. Effect on Power flows at B1, B2 and B3 in Increasing Load Condition (Case-3)
4. Effect on Voltages of System buses at B1, B2 and B3 for steady state, HV, LV and increasing load condition (Case-4)
5. Effect on Power flows due to Optimal Location of STATCOM (Case-5)

A. Case-1

Fig.7 and Fig.8 highlights the real and reactive power control at the three stages when the STATCOM is not connected i.e. without compensation.

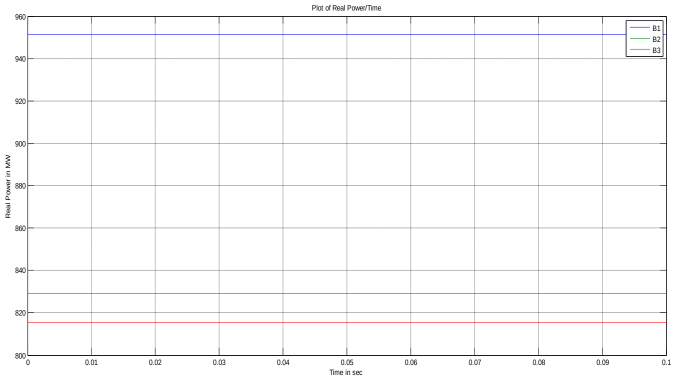

Fig.7 Real Power at B1, B2 & B3 without compensation

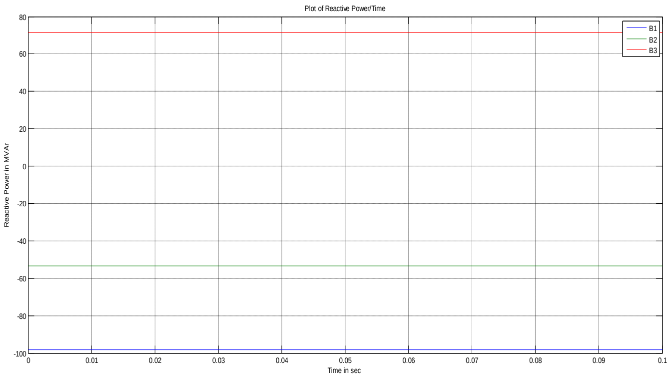

Fig.8 Reactive Power at B1, B2 & B3 without compensation

Fig.9 and Fig.10 highlights the real and reactive power control at the three stages when the STATCOM is connected at Sending End i.e. with compensation.

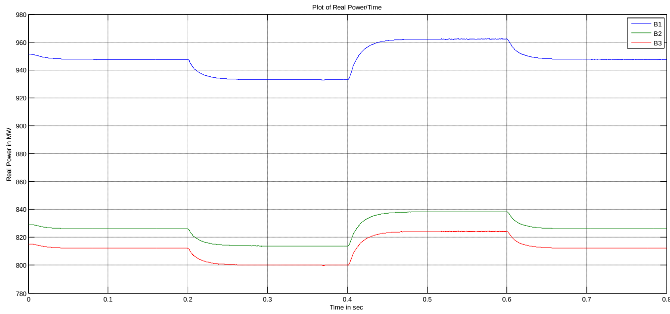

Fig.9 Real Power at B1, B2 & B3 when STATCOM is at Sending End

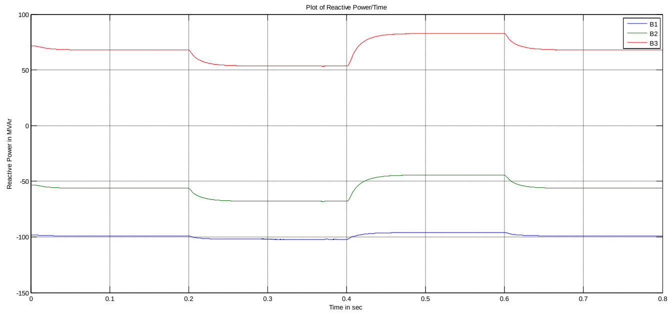

Fig.10 Reactive Power at B1, B2 & B3 when STATCOM is at Sending End

B. Case-2

Fig.11 and Fig.12 highlights the real and reactive power control at the three stages when the STATCOM is not connected i.e. without compensation in HV Condition. Fig.13 and Fig.14 highlights the real and reactive power control at the three stages when the STATCOM is not connected i.e. without compensation in LV Condition.

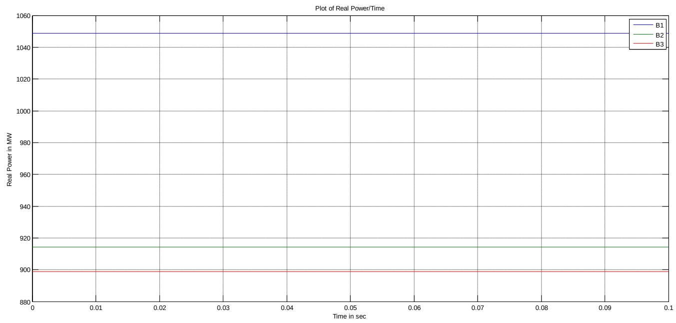

Fig.11 Real Power at B1, B2 & B3 without compensation for High voltage condition

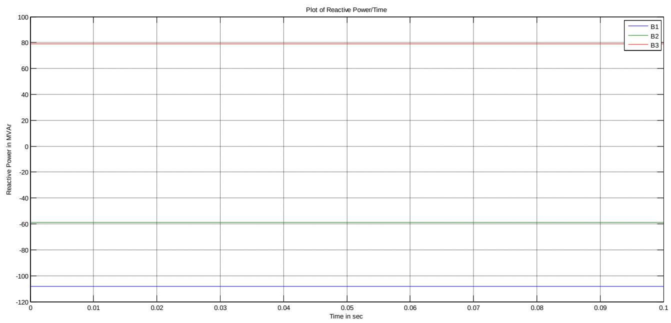

Fig.12 Reactive Power at B1, B2 & B3 without compensation for High voltage condition

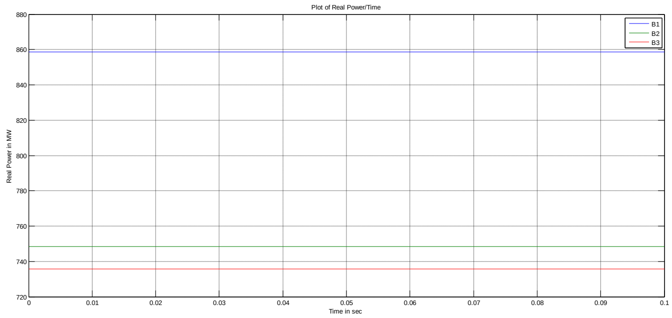

Fig.13 Real Power at B1, B2 & B3 without compensation for Low voltage condition

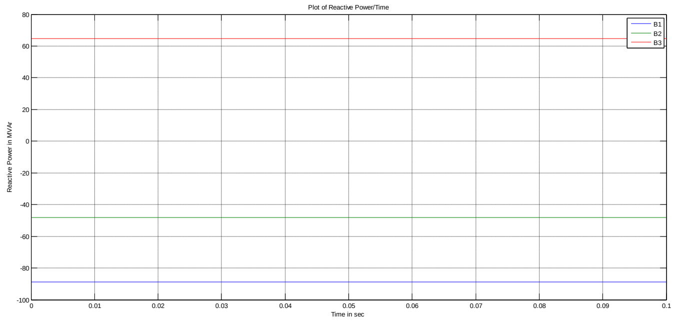

Fig.14 Reactive Power at B1, B2 & B3 without compensation for Low voltage condition

Fig.15 and Fig.16 highlights the real and reactive power control at the three stages when the STATCOM is connected at Sending End i.e. with compensation in HV Condition. Fig.17 and Fig.18 highlights the real and reactive power control at the three stages when the STATCOM is connected at Sending End i.e. with compensation in LV Condition.

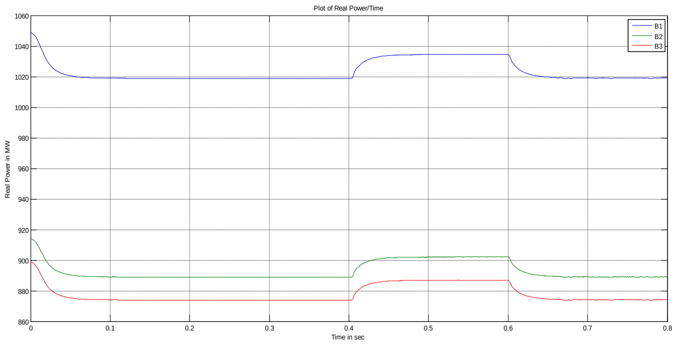

Fig.15 Real Power at B1, B2 & B3 when STATCOM is at Sending End for high voltage Condition

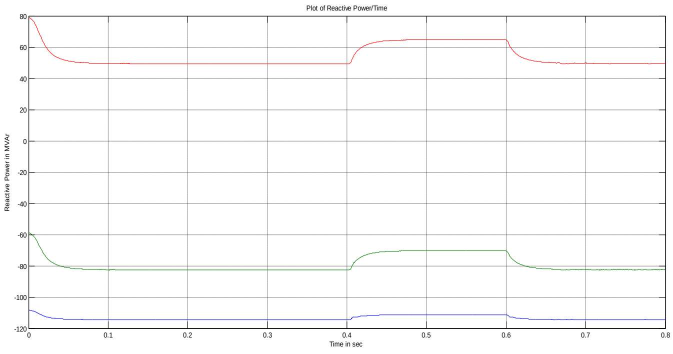

Fig.16 Reactive Power at B1, B2 & B3 when STATCOM is at Sending End for high voltage Condition

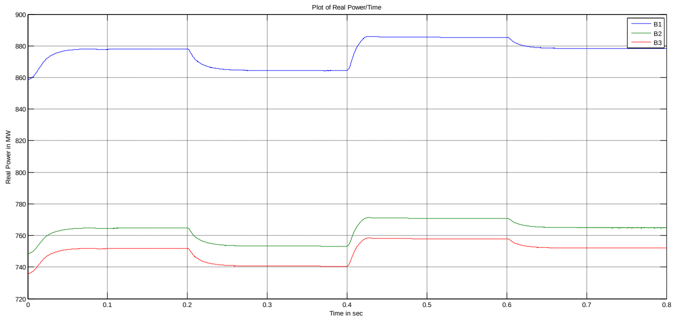

Fig.17 Real Power at B1, B2 & B3 when STATCOM is at Sending End for low voltage Condition

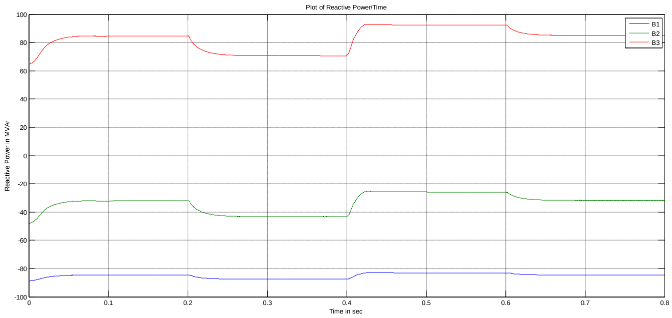

Fig.18 Reactive Power at B1, B2 & B3 when STATCOM is at Sending End for Low voltage Condition

C. Case-3

Fig.19 and Fig.20 highlights the real and reactive power control at the three stages when the STATCOM is not connected i.e. without compensation in Increasing Load Condition.

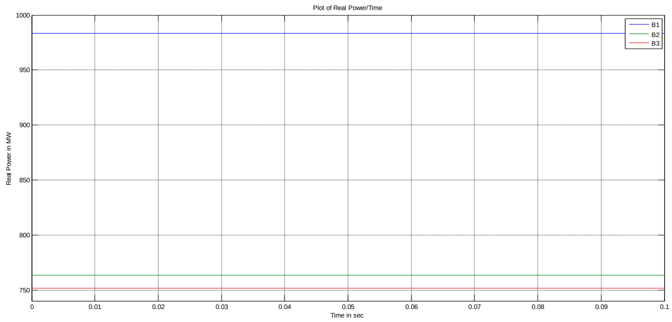

Fig.19 Real Power at B1, B2 & B3 without compensation for Increasing Load

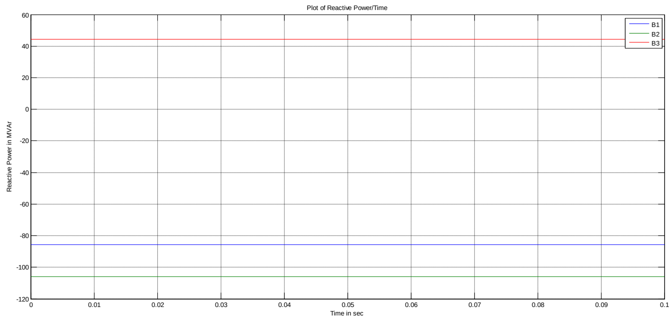

Fig.20 Reactive Power at B1, B2 & B3 without compensation for Increasing Load

Fig.21 and Fig.22 highlights the real and reactive power control at the three stages when the STATCOM is connected

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at Sending End i.e. with compensation in Increasing Load Condition.

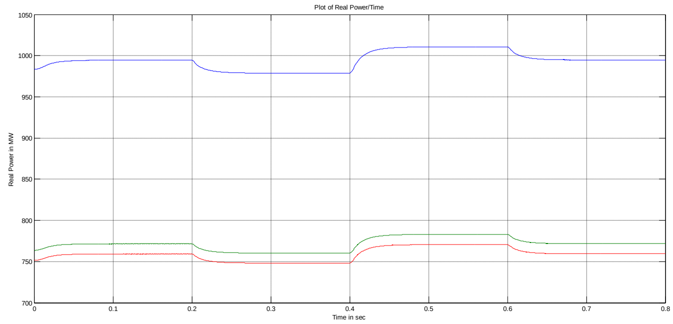

Fig.21 Real Power at B1, B2 & B3 when STATCOM is at sending end for Increasing Load Condition

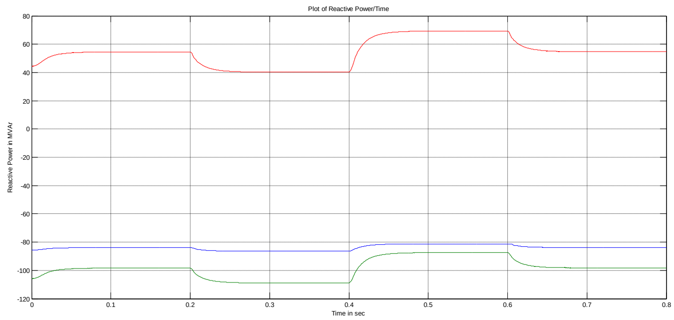

Fig.22 Reactive Power at B1, B2 & B3 when STATCOM is at sending end for Increasing Load Condition

D. Case-4

Fig.23 to Fig.26 highlights the Voltages at the three stages when the STATCOM is not connected i.e. without compensation in Steady State, HV, LV and Increasing Load Condition respectively.

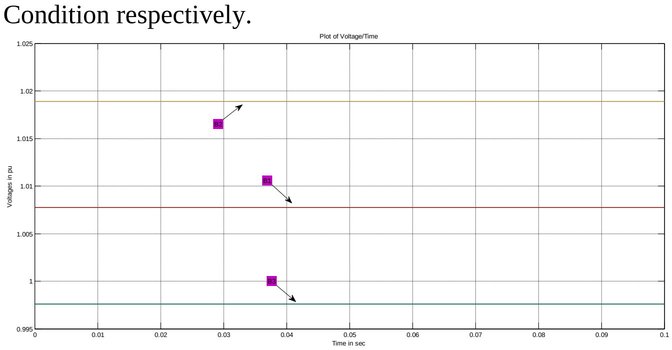

Fig.23 Voltages of system bus B1, B2 and B3 without compensation for Steady state Condition

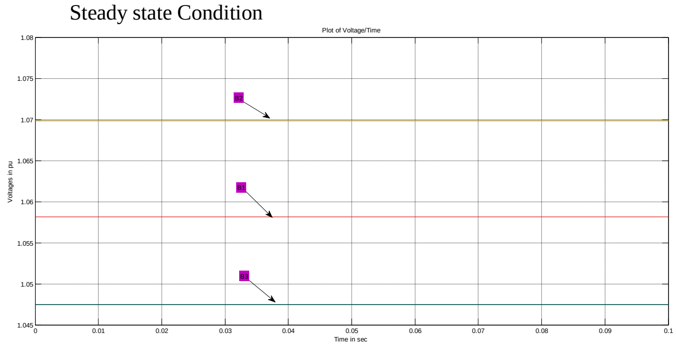

Fig.24 Voltages of system bus B1, B2 and B3 without compensation for High Voltage Condition

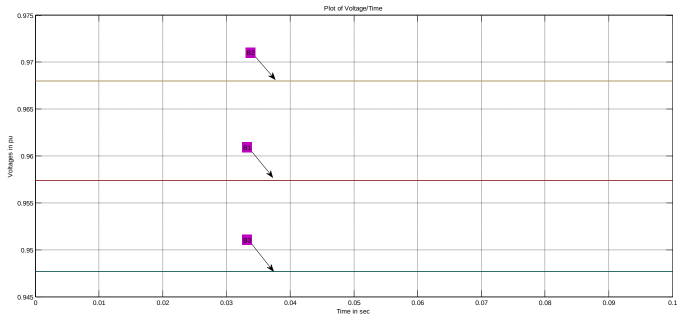

Fig.25 Voltages of system bus B1, B2 and B3 without compensation for Low Voltage Condition

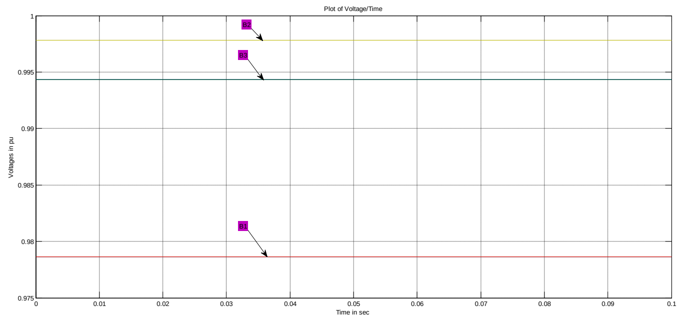

Fig.26 Voltages of system bus B1, B2 and B3 without compensation for Increasing Load Condition

Fig.27 to Fig.30 highlights the voltages at the three stages when the STATCOM is connected at Sending End i.e. with compensation in Steady State, HV, LV and Increasing Load Condition respectively.

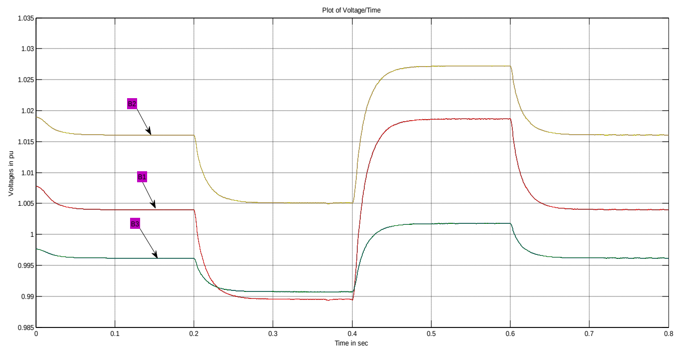

Fig.27 Voltages of system bus B1, B2 and B3 with compensation for Steady state Condition

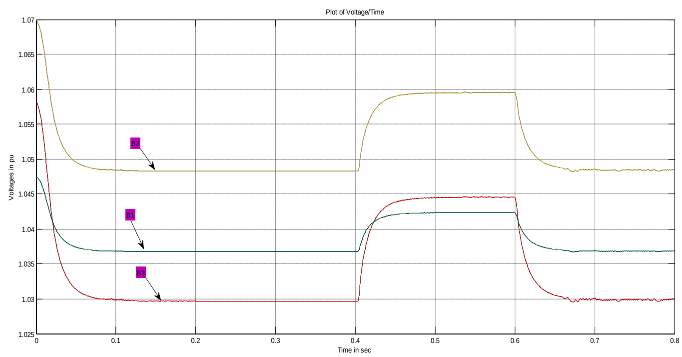

Fig.28 Voltages of system bus B1, B2 and B3 with compensation for High voltage Condition

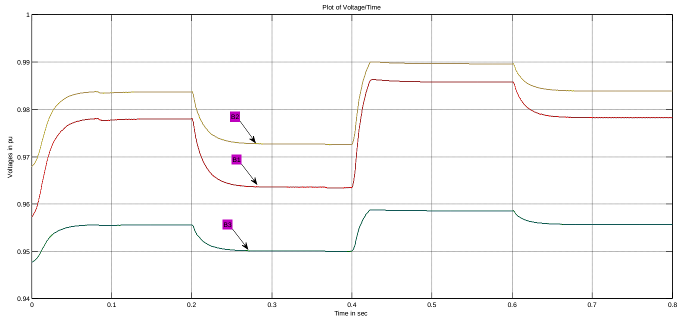

Fig.29 Voltages of system bus B1, B2 and B3 with compensation for Low voltage Condition

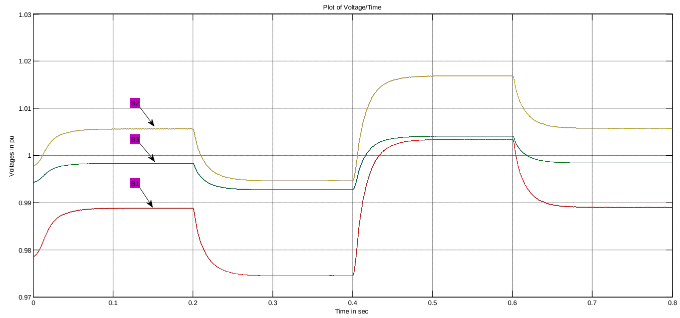

Fig.30 Voltages of system bus B1, B2 and B3 with compensation for Increasing Load Condition

E. Case-5

Fig.31 and Fig.32 highlights the real and reactive power control at the three stages when the STATCOM is connected at Sending End.

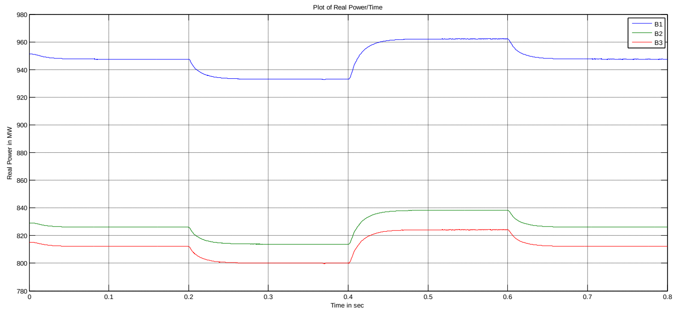

Fig.31 Real Power at B1, B2 & B3 when STATCOM is at Sending End

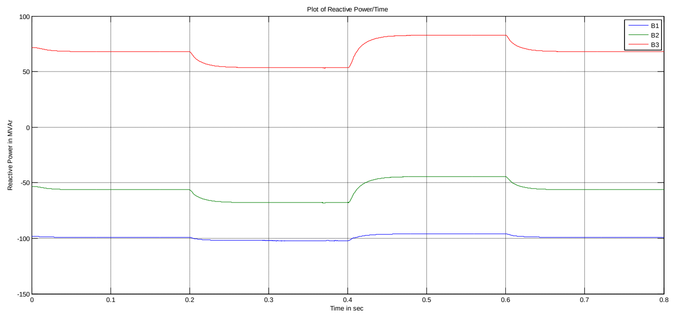

Fig.32 Reactive Power at B1, B2 & B3 when STATCOM is at Sending End

Fig.33 and Fig.34 highlights the real and reactive power control at the three stages when the STATCOM is connected at Middle.

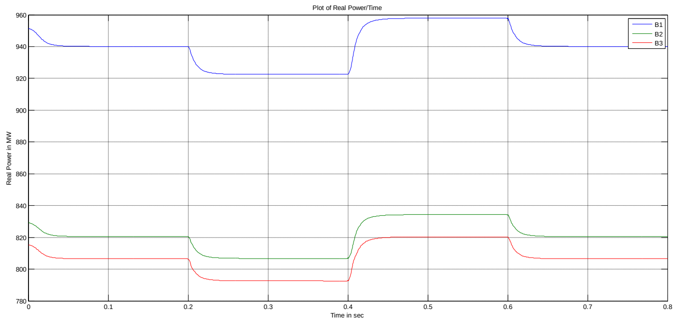

Fig.33 Real Power at B1, B2 & B3 when STATCOM is at Middle

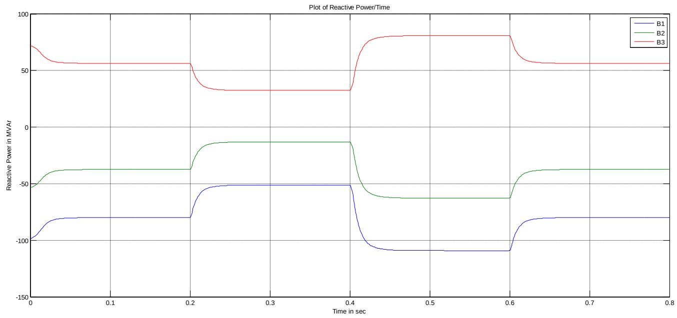

Fig.34 Reactive Power at B1, B2 & B3 when STATCOM is at Middle

Fig.35 and Fig.36 highlights the real and reactive power control at the three stages when the STATCOM is connected at Receiving End.

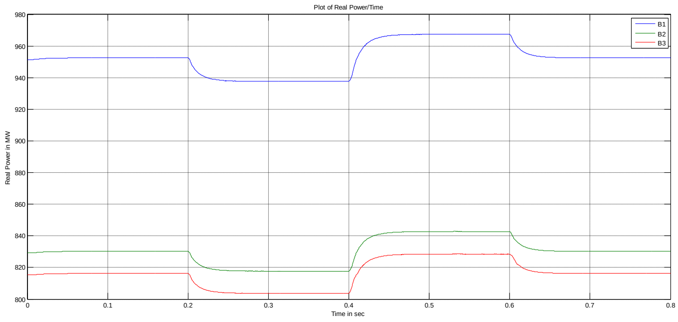

Fig.35 Real Power at B1, B2 & B3 when STATCOM is at Receiving End

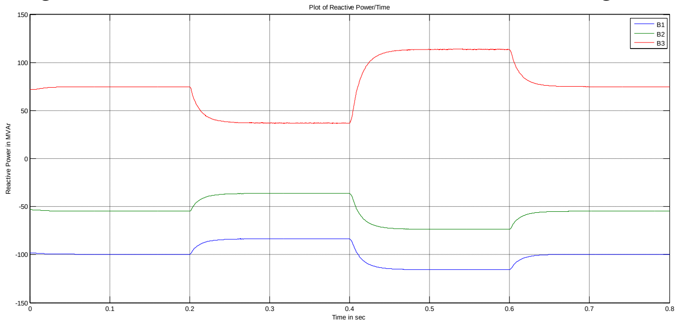

Fig.36 Reactive Power at B1, B2 & B3 when STATCOM is at Receiving End

VI. CONCLUSION

The vital role of shunt FACTS devices, which are connected in long distance transmission lines, are to improve the power transfer capability and also to control the power flow in the power system network. In this proposed work STATCOM is employed as a shunt FACTS device. STATCOM is connected at the various locations such as sending end, middle and receiving end of the transmission line. The results were obtained with and without compensation. The simulation results reveals that the reactive power generated is better at the middle of the transmission line when compared with the other ends of the transmission line and also the voltage is controlled at the middle of the line. So, the location of STATCOM is optimum when connected at the middle of the line.

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TABLE I
COMPARISON OF P & Q

Bus Number	STATCOM at Sending End		STATCOM at Middle		STATCOM at Receiving End	
	P in MW	Q in MVAr	P in MW	Q in MVAr	P in MW	Q in MVAr
B1	947.5	-99.1	940.1	-79.97	952.5	-99.61
B2	826	-56.34	820.5	-37.43	830.2	-54.79
B3	812.1	67.95	806.5	56.36	816.2	74.8