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COMPARISON OF HT SHUNT CAPACITORS AND SVC FOR ACTIVE AND REACTIVE POWER FLOW CONTROL IN TRANSMISSION LINE:

THE CASE OF RRVPNL POWER GRID

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ABSTRACT

This paper investigates the opportunities to install FACTS devices in the electric transmission network of RRVPNL power grid for the improvement in active and reactive power flow in electric transmission line. A 132 KV transmission line used to transfer electric power from a 220 KV GSS to a 132 KV GSS is modeled in MATLAB/Simulink environment. The simulation results of load flow for real and reactive power flow in the electric transmission line for an uncompensated system are studied. The results so obtained are compared with the results obtained after compensating the system by fixed (already installed) HT Shunt Capacitor Banks and SVC, a shunt compensating FACTS device, to show the improvement in active and reactive power flow in the transmission line. The results obtained after simulation demonstrate the performance of system with compensation by HT Shunt Capacitor banks and SVC.

KEYWORDS: Active Power, FACTS, HT Shunt Capacitor Banks, Reactive Power, RRVPNL Power Grid, SVC

INTRODUCTION

In today's highly complex and interconnected power system, there is a great need to improve electric power utilization while still maintaining reliability and security. While power flows in some of the transmission lines are well below their normal limits, other lines are overloaded, which has an overall effect on deteriorating voltage profiles and decreasing system stability and security [1]. Because of all that, it becomes more important to control the power flow along the transmission lines to meet the need of power transfer. The traditional HT Shunt Capacitor Banks provide the fixed reactive compensation in the network [2]. The power flow control in the transmission lines with the help of HT Shunt capacitor banks is not flexible and smart.

The power flow through transmission line is a function of line impedance, magnitude and phase angle of bus voltage [3]. If these parameters can be controlled, the power flow through the transmission line can be controlled in a predetermined manner. There are many advanced devices that have been proposed during the last three decades to improve stability of power system such as High Voltage Direct Current (HVDC) system and Flexible AC Transmission system [4]. Flexible AC Transmission System (FACTS) uses advanced power electronics to control the parameters in the power system in order to fully utilize the existing transmission facilities. Recently FACTS technology has become a very effective means to enhance the capacity of existing power transmission networks to their limits without the necessity of adding new transmission lines. Better utilization of existing power system capacities is possible by connecting FACTS devices in the transmission network [5]-[10]. By introduction of FACTS devices, flexible power flow control is possible.

The Static VAR Compensator (SVC) is a first generation FATCS device that can control voltage at the required bus thereby improving the voltage profile of the system [11]. The primary task of an SVC is to maintain the voltage at a particular bus by means of reactive power compensation (obtained by varying the firing angle of the thyristors). SVCs have been used for high performance steady state transient voltage control compared with classical shunt compensation. SVCs are also used to dampen power swings, improve transient stability, and reduce system losses by optimized reactive power control.

The objective of this paper is to investigate the opportunities to install FACTS devices in the electric transmission network of the RRVPNL power grid for the improvement in active and reactive power flow in electric transmission lines. The 132 KV Transmission line used to transfer power from 220 KV GSS Swaimadhopur to the 132 KV GSS Newai is modeled in MATLAB/Simulink environment. The active and reactive power flow in uncompensated transmission line, transmission line compensated by HT Shunt capacitor bank and transmission line compensated by SVC at load end are obtained.

REACTIVE POWER COMPENSATION PRINCIPLES

Fig. 1 shows the simplified model of a power transmission system. Two power grids are interconnected by a transmission line which is assumed lossless and represented by the reactance X_L. $V_1\angle\delta_1$ and $V_2\angle\delta_2$ represent the voltage phasors of the two power system buses with angle $\delta = \delta_1 - \delta_2$ between the two.

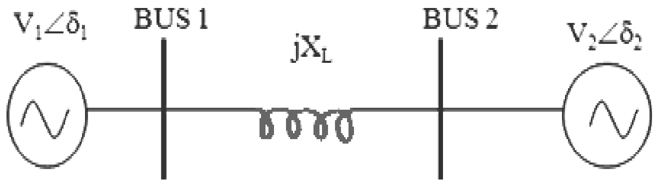

Figure 1: Simplified Model of Power Transmission System

The active power (P_{12}) and reactive power (Q_{12}) flow between buses 1 and 2 of a lossless transmission line are given by the following equations [12].

$$P_{12} = \frac{V_1 V_2}{X_L} \sin(\delta_1 - \delta_2) \tag{1}$$

where P_{12} is active power flow from bus 1 to bus 2.

$$Q_{12} = \frac{V_1^2}{X_L} - \frac{V_1 V_2}{X_L} \cos(\delta_1 - \delta_2) \tag{2}$$

where Q_{12} is reactive power flow from bus 1 to bus 2

The reactive power compensation of transmission system is divided into two main groups: Shunt and series reactive compensation [13]. Shunt reactive compensation has been widely used in transmission system to regulate the voltage magnitude, improve the voltage quality, and enhance the system stability. The series reactive compensation aims to directly control the overall series line impedance of the transmission line [11].

All shunt controllers inject current in to the system at the point of connection. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power.

Series compensation adds a voltage in opposition to the transmission line voltage drop, thereby reducing the series line impedance. As long as the injected voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power [14].

HT SHUNT CAPACITOR BANKS

Shunt capacitor banks are used to improve the quality of the electrical supply and the efficient operation of the power system. Studies show that a flat voltage profile on the system can significantly reduce line losses. Shunt capacitor banks are relatively inexpensive and can be easily installed anywhere on the network. Shunt capacitor banks are mainly installed to provide capacitive reactive compensation/ power factor correction [2]. Om Prakash Mahela *et al.* [15] presented different analytical optimization and heuristic optimization techniques of HT shunt capacitor placement in transmission and distribution networks to reduce line losses and voltage stability enhancement. Masoum et al. [16] used fuzzy set theory for the discrete optimization problem of fixed shunt capacitor placement and sizing under harmonic conditions. Hsiao *et al.* [17] applied the Simulated Annealing (SA) method to optimal VAR source planning in large-scale power systems. Chang C.F. in [18] presented Ant Colony Optimization based algorithm for the feeder reconfiguration and capacitor placement of distribution systems. The objective of this study was to present new algorithms for solving the optimal capacitor placement problem, the optimal feeder reconfiguration problem and a combination of two. In [19] elite based simplex genetic algorithm (GA) hybrid approach combined with multi population GA to determine the location, size and number of capacitors in unbalanced distribution systems is proposed, although the harmonic distorted systems were not considered in this study.

In the RRVPNL power grid the reactive power is injected at 33KV voltage level with the help of 38KV, 7.2 MVAR or 33KV, 5.43MVAR HT Shunt Capacitor banks consisting of two sections connected in parallel controlled by different isolators. The capacitor bank is star connected with floating neutral. Two sections of rating 2.715 MVAR are used to provide greater flexibility. The unbalanced protection is provided with the help of Residual voltage transformer (RVT). The general setting of Neutral displacement relay (NDR) is 5.04 Volts. The capacitor units of 150 KVAR, 200KVAR and 400KVAR are used in the series and parallel combinations in the capacitor banks to meet out the required voltage and MVAR rating [20]. The capacitor units of 150 KVAR, 11 KV are connected in two series groups as shown in Fig. 2, and capacitor units of 200 KVAR, 7.3 KV and 400 KVAR, 7.3 KV are connected in three series groups as shown in Fig. 3.

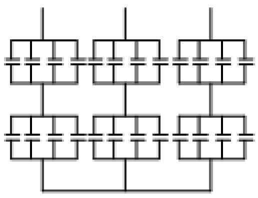

Figure 2: 33 KV 5.43 MVAR HT Shunt Capacitor Bank with Two Series Group

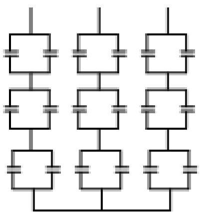

Figure 3: 33 KV 5.43 MVAR HT Shunt Capacitor Bank with Three Series Group

STATIC VAR COMPENSATOR (SVC)

Static VAR Compensator (SVC) is a shunt-connected VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage) [21]. Static VAR Systems are applied by utilities in transmission applications for several purposes. The primary purpose is usually for rapid control of voltage at weak points in a network. Installations may be at the midpoint of transmission interconnections or at the line ends. In its simple form, SVC is connected as Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) configuration as shown in Fig. 4 [22]. The SVC is connected to a coupling transformer that is connected directly to the ac bus whose voltage is to be regulated. The effective reactance of the FC-TCR is varied by firing angle control of the anti parallel thyristors. The firing angle can be controlled through a PI (Proportional + Integral) controller in such a way that the voltage of the bus, where the SVC is connected, is maintained at the reference value.

E. Lerch *et al.* [23] used SVC for damping power system oscillations. A.E. Hammad in [24] used SVC for analysis of power system stability enhancement. Patricio Flores *et al.* [25] used SVC and Active Power Filter with power injection capability, using 27-level inverters and photovoltaic cells to produce active power and even to feed the loads during prolonged voltage outages. Priyanath Das *et al.* [26] used SVC for improvement of voltage security in a multi-bus power system using SVC.

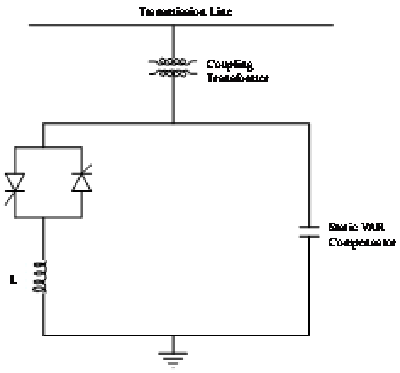

Figure 4: SVC Connected to Transmission Line

THE RRVPNL POWER GRID AND ITS EXISTING PROBLEM

The RRVPNL power-grid is the power transmission network of Rajsthan state of India. High power losses are one of the serious problems in the transmission and distribution systems in Rajasthan, where power system is compensated in terms of fixed HT shunt capacitor banks. The losses in the transmission network of RRVPNL power grid was 4.86% in the year 2011-12 [27]. The losses in distribution network of Rajasthan State of India are 15-20% [28]. In transmission network the HT shunt capacitor banks of 33 KV, 5.43 MVAR and in distribution system capacitor banks of 11 KV, 2.0 MVAR are used. The FACTS devices are not installed anywhere in the transmission and distribution network of Rajasthan. The main problem of the system is that the compensation required in the system is not step less but it is in the steps of 2.715 MVAR in transmission system and 1.0 MVAR in distribution system as the HT Shunt capacitor banks are provided in two half sections [29]. Therefore the system is either over compensated or under compensated when the capacitor banks are switched ON or OFF.

THE PROPOSED POWER SYSTEM MODEL

The 132 KV power transmission line used to transfer power from 220 KV GSS Swaimadhopur to the 132 KV GSS Newai is modeled. The 132 KV Bus of 220 KV GSS Swaimadhopur is taken as swing bus and the 132 KV bus of 132 KV GSS Newai is taken as the load bus. Fig. 5(a) shows the system without reactive compensation. Fig. 5(b) shows the system compensated with HT shunt capacitor bank. Fig.5(c) shows the system compensated with SVC, the shunt FACTS device.

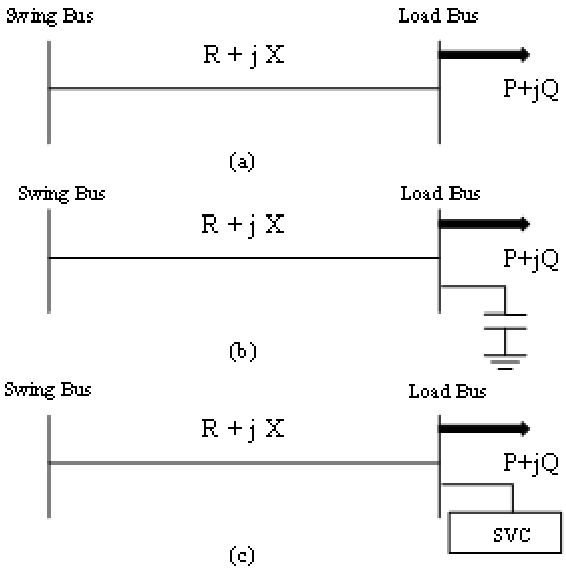

Figure 5: (a) Transmission Line without Compensation (b) Transmission Line Compensated by HT Shunt Capacitor Bank (c) Transmission Line Compensated by SVC

SIMULATION RESULTS AND DISCUSSIONS

The 65 Km long 132 KV transmission line of RRVPNL power grid used to transfer power from 220 KV GSS Swaimadhopur to 132 KV GSS Newai is modeled on single phase basis in the MATLAB/Simulink environment. The transmission line parameters are given in Table. I [20].

Table I: Transmission Line Parameters

S. No.	Parameters of Transmission Line	Value of Parameters
1	Positive sequence reactance	1.30890E-3 H/Km
2	Zero Sequence Reactance	3.27225E-3 H/Km
3	Positive sequence Resistance	0.15850 Ω/Km
4	Zero Sequence Resistance	0.39625 Ω/Km
5	Positive sequence Resistance	9.13424E-9 F/Km
6	Zero Sequence Resistance	3.27225E-9 F/Km
7	Transmission line length	65 Km
8	Voltage of swing bus	132 KV
9	Surge Impedance Loading	50MW

Transmission Line without Compensation

The 132 KV Transmission line without compensation shown in Fig. 5(a) is considered in study. The line is simulated in Matlab/Simulink environment and the corresponding graphs of active and reactive power flow in the transmission line at sending end and receiving end are shown in Fig. 6 and Fig. 7 respectively.

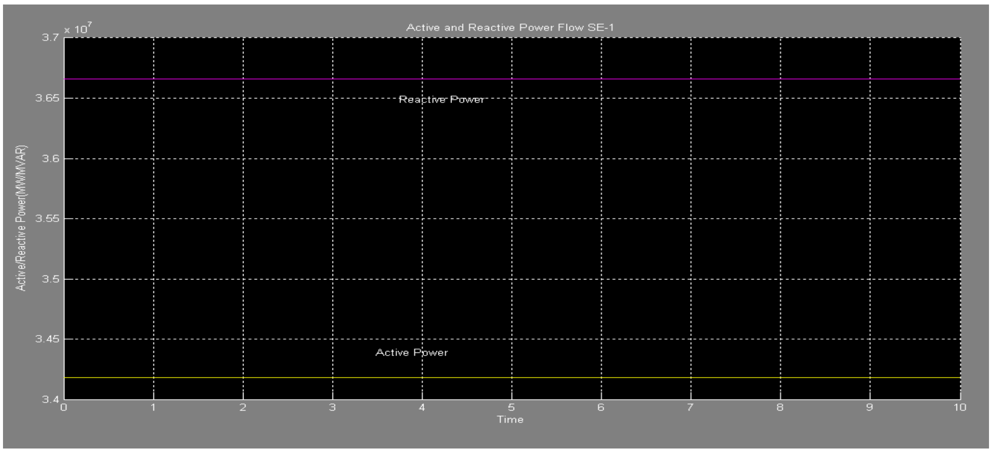

Figure 6: Active and Reactive Power Flow at Sending End of Uncompensated Transmission Line

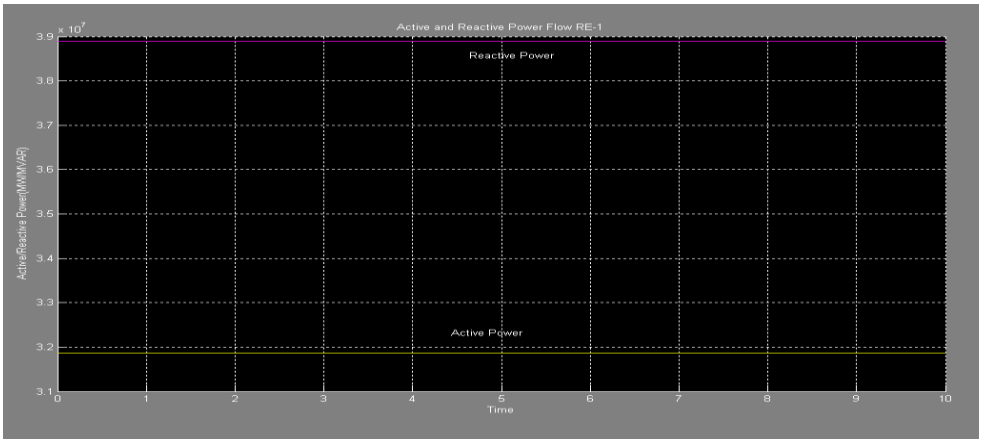

Figure 7: Active and Reactive Power Flow at Receiving End of Uncompensated Transmission Line

Transmission Line Compensated by Existing HT Shunt Capacitor Bank

The 132 KV Transmission line compensated by existing HT Shunt Capacitor bank shown in Fig. 5(b) is considered in study. The line is simulated in Matlab/Simulink environment and the corresponding graphs of active and reactive power flow in the transmission line at sending end and receiving end are shown in Fig. 8 and Fig. 9 respectively. Two HT shunt capacitor banks of rating 33KV 5.43 MVAR each are switched ON for reactive compensation of the transmission line.

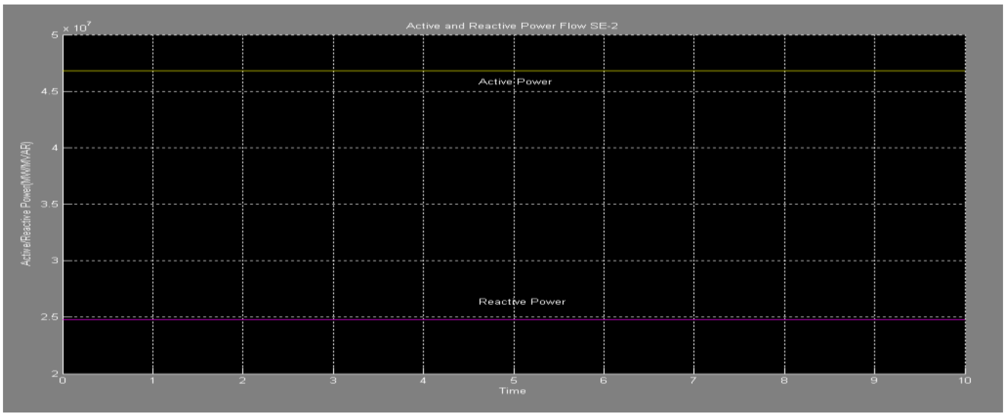

Figure 8: Active and Reactive Power Flow at Sending End of Transmission Line Compensated by HT Shunt Capacitor Banks

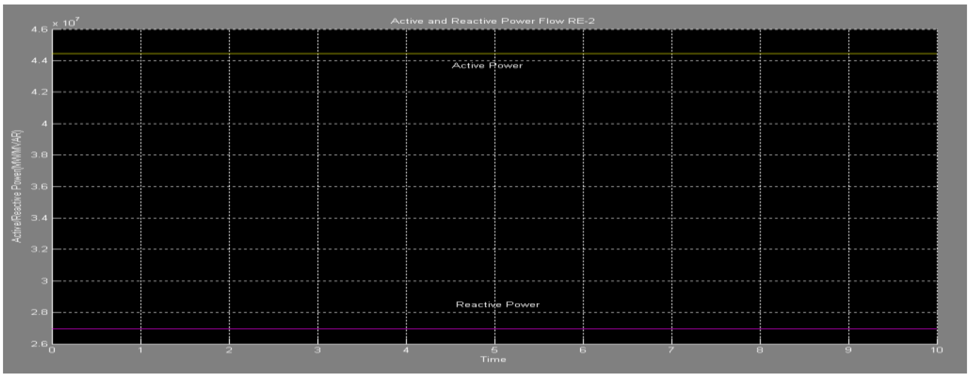

Figure 9: Active and Reactive Power Flow at Receiving End of Transmission Line Compensated by HT Shunt Capacitor Banks

Transmission Line Compensated by SVC

The 132 KV Transmission line compensated by SVC shown in Fig. 5(c) is considered in study. The line is simulated in Matlab/Simulink environment and the corresponding graphs of active and reactive power flow in the transmission line at sending end and receiving end are shown in Fig. 10 and Fig. 11 respectively.

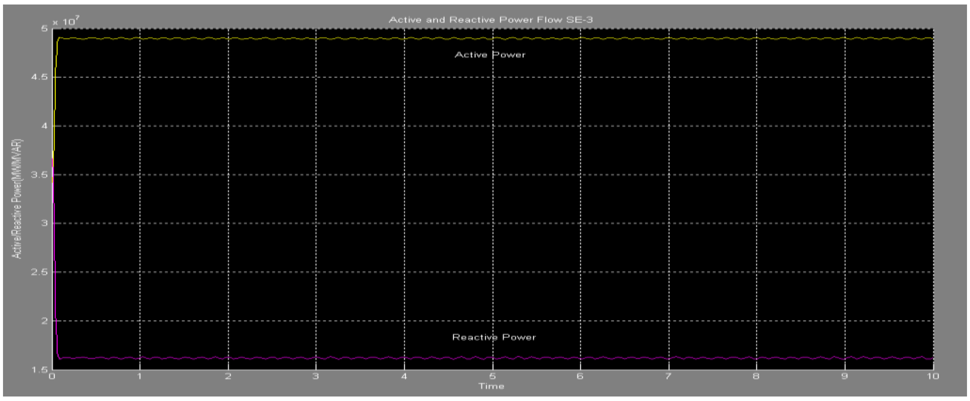

Figure 10: Active and Reactive Power Flow at Sending End of Transmission Line Compensated by SVC Installed at Load End

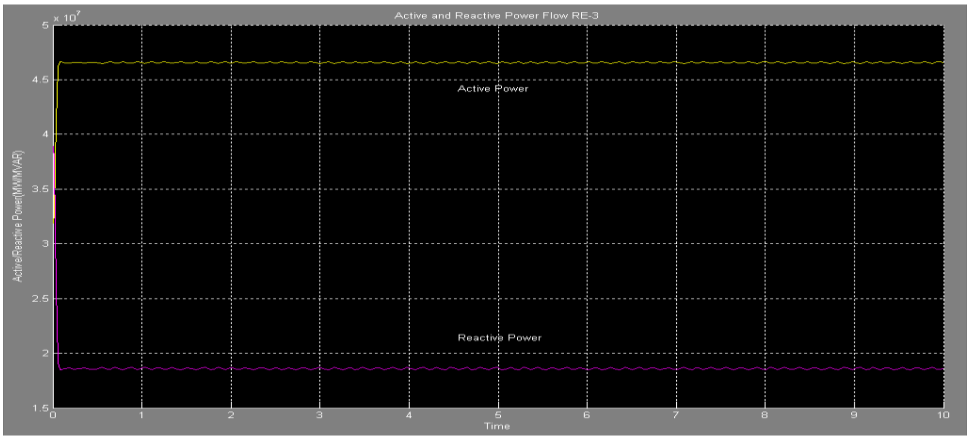

Figure 11: Active and Reactive Power Flow at Receiving End of Transmission Line Compensated by SVC Installed at Load End

The graphs of Fig. 6, 8 and 10 show that the sending end active power flow in the transmission line increases with compensation by HT Shunt capacitor banks and further increases by the compensation with SVC approaching the SIL of transmission line and simultaneously the reactive power flow decreases with compensation by HT shunt capacitor banks and further decreases with compensation by SVC. The graphs of Fig. 7, 9 and 11 show that the receiving end active power flow in the transmission line increases with compensation by HT Shunt capacitor banks and further increases by the compensation with SVC and simultaneously the reactive power flow decreases with compensation by HT shunt capacitor banks and further decreases with compensation by SVC. The study of graphs of Fig. 6 & 7, Fig. 8 & 9, and Fig. 10 & 11 show that the transmission line losses decreases with compensation of transmission line with HT shunt capacitor banks which further decreases with compensation by SVC.

CONCLUSIONS

This paper investigates the opportunities to install FACTS devices in the transmission network of Rajasthan Rajya Vidhyut Prasaran Nigam Ltd. (RRVPNL). The active and reactive power flow in transmission line studied. The study has shown that transmission capacity of the line increases when it is compensated with HT Shunt capacitor banks and it further improves and transmission line is loaded near surge impedance loading with compensation by SVC. The transmission line loss also decreases with compensation by HT shunt capacitor banks and further decreases with compensations by SVC. The simulation results tested on 132 KV Transmission line used to transfer power from 220 KV GSS Swaimadhopur to the 132 KV GSS Newai in RRVPNL power grid shows the superiority of SVC as compared to the HT Shunt capacitor banks for active and reactive power flow in the transmission line.

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BIOGRAPHIES

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