Venu Yarlagadda[1,*]
A. Giri Prasad[1]
Ch. Rami Reddy[2,4],
T. Nireekshana[1]
B. V. Seshu Kumari[3]
P.V.V Satyanarayana[4]

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Regular paper

Suppression of Ferranti Effect of Transmission System Using Closed Loop Control of FACTS Devices

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Modern power systems need the expansion of EHV and UHV power Transmission networks due to the exponential rise in power demand. The Ferranti effect needs the attention of researchers on the dynamic variation of loads in interconnected power systems. This article focuses on the development of closed-loop control circuitry for both Static Synchronous Compensator (STATCOM) and Static Var Compensator (SVC). The developed transmission system Simulink model has been simulated and Ferranti Effect is observed for both no-load and lightly loaded conditions. The closed-loop control circuits along with power circuits of STATCOM and SVC have been developed and simulated and the results show the significant suppression of the Ferranti effect by both of the shunt devices.

Keywords: Ferranti effect; closed-loop control of SVC; TSC-TCR; Suppression of Ferranti effect; Closed loop control of SVC, STATCOM.

1. Introduction

The transmission system is used to enhance the power transmission capability of the interconnected power system network in which the Ferranti effect significantly influences the system behavior all over the network due to dynamic load disturbances [1-2]. The severity of the effect adversely affects due to the increase of line lengths of both medium and long transmission lines [3]. This effect is addressed with the application of Flexible A.C Transmission Systems(FACTS) devices especially shunt-connected devices viz [4]. STATCOM and SVC. The main author contributions are as follows

- Transmission systems models with medium and long transmission lines have been developed for the simulation study of the Ferranti effect and its suppression.
- Designed and developed the models of shunt FACTS devices such as STATCOM and SVC.
- Developed the closed-loop control system for both of the said devices for mitigation of the Ferranti effect.
- Analysis has been performed for suppression of the Ferranti effect using both devices and results have proved the significance of closed-loop control in omitting the Ferranti effect.

The remaining article is structured as follows
Section II is describing the various components of the test systems, STATCOM power and closed-loop control circuits, SVC power and closed-loop control circuits and Section III used to describe the simulation results without any controller, with closed-loop control of

* Corresponding author: Venu Yarlagadda, Electrical and Electronics Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India 500090 E-mail: venu_y@vnrvjiet.in
[1]Department of Electrical and Electronics Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad
[2]Department of Electrical and Electronics Engineering, Joginapally B. R. Engineering College, Hyderabad, India 500034
[3]Department of Information Technology, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad 500090
[4] Department of Electrical and Electronics Engineering, Malla Reddy Engineering College, Secunderabad, India 500100

STATCOM and with closed-loop control of SVC and lastly conclusions of this work followed by the references.

2. Materials and Methods

2.1 The Transmission system

The medium and long transmission lines are the main constituent part of the transmission system which is the root cause of the Ferranti effect and it is observed in both medium and long transmission lines [5]. A long transmission line equivalent circuit is depicted in Fig.1model and it is clearly illustrated in Fig.2,the receiving end voltage magnitude (V_R) is higher than that of sending end voltage (V_S) and it adversely increases with line length [6-8].

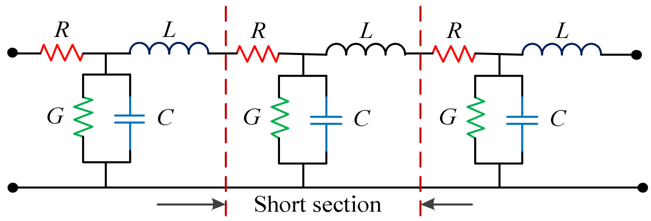

Fig.1. Long Transmission line model

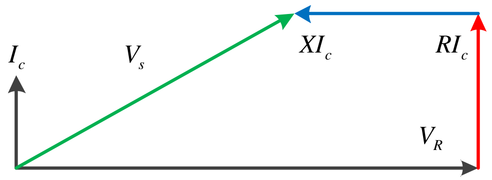

Fig.2. Ferranti effect phasor illustration

2.2. Static Var Compensator (SVC)

The developed system for the simulation study as illustrated inFig.3comprises the generating station, transmission system feeding the load, SVC is connected at the receiving end load bus including a closed-loop controller [9,15]. The susceptance of the device can be controlled with the control of the firing angle of the TCR and Fig.4. Shows the schematic diagram of SVC and the equations from (1) to (7) describes the mathematical modeling of SVC [10,15].

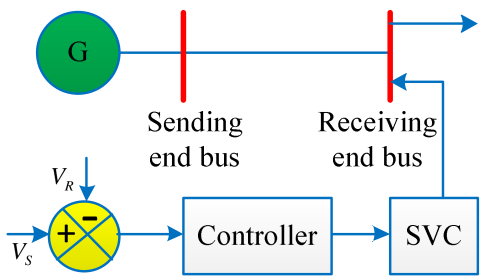

Fig.3. Test system single line diagram with closed loop controlled SVC

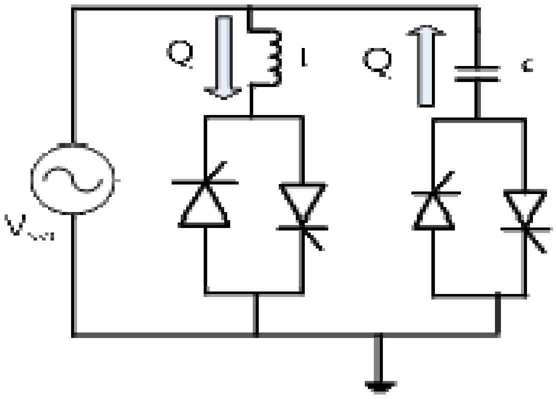

Fig.4 :SVC Schematic circuit of SVC

$$B_{SVC} = B_{TSC} - B_{TCR} \quad (1)$$

$$= X_L - X_C / \pi[2(\pi-\alpha)+\sin 2\alpha] \div [X_C X_L] \quad (2)$$

$$B_{TCR} = B_L\,((\pi-2\alpha-\sin\alpha)/\pi) + Bc \quad (3)$$

$$Q_{SVC} = V_{BUS}^2 \, \frac{(Xc\,[2\pi-\alpha+\sin 2\alpha]-\pi XL)}{\ldots} \quad (4)$$

$$Q_{SVC} = V_t(V_t - V_{ref})\, X_{SL} \quad (5)$$

$$Q_{SVC} = B_{SVC} \times V_{ref}^2 \quad (6)$$

$$Q_{SVC}^{min} \leq Q_{SVC} \leq Q_{SVC}^{max} \quad (7)$$

2.3. STATCOM

STATCOM is a shunt-connected device and the mathematical modelling of STATCOM has been described in equations (8) to (10) andFig.5 depicts the STATCOM Schematic Diagram [11,16]

$$L\frac{di_{ac}}{dt} = R + V_{ac} - V_{at} \quad (8)$$

$$L\frac{di_{bc}}{dt} = R + V_{bc} - V_{bt} \quad (9)$$

$$L\frac{di_{cc}}{dt} = R + V_{cc} - V_{ct} \quad (10)$$

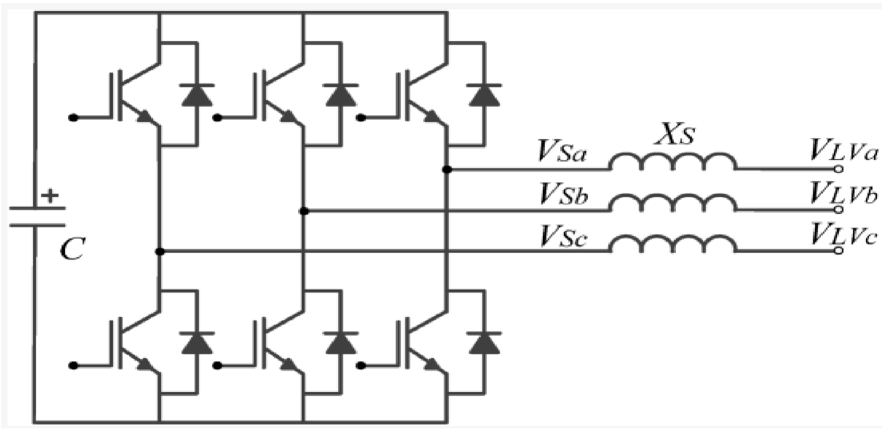

Fig.5 :STATCOM Schematic Diagram

The test system is developed with closed-loop control of the STATCOM, it is composed of a power plant feeding the load through a transmission network [12-16]. Fig.6. shows the single line diagram system of with STATCOM and Fig.7. STATCOM closed-loop control circuit

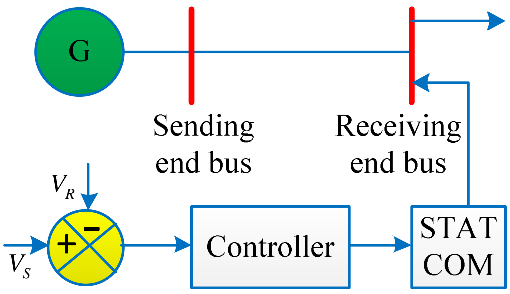

Fig.6. Single line diagram system of with STATCOM

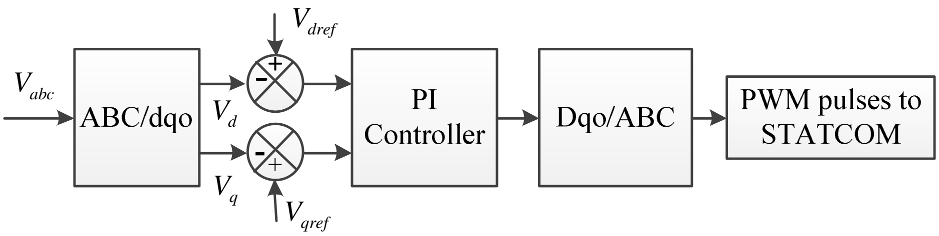

Fig.7. STATCOM closed-loop control circuit

3. Result analysis and discussion

3.1. STATCOM Results

The Simulink model of the test system for presenting the case study is developed with all described blocks said earlier and is being simulated and results have been presented int his section below and it is illustrated in Fig.8 below.

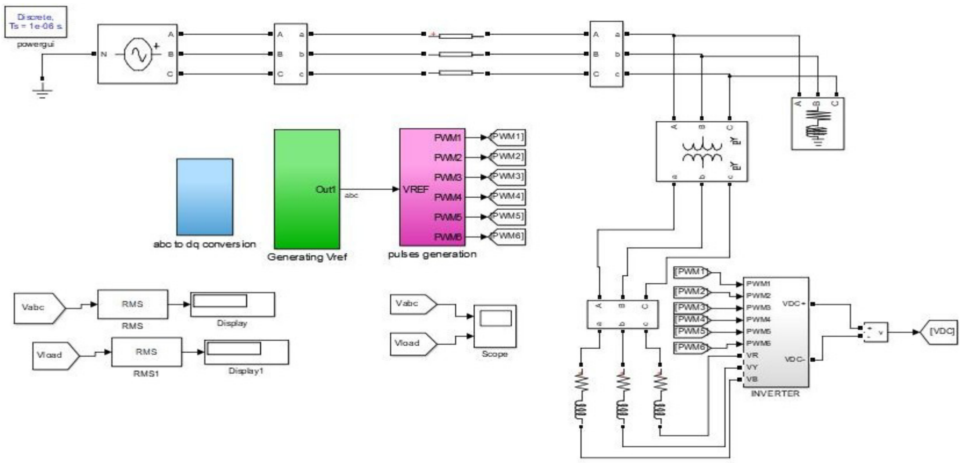

Fig.8.MATLABSimulinkmodelwith closed-loop control of STATCOM

Table.1 shows the line parameters, Table. 2depicts the simulation results of the transmission system without STATCOM, and Table.3 encapsulate the Ferranti effect results with STATCOM**.**

Table1. Transmission line parameters

S.No	Specifications	Value
1	R in Ohm/kM	0.1322
2	L in H/kM	2.1625e-3
3	C in F/kM	7.70628e-9
4	Length in kM	400,500,600
5	Sending endvoltageinkV	230 kV

Table2: The Ferranti effect results without STATCOM.

S.No	Line Length(kM)	V_S in kV	V_R in kV at NL	V_R in kV at Lightly loaded conditions
1	400	230	263	260.4
2	500	230	286.8	281.3
3	600	230	319.5	310.8

Table. 3: The Ferranti effect results with STATCOM.

S.No	Line Length(kM)	V_S in kV	V_R in kV at NL	V_R in kV at Lightly loaded conditions
1	400	230	230	230
2	500	230	230	230
3	600	230	230	230

3.1. SVC Results

This part shows the simulation results of SVC, Table3 illustrates the simulation results for no load and lightly loaded conditions without SVC and Table4:Simulation results for no load and lightly loaded conditions with SVC, which proves that the closed-loop control of SVC is quite effective in suppressing the Ferranti effect. Fig.9. shows the Simulink power circuit and closed-loop control circuits with SVC, Fig.10. depicts the Closed loop control circuit of SVC Fig.11. shows the Closed loop firing circuit of SVC. Fig.12 to 21 illustrate the waveforms of receiving and sending voltages without and with SVC, these results prove that the closed-loop control of SVC is quite effective in suppressing the Ferranti effect for both no load and lightly loaded conditions.

Table3:Simulation results for no load and lightly loaded conditions without SVC

S. No	Line Length in kM	Vs in kV	Vr in KV Under no load	Vr in KV under lightly loaded condition
1.	400	230	263	260.4
2.	500	230	286.8	281.3
3.	600	230	319.5	310.8

Table4:Simulation results for no load and lightly loaded conditions with SVC

S. No	Line Length in kM	Vs in kV	Vr in kV Under no load	Vr in kV under lightly loaded condition
1.	400	230	230	230
2.	500	230	230	230
3.	600	230	230	230

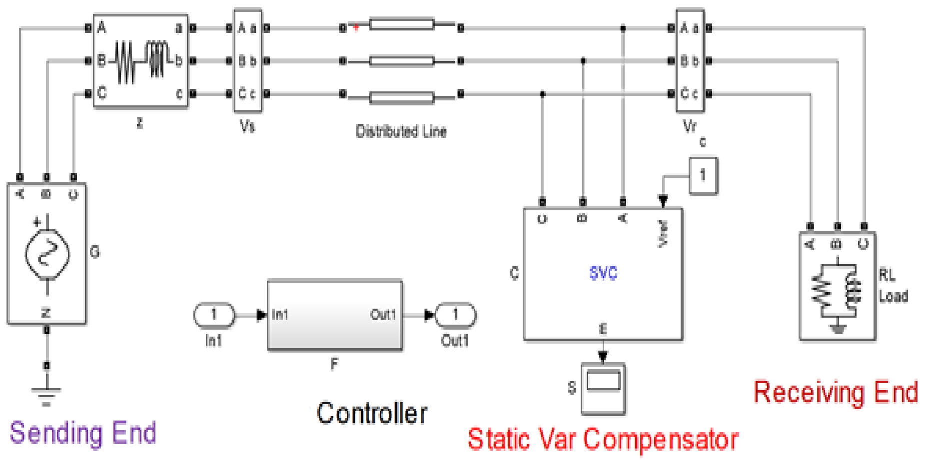

Fig.9. Simulink Power Circuit and closed loop control circuits with SVC

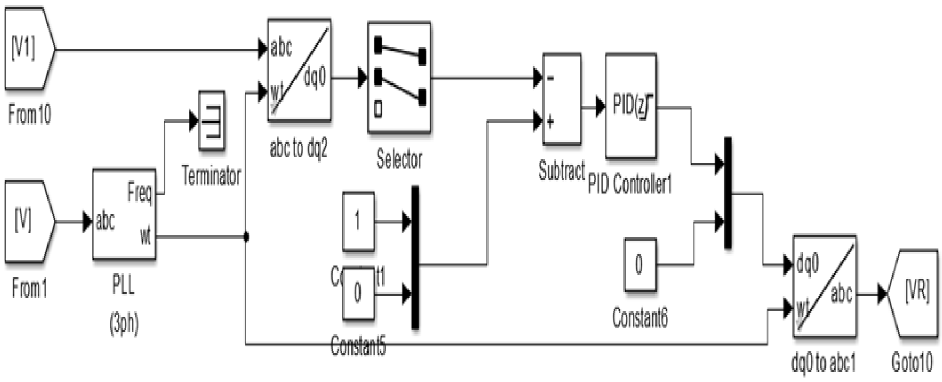

Fig.10. Closed loop control circuit of SVC

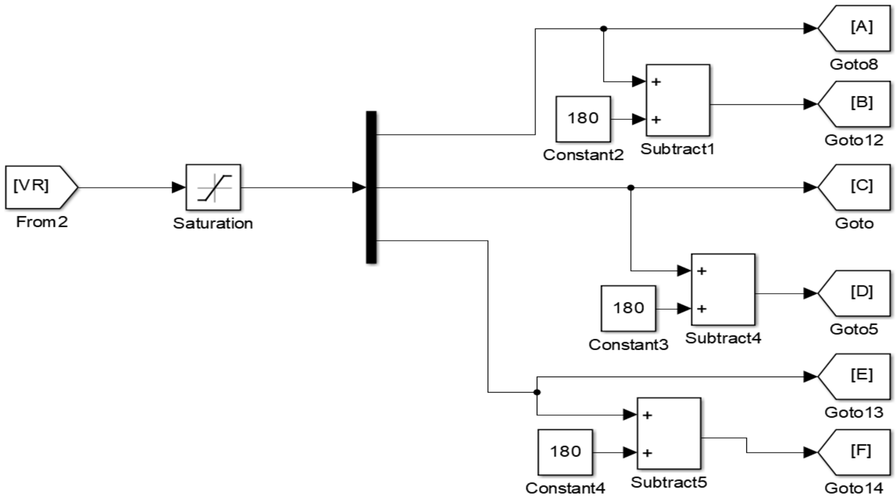

Fig.11. Closed loop firing circuit of SVC

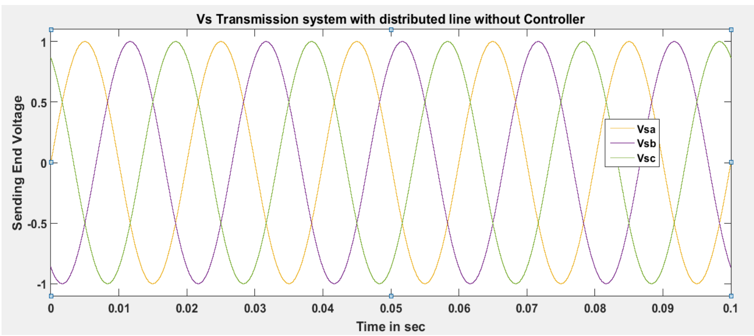

Fig.12. Vs without controller with distributed line

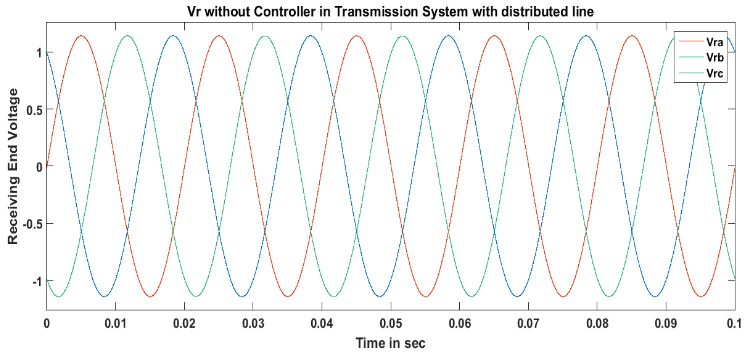

Fig.13. Vr without controller with distributed line

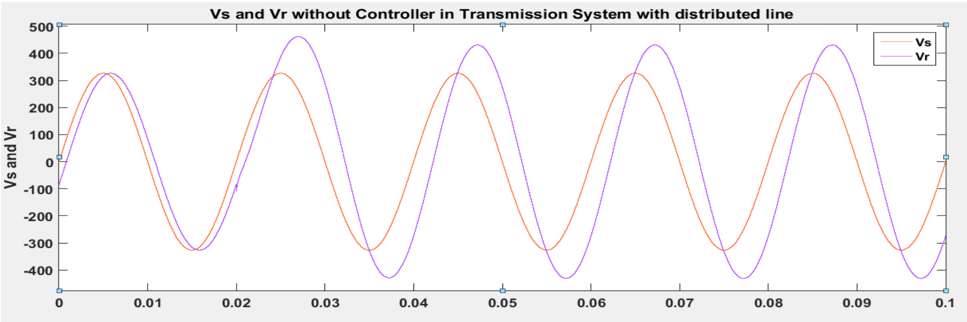

Fig.14. Vs and Vr in distributed line without controller

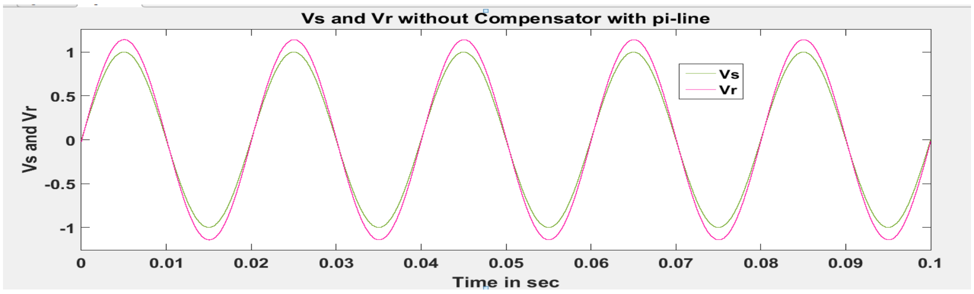

Fig.15. Vs and Vrin distributed line without controller

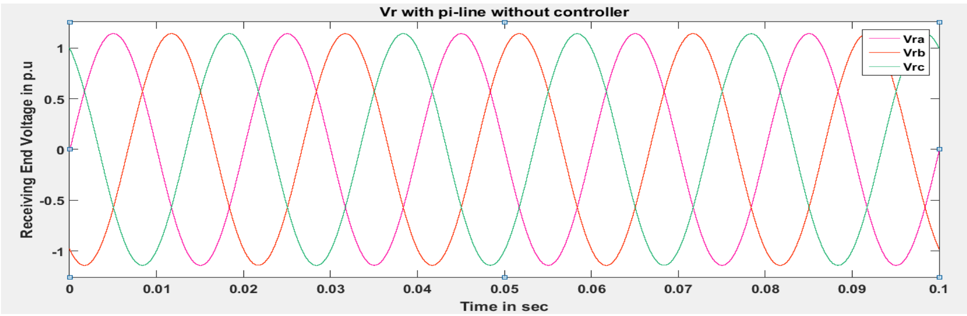

Fig.16. Vr with pi-line without controller

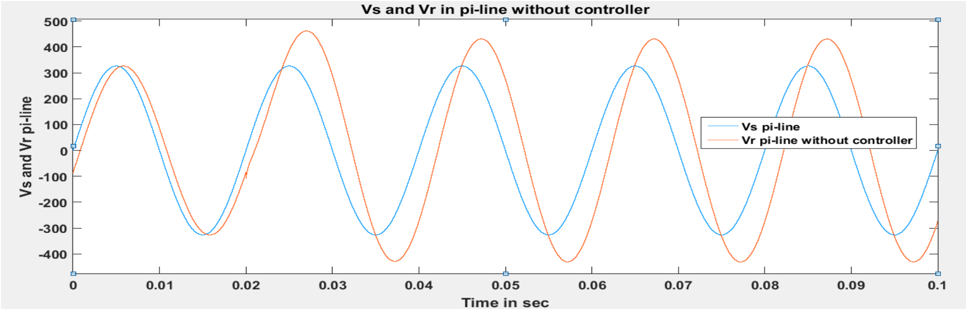

Fig.17. Actual values of Vs and Vr with pi-line and without controller

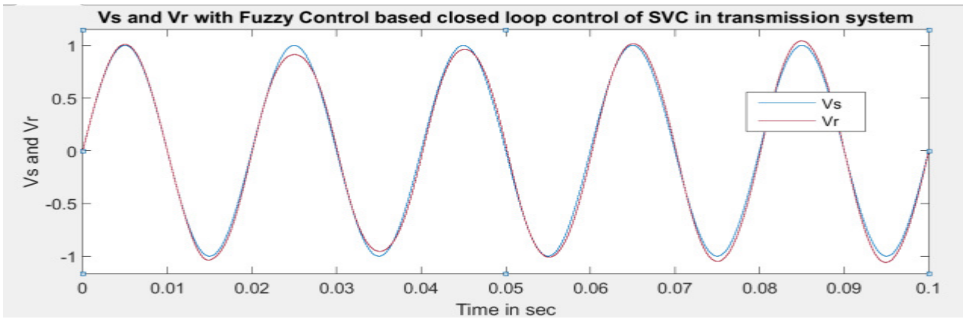

Fig.18. Vs and Vr in with fuzzy controlled SVC for nominal pi-line

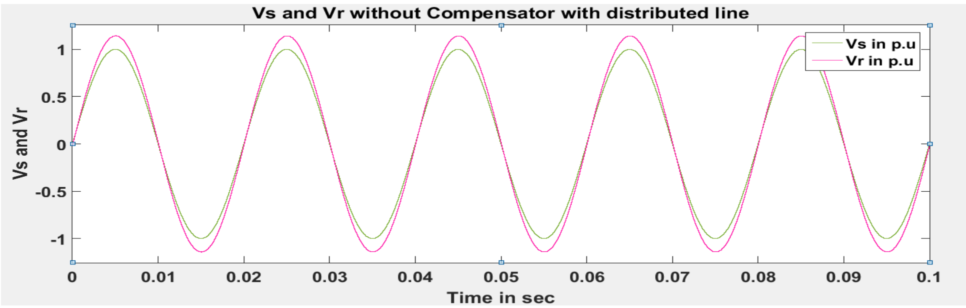

Fig.19. Vs and Vr in without SVC for didtributed line

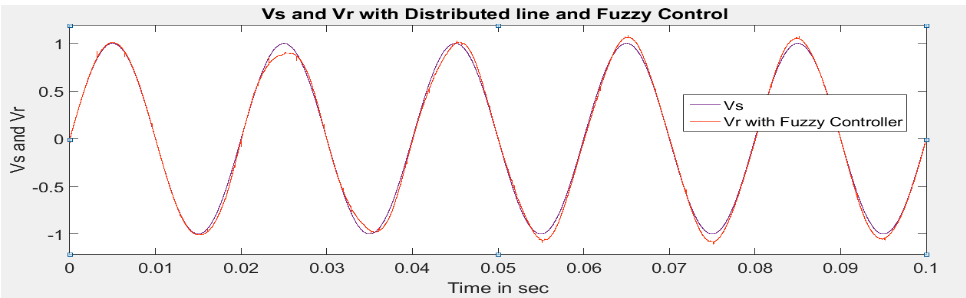

Fig.20. Sending end and receiving end voltages with SVC for didtributed line

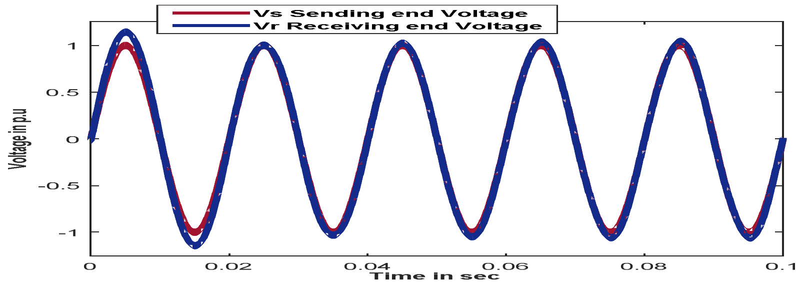

Fig.21. Sending end and receiving end voltages at NL

The Transmission test systems have been developed and simulated for both no load and lightly loaded conditions and the Ferranti effect has been adversely increasing as Fig.22 depictstheFerranti effect with the variation of line length on noload and Fig.23 Illustrates the Ferranti effect with a variation of line length on lightly loading conditions. The closed-loop control systems were developed for both STATCOM and SVC separately and simulated the test system with these controllers and suppressed the Ferranti effect as illustrated by the following figures. Fig. 24 shows the no-load voltages at 400 km line length which illustrates no-load receiving voltages without any controller, with closed-loop control of STATCOM and with closed-loop control of SVC, similarly,Fig. 25 encapsulates the no-load voltages at 500 km line length and Fig. 26 depicts no load voltages at 600 km line length. The subsequent figures illustrate as Fig. 27 shows lightly loaded condition voltages at 400 km line length, Fig. 26 illustrates the lightly loaded condition voltages at 500 km line length and Fig. 28 depicts the lightly loaded condition voltages at 600 km line length respectively and Fig. 29 shows Lightly loaded condition voltages at 600 km line length. All these results prove that both of the shunt-connected FACTS devices such as STATCOM and SVC are quite effective in suppressing the Ferranti effect with closed-loop control mode.

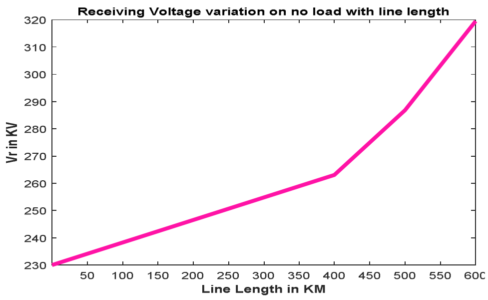

Fig.22 Illustration of ferranti effect with variation of line length on no laod

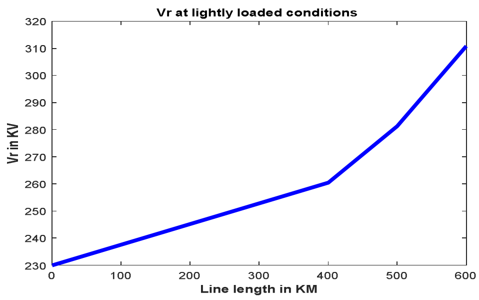

Fig.23 Illustration of ferranti effect with variation of line length on lightly loading conditions

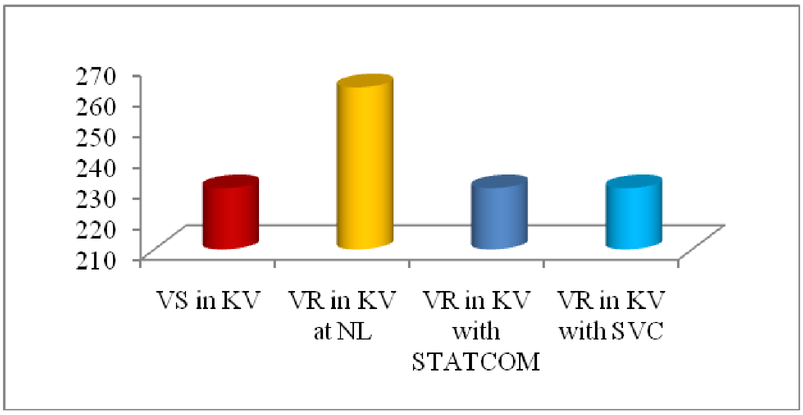

Fig. 24: No load voltages at 400 km line length

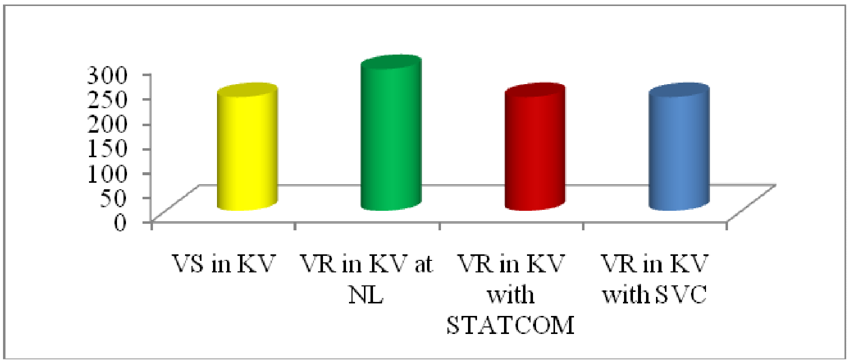

Fig. 25: No load voltages at 500 km line length

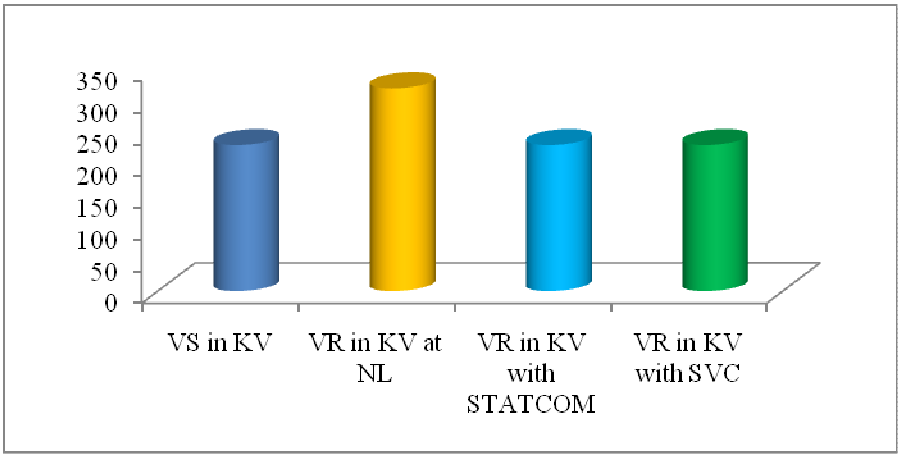

Fig. 26: No load voltages at 600 km line length

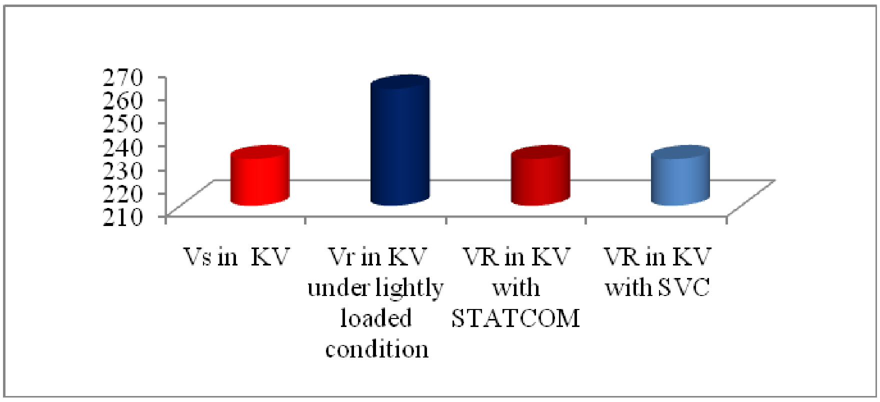

Fig. 27: Lightly loaded condition voltages at 400 km line length

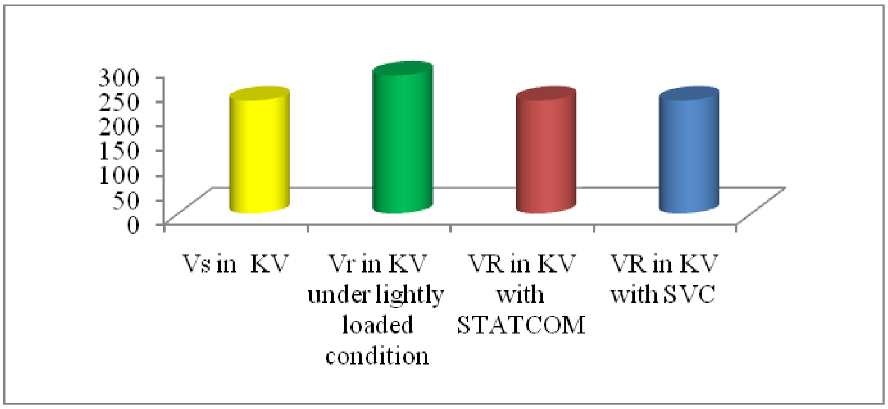

Fig. 28: Lightly loaded condition voltages at 500 km line length

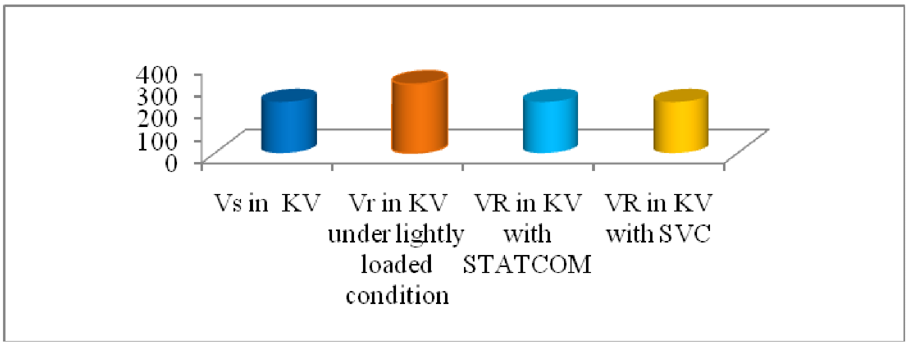

Fig. 29: Lightly loaded condition voltages at 600 km line length

4. Conclusions

The test systems for the case study have been built with medium and long lines. Both models for case1 and case2 have been simulated without and with closed-loop controls of both Static Synchronous Compensator(STATCOM) and Static Var Compensator (SVC) under no-load and lightly loaded conditions. Simulation results without any controller show the adverse effect of the Ferranti effect and closed loop controls of both STATCOM and SVC results prove that these two shunt-type FACTS Controllers are quite effective in controlling receiving end voltage for both no load as well as lightly loaded conditions.

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