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Reactive Power Compensation in Single Phase Distribution System using SVC, STATCOM & UPFC

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Abstract - *Matlab-Simulink Model of a single-phase grid with a Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM) and Unified Power Flow Controller (UPFC) for compensation of reactive power and for maintaining the power factor in the grid close to unity is presented. Facts devices used in transmission and distribution system to improve power transfer capability and enhance power system stability. First the Uncompensated model of single phase distribution system is considered for 25MW and 50MVAR load and the system is analyzed. Then the same model is compensated using Facts devices like SVC, STATCOM and UPFC. In this paper, it is tried to show the application of SVC, STATCOM and UPFC in single phase distribution system for compensation of reactive power. Next the comparative study has been done among SVC, STATCOM and UPFC and tried to figure out which device is best suited and provide optimal compensation to the system. The entire work has been done in MATLAB/SIMULINK environment.*

Key Words*: *FACTS, SVC, STATCOM, UPFC, Reactive Power

1.INTRODUCTION

Power Generation and Transmission is a complex process, requiring the working of many components of the power system in tandem to maximize the output. One of the main components to form a major part is the reactive power in the system. The total power in AC network is calculated as algebraic sum of Active and Reactive power. In which compensation of reactive power improves the quality of power. [1] It is required to maintain the voltage to deliver the active power through the lines. Loads like motor loads and other loads require reactive power for their operation. To improve the performance of ac power systems, we need to manage this reactive power in an efficient way and this is known as reactive power compensation. There are two aspects to the problem of reactive power compensation: load compensation and voltage support. Load compensation consists of improvement in power factor, balancing of real power drawn from the supply, better voltage regulation, etc. of large fluctuating loads. Voltage support consists of reduction of voltage fluctuation at a given terminal of the transmission line. Two types of compensation can be used: series and shunt compensation. These modify the parameters of the system to give enhanced VAR compensation.

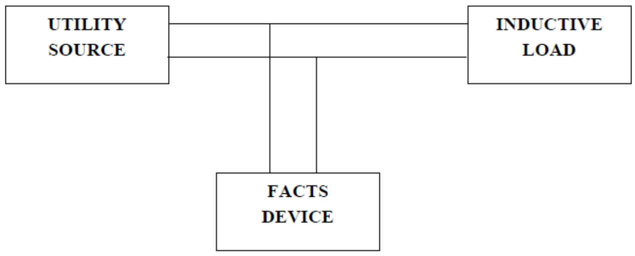

Figure 1: Block Diagram of Reactive Power Compensation Technique

Development of power electronics based devices help to improve transmission loss and increase the power transfer capability of power system. Parameters like voltage, real and reactive power flow can be controlled by using FACTS devices in transmission line. In this paper Static Synchronous Compensator (STATCOM), Static VAR Compensator (SVC) and Unified Power Flow Controller (UPFC) have been used to verify the performance and determine the power transfer quality. [2] Flexible AC Transmission (FACT) devices are static equipments which helps in not only for compensating reactive power but also control one or more AC transmission parameters. Flexible AC Transmission Devices includes Static synchronous compensator, Thyristor switched reactor, Static synchronous series compensator, Thyristor switched capacitor, Thyristor switched series reactor. All these equipment are static instruments, so there is no dynamic effect. Static synchronous compensator (STATCOM) basically includes a DC power capacitor, a converter (may act as rectifier when reactive power is being absorbed and as an inverter when reactive power is being supplied to the transmission system), step up transformer, series inductors etc.

1.1 Static Var Compensator (SVC)

Static var systems are used in transmission line for rapid control of voltage at weak point in a network. [5] Static Var Compensator (SVC) is a power quality device, which employs power electronics to control the reactive power flow of the system where it is connected. As a result, it is able to provide fast-acting reactive power compensation on electrical systems. In other words, static var compensators have their output adjusted to exchange inductive or capacitive current in order to control a power system variable such as the bus voltage.

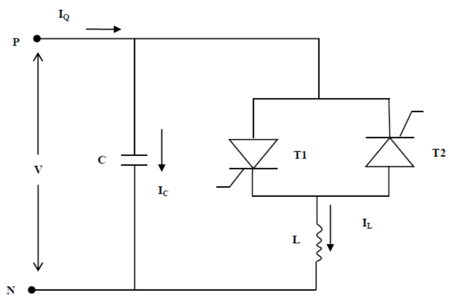

Figure 2: SVC (Static Var Compensator)

The variation of reactive power is accomplished by controlling the thyristor's firing instants and, accordingly, the current that flows by the reactance.

1.2 Static Synchronous Compensator (STATCOM)

STATCOM is a shunt connected Fact device. Its capacitive or inductive output current is controlled independent of the ac system voltage. Fig 3: shows a simple one line diagram of STATTCOM based on a voltage source converter.

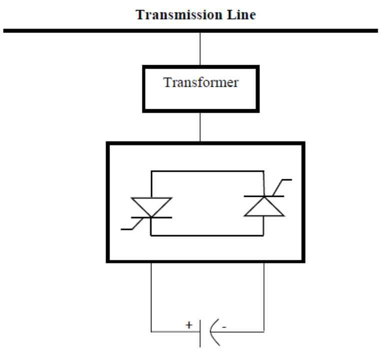

Figure 3: Static Synchronous Compensator (STATCOM)

The voltage converter converts dc voltage to ac voltage by using power electronics devices such as GTO, MOSFET, Thyristors and the ac voltage inserted into the line using transformer. If output of the STATCOM is more than the line voltage, converter will supply lagging reactive power to the transmission line. If line voltage is more than the STATCOM output voltage then STATCOM will absorbs lagging reactive power from the system.

1.3 Unified Power Flow Controller (UPFC)

UPFC is a device which can be used as multifunctional Facts device. UPFC has back-to-back voltage source converters. One is connected in parallel to the line and other is connected in series with the line through transformer as shown in Fig. 4. Both converters are operated from common dc link which is provided by a dc storage capacitor.

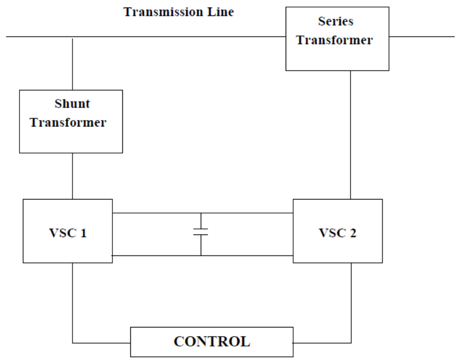

Figure 4: Unified Power Flow Controller (UPFC)

It is an ideal ac-to-ac converter in which real power can flow both sides between ac terminals of the two converters. Independently both converters can absorb or generate reactive power at it ac output terminals. The voltage source converter 1 is supply or absorbs the real power demand by voltage source converter 2 at the common dc link to support the real power exchange resulting from the series voltage injection. The voltage source converter 1 which is connected to transmission line via shunt transformer to fulfill the dc link power demand by voltage source converter 2. The Independent shunt reactive compensation for the line is done by voltage source converter 1, which can also generate or absorb controllable reactive power.

2. OBJECTIVE

The main objective of this paper is to implement facts devices in single phase distribution system for increasing the flow of real and reactive power to the load and improvement in the power factor of the utility end irrespective of the load.

2.1 Description of the system

A basic single phase distribution system (11kV) model has been employed in Matlab/Simulink program to find out the performance of SVC, STATCOM and UPFC in increasing the flow of real and reactive power i.e. compensation of reactive power to the load. The parameters of the basic model used for implementation of single phase distribution system have been given in table 1.

Table 1: System Parameters

Grid	
Voltage	11 kV
Frequency	50 Hz
Source Resistance	0.01Ω
Source Inductance	1mH
Transmission line	
Frequency	50 Hz
R	0.02568 Ω per unit length
L	0.2 mH per unit length
Length	10 kM
R-L Load	
Nominal Voltage	11 kV
Nominal Frequency	50 Hz
Active Power	25 MW
Reactive Power	50 MVAR

3. SIMULATION RESULTS

3.1 Simulink model of the system without compensation

The Simulink model of the single phase distribution system is shown in fig.5.

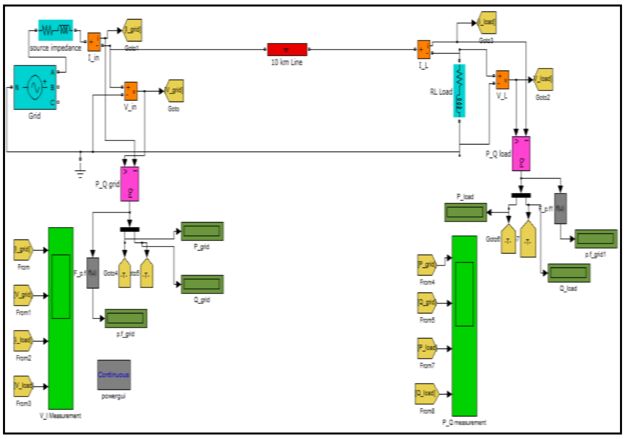

Figure 5: System without compensation

Results obtain after simulation is shown in table 2.

Table 2: Parameters before compensation

	Real Power (P in MW)	Reactive Power (Q in MVAR)	Power factor
Grid	5.055	10.53	0.4327
Load	3.994	7.951	0.448

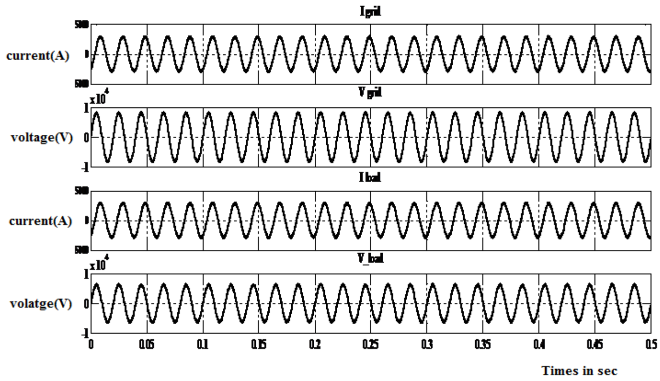

Figure 6: Shows the voltage and current waveform of the grid side and load side before compensation

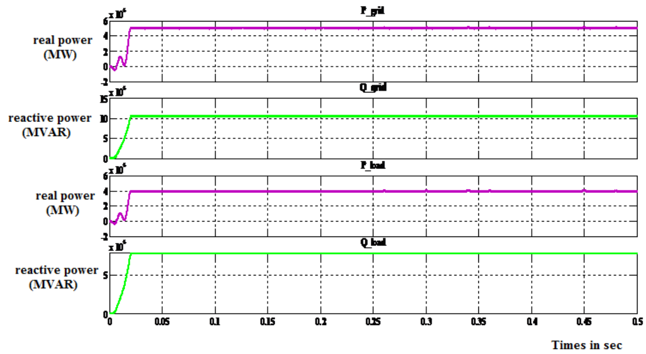

Figure 7: Shows the waveform for the real power and reactive power for the grid side and load side before compensation

3. 2 Simulink Model of the system using Static Var Compensator (SVC)

In this nominal system is compensated for reactive power using SVC (Static Var Compensator). An SVC shown in Fig.8 is modeled with the help of back to back thyristors connected with suitable values of inductor and capacitor. A simple firing angle control strategy is adopted in the system. Pulse generator 1 is fired at 0 degree with 50% pulse width and Pulse generator 2 is fired at 180 degree. The Static Var Compensator is connected in the system at the load end (shown in Fig 9) to compensate the reactive power.

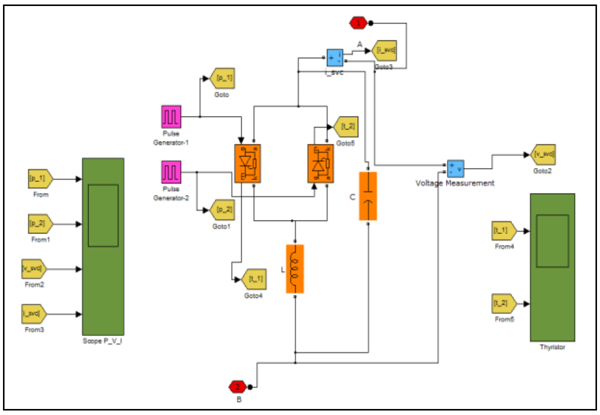

Figure 8: Simulink Model of Static Var Compensator (SVC)

Table 3: Variation of Power Flow with change in value of capacitor

S.N	C(µF)	PGRID (MW)	QGRID (MVAR)	Power Factor (grid)	PLOAD (MW)	QLOAD (MVAR)	Power Factor (load)
1.	100	5.046	10.55	0.4313	3.983	7.965	0.4473
2.	200	5.129	10.05	0.4546	4.153	8.298	0.4475
3.	400	5.325	8.941	0.5117	4.515	9.02	0.4476
4.	600	5.582	7.709	0.5865	4.924	9.837	0.4476
5.	800	5.914	6.33	0.6826	5.387	10.76	0.4476
6.	1000	6.338	4.784	0.7982	5.914	11.82	0.4476
7.	1200	6.882	3.04	0.9147	6.516	13.02	0.4475
8.	1300	7.206	2.085	0.9606	6.85	13.69	0.4475
9.	1400	7.569	1.07	0.9902	7.207	14.4	0.4475

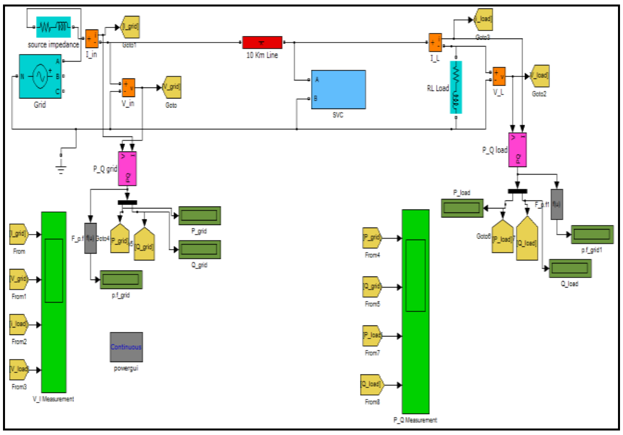

Figure 9: Simulink Model of the system with Static Var Compensator (SVC)

SVC connected in the system will inject reactive power to compensate the reactive power in the system. Results obtain after simulation in shown in table 3 and response of the system is shown in Fig.10 and Fig.11.

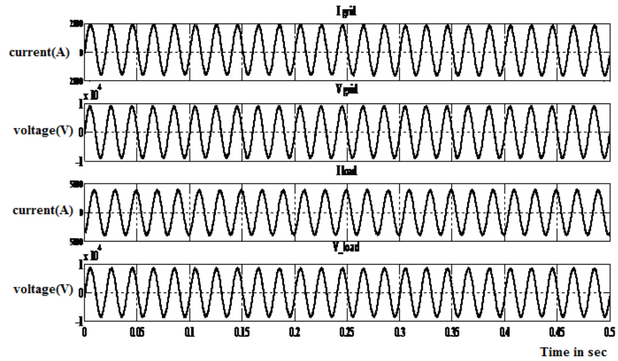

Figure 10: Shows the voltage and current waveform of the grid side and load side when SVC is connected in the system

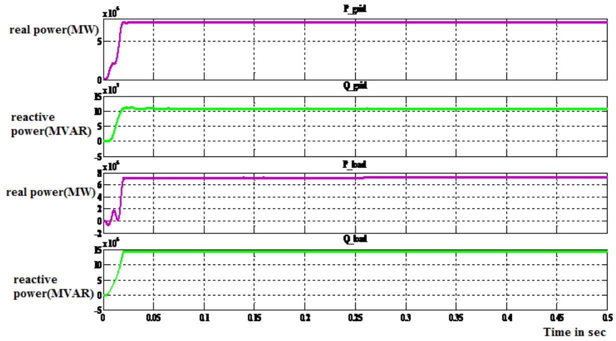

Figure 11: Shows the waveform for the real power and reactive power for the grid side and load side when SVC is connected in the system

3.3 Simulink Model of the system using Static Synchronous Compensator (STATCOM)

Simulink model for STATCOM (Static Synchronous Compensator) is shown in Fig.12. A Matlab/Simulink model of STATCOM is design with help of thyristors and diodes. Thyristors and diodes with pulse generators comprise voltage source convertor which converts dc into ac. A dc voltage is provided by a capacitor which is connected to a voltage source convertor as shown in Fig.12. A harmonic filter is used for reducing harmonics. STATCOM connected system is shown in Fig.13. A firing angle delay technique is employed here for controlling of STATCOM. Pulse generator 1 is fired at 0 degree while Pulse generator 2 is fired after a delay of 180 degree. With the variation of the value of capacitor reactive power compensation is achieved.

Results obtain after simulation is shown in table 4 and response is shown in Fig 14 and Fig 15 respectively.

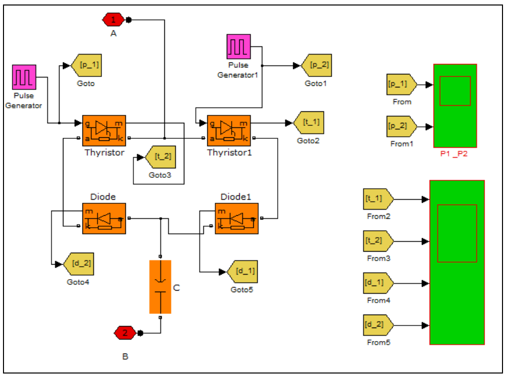

Figure 12: Simulink model of Static Synchronous Compensator (STATCOM)

Table 4: Variation of Power Flow with change in value of capacitor

S.N	C(μF)	P_{GRID} (MW)	Q_{GRID} (MVAR)	Power Factor (grid)	P_{LOAD} (MW)	Q_{LOAD} (MVAR)	Power Factor (load)
1.	5	7.748	0.915	0.9913	7.19	14.47	0.4449
2.	10	7.77	0.855	0.994	7.209	14.52	0.4448
3.	15	7.798	0.7936	0.9949	7.234	14.56	0.4449
4.	20	7.824	0.7312	0.9957	7.263	14.6	0.4453
5.	25	7.852	0.6698	0.9964	7.287	14.65	0.4454
6.	30	7.88	0.6033	0.9971	7.312	14.69	0.4455
7.	35	7.91	0.5369	0.9977	7.339	14.74	0.4457
8.	40	7.94	0.4714	0.9982	7.36	14.79	0.4456
9.	45	7.97	0.4088	0.9987	7.386	14.83	0.4458
10.	50	8	0.3443	0.9991	7.41	14.88	0.4458

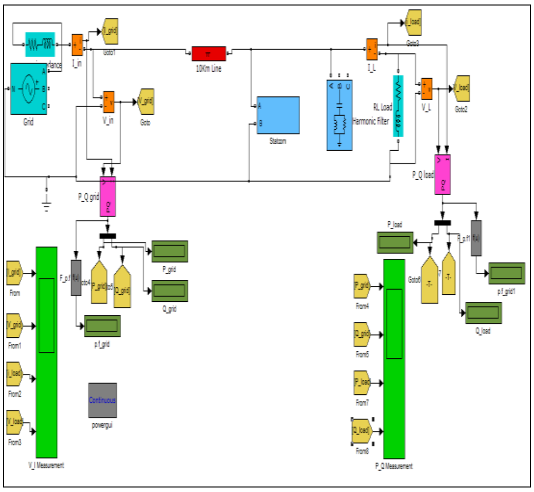

Figure 13: Simulink Model of the system with Static Synchronous Compensator (STATCOM)

As shown in above table, with the increase in capacitance power flow to the load is increasing. Also power factor at supply/grid end is also increasing with the increase in capacitance. Power factor at the supply end is improving because as the value of capacitor is increasing, flow of active power at supply end is increasing while reactive power is reducing. Best compensation is achieved at the value of 50μF. Response of the system voltage, current, active and reactive power flow is shown in Fig.14 and Fig.15 respectively. It should be noted that response shown in Fig.14 and Fig.15 is shown for capacitor value of 50μF i.e. responses are shown for best compensation.

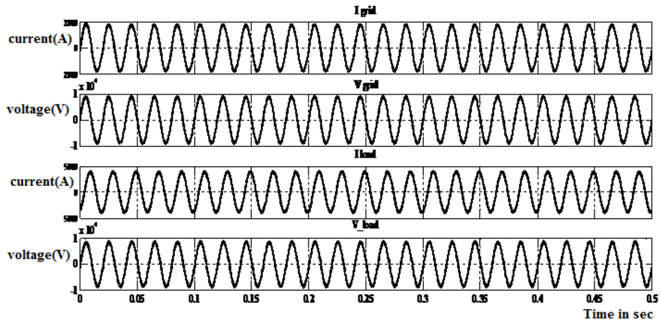

Figure 14: Shows the voltage and current waveform of the grid side and load side when STATCOM is connected in the system

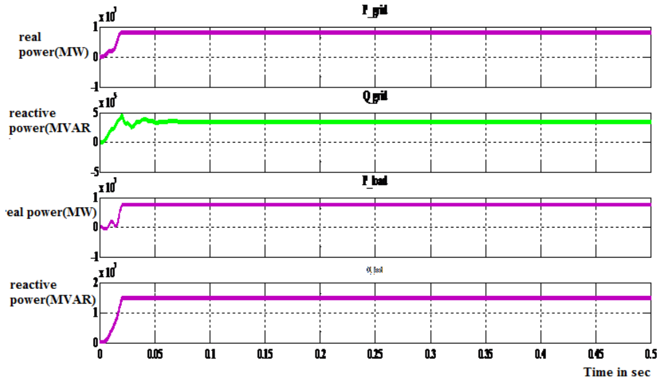

Figure 15: Shows the waveform for the real power and reactive power for the grid side and load side when STATCOM is connected in the system

3.4 Simulink Model of the system using Unified Power Controller (UPFC)

An UPFC model shown in Fig.16 consists of two voltage source convertor connected by a dc capacitor. Each voltage source convertor contains two back to back thyristors followed by a two back to back diodes. Four pulse generators are used for firing thyristors at different instant. Firing angle delay method is used here for controlling the UPFC output. Pulse generator 1 and Pulse generator 3 has phase delay of 0 degree and Pulse generator 2 and Pulse generator 4 has a phase delay of 180 degrees. By changing the value of dc capacitance flow of power is controlled in the system shown in Fig 16.

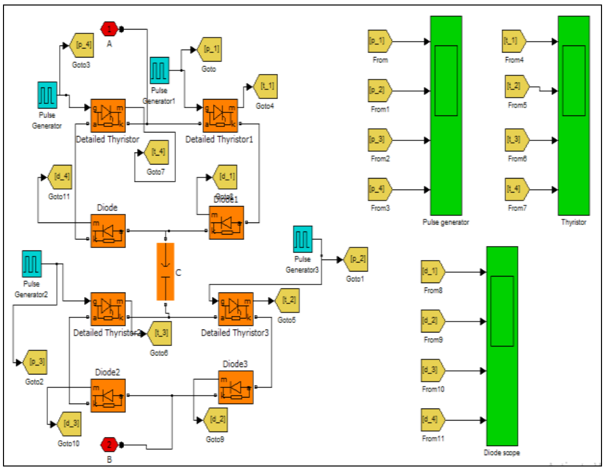

Figure 16: Simulink model of Unified Power Flow Controller (UPFC)

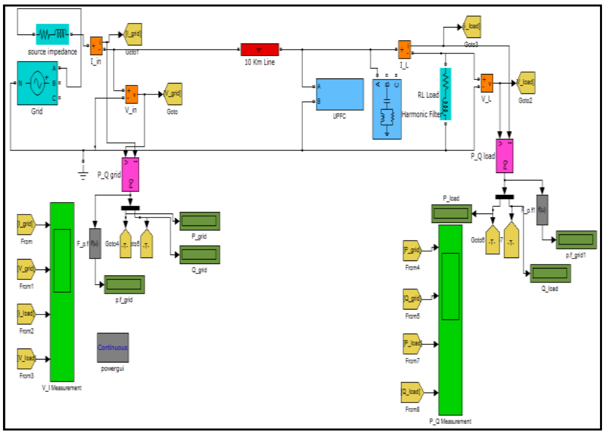

Figure 17: Simulink Model of the system with Unified Power Controller (UPFC)

Table 5: Variation of Power Flow with Change in value of Capacitor

S.N	C(μF)	P_{GRID} (MW)	Q_{GRID} (MVAR)	Power Factor (grid)	P_{LOAD} (MW)	Q_{LOAD} (MVAR)	Power Factor (load)
1.	5	7.744	0.9151	0.9931	7.187	14.47	0.4448
2.	10	7.771	0.8523	0.994	7.221	14.52	0.4453
3.	15	7.797	0.7851	0.995	7.245	14.56	0.4454
4.	20	7.826	0.7219	0.9958	7.274	14.61	0.4457
5.	25	7.846	0.6578	0.9965	7.294	14.66	0.4455
6.	30	7.878	0.5841	0.9973	7.323	14.71	0.4456
7.	35	7.907	0.5119	0.9979	7.354	14.76	0.446
8.	40	7.946	0.4396	0.9985	7.377	14.81	0.4459
9.	45	7.973	0.3676	0.9989	7.405	14.86	0.446
10.	50	8.008	0.2978	0.9993	7.43	14.91	0.446

With the use of UPFC power flow in the system is increased. Results obtain after simulation is shown in table V and response is shown in Fig 18 and Fig 19 respectively.

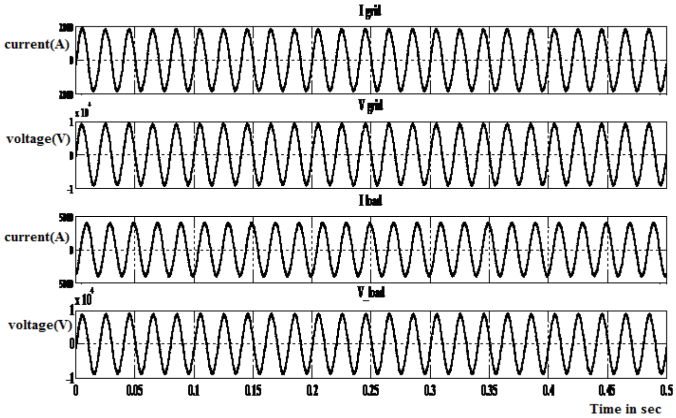

Figure 18: Shows the voltage and current waveform of the grid side and load side when UPFC is connected in the system

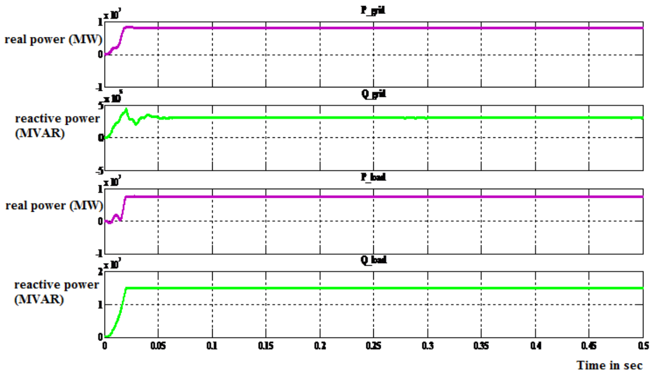

Figure 19: Shows the waveform for the real power and reactive power for the grid side and load side when UPFC is connected in the system

As shown in the table above, with the increase in capacitance power flow to the load is increasing. Also power factor at supply/grid end is also increasing with the increase in capacitance. Power factor at the supply end is improving because as the value of capacitor is increasing, flow of active power at supply end is increasing while reactive power is reducing. Best compensation is achieved at the value of 50μF. Response of the system voltage, current, active and reactive power flow is shown in Fig.18 and Fig.19 respectively. It should be noted that response shown in Fig.18 and Fig.19 is for capacitor value of 50μF i.e. responses are shown for best compensation.

As shown in the table 5, with the increase in capacitance power flow to the load is increasing. Also power factor at supply/grid end is also increasing with the increase in capacitance. Power factor at the supply end is improving because as the value of capacitor is increasing, flow of active power at supply end is increasing while reactive power is reducing. Best compensation is achieved at the value of 50μF.

Response of the system voltage, current, active and reactive power flow is shown in Fig.18 and Fig.19 respectively. It should be noted that response shown in Fig.18 and Fig.19 is for capacitor value of 50μF i.e. responses are shown for best compensation.

3.5 Comparison of Results Obtain Using SVC, STATCOM, UPFC

After comparative analysis as shown in table 5, it is seen that best compensation is achieved with STATCOM and UPFC. Active power flow and reactive power flow is increased to the load in the system at power factor closed to unity at grid side.

Table 6: Shows comparison of results when system is connected with SVC, STATCOM and UPFC

	No compensation		SVC		STATCOM		UPFC	
	Grid	Load	Grid	Load	Grid	Load	Grid	Load
C(μF)	N.A		1400		50		50	
Real Power (MW)	5.055	3.994	7.569	7.207	8	7.41	8.008	7.43
Reactive Power (MVAR)	10.53	7.951	1.07	14.4	0.3443	14.88	0.2978	14.91
Power factor	0.4327	0.448	0.9902	0.4475	0.9991	0.4458	0.9993	0.446

4. CONCLUSION

In nominal system there are transmission losses and power flow to the load is very low. Grid is supplying power to load at very poor power factor (shown in TABLE VI). Also power flow to the load is also poor. Hence Facts devices was needed to increase the power flow to the load at the improved power factor.

When SVC (Static Var Compensator) is connected in the system then grid power factor starts improving as the value of capacitor is increasing. Best compensation is achieved at 1400μF (shown in TABLE VI). Since compensation is achieved at such a high value of capacitor, hence cost of the scheme will increase. This is the drawback of this scheme.
When STATCOM (Static Synchronous Compensator) is connected in the system then grid power factor starts improving as the value of capacitor is increasing. Best compensation is achieved at 50μF (shown in TABLE VI). Compare to SVC, in case of STATCOM power factor is improved up to 0.9991 and power flow is also increased more than compared to SVC (shown in TABLE VI). Since in this case best compensation is achieved at the value of 50μF only, hence this scheme is cost effective also.

When UPFC (Unified Power Flow Controller) is connected in the system then grid power factor starts improving as the value of capacitor is increasing. Best compensation is achieved at 50μF (shown in TABLE VI). Compare to SVC, and STATCOM power factor is improved up to 0.9993 in the case of UPFC. Power flow is also increased more than compared to SVC and slightly more than STATCOM (shown in TABLE VI). Since in this case best compensation is achieved at the value of 50μF only, hence this scheme is cost effective also.

REFERENCES

[1] M.Gerald Geafari Titus, " Reactive Power Compensation using STATCOM for Single Phase Distribution System", in IEEE International Conference on Circuit, Power and Computing Technologies, pp. 1-5, March 2015.

[2] S.Bagchi, R Bhaduri, P N Das and S Banerjee, " Ananlysis of Power Transfer Capability of a Long Transmission Line using FACTS Devices", in IEEE International Conference on Advances in Computing, Communications and Informatics, pp. 601-606, Aug 2015.

[3] Gaurav Tembhunikar, Ajit Chaudhari, Nilesh Wani, Atul Gajare and Pankaj Gajare, " A Review on Reactive Power Compensation Techniques using FACTS Devices", International Journal of Engineering and Management Research, vol 4, no.1, pp. 76-80, Feb. 2014.

[4] Manisha Jaswani, Satyadharma Bharti and S.P Dubey, "A Study of Reactive Power Compensation in Transmission System", International Journal of Advanced Research and Studies, pp.351-353,March 2015.

[5] Dipti Mohanty, Aziz Ahamad and A.Khan, "Modeling, Simulation and Performance Analysis of FACTS Controller in Transmission Line", International Journal of Emerging Technology and Advanced Engineering, vol.3, no.5, pp. 428-435, May.2013.

[6] B.S. Krishna Verma, G. Vineesha, J. Trupti Kumar, K.Sasank and P.Naya Yasasvi, "Simulated Control System Design of a Multilevel STATCOM for Reactive Power Compensation", in IEEE-international Conference On Advances In Engineering, Science And Management, pp. 257-263, March.2012.

[7] S.Selvakumaran and S.M Kalidasan, " Power Quality Improvement in Transmission System using FACTS Devices", in IEEE Online International Conference on Green Engineering and Technologies, pp. 1-4, Nov.2016.

[8] Sreejith.S, Shriram.S.Rangarajan, Ambili.M, Sujyothi.P and Nithya V.G, " Enhancing Power Transfer Capability in a Power System Network using Series Connected FACTS Devices for Increased Renewable Penetration", in IEEE International Conference on Advances in Electrical Engineering, pp. 1-6, Jan. 2014.

[9] Samima Akter, Anulekha Saha and Priyanath Das, " Modeling, Simulation and Comparison of Various FACTS Devices in Power System", International Journal of Engineering Research & Technology (IJERT), vol.1, no.8, Oct. 2012.

[10] P.S Sensarma, K.R. Padiyar and V. Ramanarayanan, "Analysis and Performance Evaluation of a Distribution STATCOM for Compensating Voltage Fluctuations", IEEE Trans. on Power Delivery, vol.16, no.2, pp.259-264, April.2001.

[11] Khaliq Ahmed and C Veeresh , " An Extensive Review on Reactive Power Compensation using STATCOM and SVC", International Journal of Emerging Technology and Advanced Engineering , vol.4, no.11, pp.131-134, Nov. 2014.

[12] Joaoi, Yutaka Ota, Yuji Shitano, Naoto Niimwra and Hirofumi Akagi, "A Phase-Shifted-PWM D-STATCOM Using a Modular Multilevel Cascade Convertor (SSBC)-Part I : Modelling, Analysis and Design of Current Control", IEEE Trans.on Industry Applications, vol.51, no.1, pp. 279-288, Feb.2015.

[13] Jadhav Prajakta S. and A.R Thorat, " Simulation of Sinusoidal Pulse Width Modulation (SPWM) Based DSTATCOM for Compensation of Reactive power", ARPN Journal of Engineering and Applied Sciences,vol.10, no.7,pp.2887-2892, April 2015.

[14] Manisha Rani and Anju Gupta, " Steady State Voltage Stability Enhancement of Power System using FACTS Devices", in IEEE Power India International Conference (PIICON), pp. 1-6, Dec.2014.

[15] Juan Dixon, Luis Moron, Jose Rodriguez and Ricarolo Domke, "Reactive Power Compensation Technologies : State of-the-Art Review", in IEEE Proceedings, vol.93, no.12, pp.2144-2164, Dec. 2005.

[16] R.Mienski, R.Pawelek, I.Wasiak, "Shunt compensation for power quality improvement using a STATCOM Controller; modeling and simulation", in IEE Proceedings-Generation, Transmission and Distribution, vol.151, no.2, pp. 274-280, April 2004.

[17] Dong Shen and P.W. Lehn, "Modeling, Analysis, and Control of a Current Source Inverter-Based STATCOM", IEEE Trans. on Power Delivery, vol.17, no.1, pp.248-153, Jan. 2002.

[18] Timothy J.E Miller, Reactive Power Control in Electric Systems, John Wiley & Sons, 1807-1982.

[19] Farhad Shahnia, Sumedha Rajakaruna and Arindam Ghosh. Static Compensators (STATCOMs) in Power Systems, Springer, 2015.

[20] N. G. Hingorani and L. Gyugyi, Understanding FACTS, New York: IEEE Press, 2000.