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Mechanically coupled to Static Distributed Power Flow Controllers (DPFC)

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Abstract—In last few decades demand of electrical power has increased drastically but overhauling of the whole network can't be done with same pace hence there is need to enhance the power transfer capability of the existing system itself and also various power related mitigations need to be fixed and FACTS devices like SVC, STATCOM, UPFC, TCSC, IPFC and now D-FACTS like D-STATCOM, DPFC are playing a key role. In this paper role of these devices had been studied briefly.

Keywords—FACTS, Power quality issues, role of various FACTS, mitigation of these power quality issues.

I. Introduction

Across the globe demand of energy have increased at very fast pace in last few decades leading to increase of generation by manifold but the bottle neck lies in transmission and distribution system for providing safe, secure and reliable supply. A lot of overhauling and optimisation work has been done in generation, transmission and distribution system but a lot need to be done in transmission system as it is the most critical link between utility and consumers.

II. Need Of Use Of Facts Devices

One of the main issues faced by transmission system is related to reactive power management. For maintaining the stability of the whole system balanced reactive power is very much needed. Till date only capacitor banks are used by various utilities. For solving the issues related to VAR management N. G. Hingorani proposed for FACTS devices in his literature [1]. FACTS devices are designed to overcome the limitations posed by mechanically controlled AC power transmission system. Electronic controllers-based FACTS devices are used for reliable as well as for high-speed switching.

Use of Facts devices provide provides various advantages like greater control of power with secure loading of transmission lines on levels near to their thermal limits; helps in reducing generators reserve margin; prevention of cascading

outages by limiting the effects of faults and equipment failure. It also helped in damping the power system oscillations.

III. Literature Review

Various types of FACTS devices have been suggested by researchers for the optimal operation of transmission system. Many research papers and journals have been published regarding various findings on FACTS devices and their services to grid in a comprehensive manner. Flexible AC Transmission Systems (FACTS) devices provide such technical solutions to address the new operating challenges being faced in transmission and distribution system. FACTS devices, such as a SVC, STATCOM, SSSC, IPFC, TCSC, UPFC and DPFC etc. can be connected in series or shunt in or in different combinations to achieve various control functions, which includes voltage regulation, power flow control, and stability [2]. Use of various FACTS devices and their optimization techniques has been suggested in different literatures.

E. N. Lerch, D. Povh and L. Xu used SVC for increasing the system damping [3]. H. Ambriz-Perez, E. Acha and C. R. Fuerte-Esquivel in his paper presented two models of SVC namely SVC total susceptance model and SVC firing angle model and a Newton-Raphson load flow as well as a Newton's OPF algorithms have been upgraded to incorporate the new SVC models [4].

K. K. Sen presented model for STATCOM in his paper using EMTP simulation package. STATCOM is a solid state voltage source coupled with a transformer. A STATCOM injects sinusoidal current of variable magnitude at the point of connection. The injected current is in quadrature with line voltage thus emulating capacitive as well as inductive reactance at the point of connection [5]. C. Hochgraf and R. H. Lasseter in their research work used STATCOM for maintaining the voltage imbalance [6]. P. Garcia-Gonzalez and A. Garcia-Cerrada in his paper investigated for the possibility of using pulse width modulation (PWM) in high power applications of Static Synchronous Compensators (STATCOMs) [7]. Use of STATCOM ensured decoupled control of the real as well as reactive power exchange between electric energy system and the power converter.

M. Noroozian, N. A. Petersson, B. Thorvaldson, A. B. Nilsson and C. W. Taylor compared various SVC and STATCOM performances apart from a lot of merits there were few demerits too were noted like both SVCs and STATCOMs generate harmonics [8]. The TCR of an SVC is a harmonic current source whereas STATCOM is a harmonic voltage source. Network harmonic voltages distortion occurs as a result of the currents entering the power system. Network voltage harmonic distortion occurs as a result of voltage division between the STATCOM phase impedance and the network impedance.

K. K. Sen in his paper described the theory and modelling technique for a FACTS device, namely, Static Synchronous Series Compensator (SSSC) using an Electromagnetic Transient Program (EMTP) simulation package [9]. The SSSC which is a solid-state VSI (voltage source inverter) coupled with a transformer and connected in series with a transmission line. SSSC injects sinusoidal voltage, maybe of variable magnitude, in series with a transmission line. This injected voltage which is in quadrature with line current and hence emulating capacitive as well as inductive reactance in series with the transmission line. M. S. El-Moursi and A. M. Sharaf in their paper investigated dynamic operation of novel control scheme for both STATCOM and SSSC based on decoupled current control strategy and evaluated their performance by connecting in 230 kV grid and validated with help of digital simulation [10].

N. Yang, Q. Liu and J. D. McCalley proposed model of thyristor controlled series compensator (TCSC) to modulate the impedance of transmission system by damping interarea oscillations and thus increasing the transfer capacity [11]. C. A. Canizares and Z. T. Faur presented detailed steady state models having control of SVCs as well as TCSCs for studying the effect on voltage collapse in transmission system [12]. Application of proposed model and techniques were used on an European system for illustration. A. D. Del Rosso, C. A. Canizares and V. M. Dona addressed various control aspects for using TCSC for enhancing the system steady state as well as dynamic stability and the model was illustrated on the Argentinian high voltage interconnected system [13].

L. Gyugyi et.al. presented a new approach for power transmission control with a new model named Unified Power Flow Controller (UPFC) [14]. UPFC was able to control both transmitted real power as well as reactive power flows at both ends i.e. sending and receiving end. A. Nabavi-Niaki and M. R. Iravani showed in their work that UPFC is used for transient stability enhancement, system's oscillations mitigation, loop flow control, power flow control, reactive power voltage regulation and load sharing in between various parallel corridors [15]. C. D. Schauder et al. worked on the operation of the unified power flow controller (UPFC) under practical constraints [16]. As per the author UPFC offers major potential advantages for both static and dynamic operations of power transmission lines but pose major changes in form of complexity of the model. Later on UPFC is being used for mitigating numerous power transmission system issues like harmonic oscillations damping, balancing the power profile imbalance, power system reliability enhancement [17- 21].

R. Natesan and G. Radman studied the effects of STATCOM, SSSC and UPFC for voltage stability in the transmission line and it was found that these controllers significantly improved the voltage profile and therefore the loadability margin of systems [22]. M. A. Kamarposhti et.al. compared various FACTS devices like SVC, STATCOM, TCSC, and UPFC for Static Voltage Stability evaluation using continuation power flow method [23]. All the experiments were carried out for 14 bus system on PSAT simulation software for voltage stability studies and by changing the placing of different FACTS following results were observed.

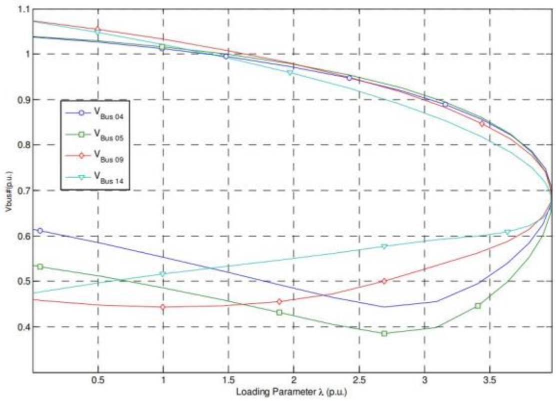

Fig 1: PV curves for 14-bus test system without FACTS.

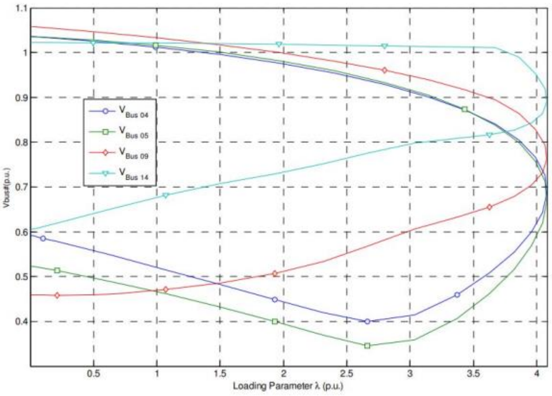

Fig 2: PV curves for 14-bus test system with SVC at bus 14.

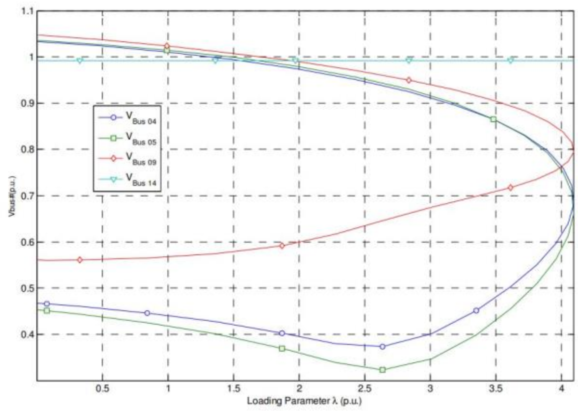

Fig 3: PV curves for 14-bus test system with STATCOM at bus 14.

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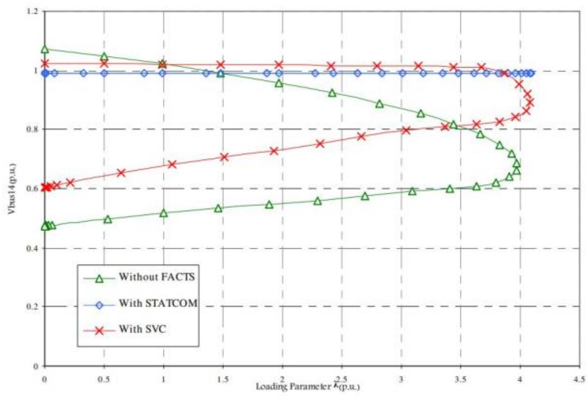
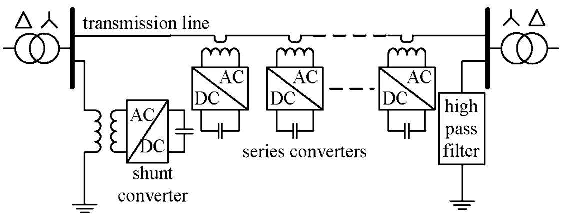


Fig 4: Voltage profile for bus 14 with and without SVC & STATCOM at bus 14.

Observation of the research was that Voltage magnitudes except at load buses 4, 5 were found lower in case of SVC. When STATCOM was introduced reactive power at bus 14, due to which voltage profile improved in its vicinity. Voltage magnitudes at load bus no. 4, 5 and 7 of the system was found lower in case of UPFC as of TCSC but magnitude of voltage at load buses 4, 7, 11, 9, 10, 11 and 14 of the system was found better in case of UPFC as in comparison with STATCOM. Reactive power capacity of UPFC has been found higher as compared to that of SVC, STATCOM and TCSC.



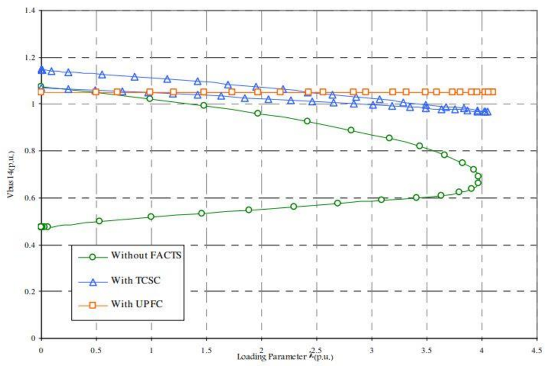


Fig 5: Voltage profile for bus 14 with and without TCSC & UPFC at line 13-14.

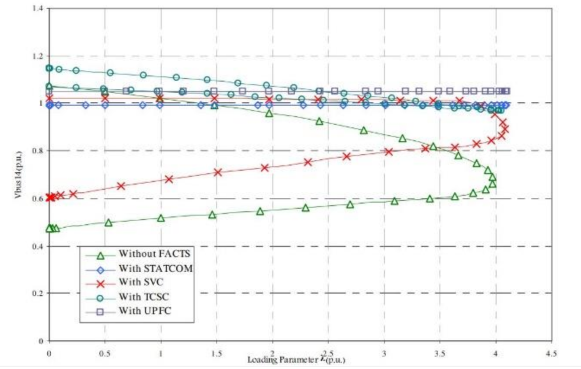


Fig 6: PV curves of base case and system with SVC and STATCOM at bus 14, TCSC and UPFC at line 1-5.

A new component was proposed in FACTS family named DPFC i.e. Distributed Power flow controller which was actually derived from the concept of Unified power flow controller (UPFC). Till this time UPFC was being considered as most powerful FACTS device for controlling various parameters of power system like bus voltage, transmission angle, line impedance and reactive power. DPFC was also able to control all the above-mentioned parameters. UPFC is a combination of series and shunt converters in which series converter is used for injecting a four-quadrant voltage with controllable phase as well as magnitude. Voltage of DC capacitor is controlled by shunt connected converter by generating or absorbing reactive power from bus. Thus shunt converter is also helpful in reactive power management. In UPFC both these shunt and series converters are connected with help of a common dc link. In case of any disturbance in any part would lead to disturbance to whole device, hence for increasing the reliability, bypass circuits and redundant backup components are needed which increases the cost of overall device [24-26]. Fig. 7. Depicts the simplified representation of UPFC

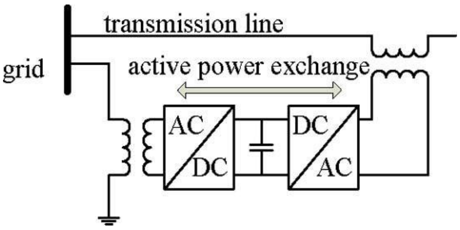


Fig.7. UPFC

To overcome this issue of UPFC, concept of DPFC was evolved in which the common dc link is removed and a single large size converter was replaced by a number of small sized converters. Evolution of DPFC from UPFC can be shown by following flow chart: -

Fig. 8. Flowchart depicting evolution of DPFC from UPFC.

Whereas after removing the common dc link and distributing the converters, DPFC can be depicted by following circuit: -

Fig. 9. DPFC

Thus, DPFC consists of one shunt converter and various series connected converters. Shunt converters act like a STATCOM whereas series converters act on the concept of D-FACTS. In DPFC transmission line works as the common link between shunt and series converters.

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IV. Observations

Use of different FACTS devices has allowed the enhancement of various parameters of power transmission line and thus optimizing the use of available infrastructure. Different FACTS helps in mitigating different problems which had been listed in following tables.

Table 1 Summary of role of different FACTS devices in power quality improvements.

Reference	FACTS device	Result
[27]	SSSC	Enhanced both transient and dynamic stability of EHV lines
[28]	SVC and TCSC	Both devices helped in improving the power limit, loading capability and the system stability.
[29]	UPQC	Compensated power quality issues related to voltage as well as current.
[30]	SVC and STATCOM	Improvement of the transient voltage behavior of power system network.
[31]	D-STATCOM	D-STATCOM compensates the power quality issues like voltage swell and sag.
[32]	Switched Capacitor Compensator (SCC)	Effective in voltage stabilization, power factor correction as well as for improvement of the power quality and in limiting inrush current conditions.
[33]	VSC, STATCOM and SSSC	Validated for voltage stabilization, reactive power compensation and power flow control.
[34]	SSSC	Improving voltage regulation and damping out of oscillations.
[35]	D-STATCOM	If D-STATCOM and SVC both are provided on a particular bus the D-STATCOM provides better economic support than SVC.
[36]	D-SSSC	Reduced the short circuit current

V. Conclusion

It is true that FACTS devices have helped in mitigating various issues related to Power transmission system and have removed various bottleneck issues and hence improvising the output of available system but future of FACTS now lies in D-FACTS so that reactive power compensation can be done in distributed manner in respect of concentrated manner as like in case of UPFC, STATCOM, TCSC etc.

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