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Investigation of Power Flow Effect of Serial and Parallel FACTS Devices

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Abstract

One of the main challenge of the future in the utility sector is constructing the new transmission line corridor. This is due to the fact that land compensation cost related to a new transmission line corridor expansion becomes very expensive. In addition to that, the high carbon emission related to the additional conventional energy based power generation to meet dramatically increased electricity demand and the volatility nature of the existing transmission networks are some of the main drivers to implement FACTS controller in transmission network for flexible, reliable, efficient and stable power transmission. In this paper a comprehensive modeling of STATCOM and UPFC FACTS controllers for improving the transmission line capacity and voltage profile of the power system are studied. The two FACTS controllers are modeled for an IEEE 5-bus power system separately using Newton Raphson load flow algorithm in PSAT to investigate their impacts on power flow (transmission line capacity and voltage profile) result. As a result of the power flow studies performed with and without FACTS controller, it was observed that the FACTS controllers increased the capacity of the existing transmission line, improving the voltage profile of the system and highly affects the power flow of the IEEE 5-bus power system network.

Keywords: FACTS controller; PSAT; STATCOM; Transmission line capacity; UPFC; Voltage profile

Introduction

The most interesting thing for transmission planners is that FACTS technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded, transmission lines. The possibility of controlling current and power flow through a line at a reasonable cost enables a large potential of increasing the capacity of existing lines with larger conductors, and use of one of the FACTS device under normal and contingency conditions [1].

These opportunities arise through the ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle, active and reactive power flow. By providing added flexibility, FACTS controllers can enable a line to carry power closer to its thermal rating [2,3].

The most common FACTS controllers used in power system application are: static VAR compensator (SVC), static synchronous compensator (STATCOM), unified power flow controller (UPFC), thyristor controlled series compensator (TCSC), interline power flow controller (IPFC), generalized unified power flow controller (GUPFC) and etc.

Materials and Methods

Unified power flow controller (UPFC)

The Unified Power Flow Controller (UPFC) is a typical shunt-series FACTS device that is the most sophisticated and complex power electronic controller and has emerged for the control and optimization of power flow and also to regulate the voltage in power transmission network. The UPFC controls three interrelated power system parameters simultaneously; the active and reactive power flow and the bus bar voltage.

All decedents underwent a full autopsy examination consisting of removal and examination of all organs of the thorax, abdomen, pelvis, and cranial vault, as well as assessment of soft tissue and bone by both visual inspection and by postmortem computed tomography. Included in this assessment was swabbing of the nasopharynx and lungs for viral and bacterial studies [4].

As per 45 CFR 46, decedents are not considered human subjects and are not subject to Institutional Review Board oversight **(Figure 1)**.

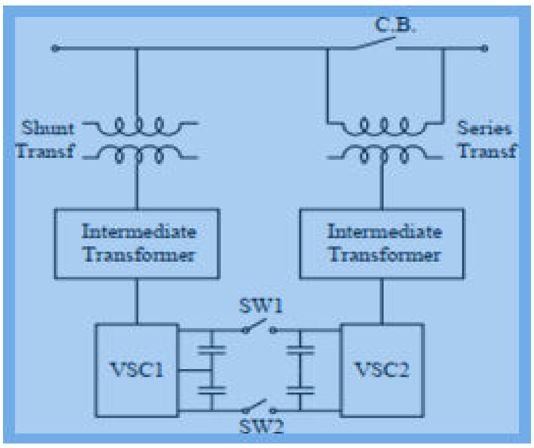

Figure 1: A UPFC Schematic

Static compensator (STATCOM)

The STATCOM represents the GTO-based version of the SVC and it consists of a Voltage Sourced Converter (VSC) behind a coupling transformer The VSC generates a balanced set of sinusoidal voltages of controllable magnitude and phase angle sourced from capacitor bank or energy storage system (ESS). For load flow calculations the STATCOM can be described as follows:

The STATCOM can provide both, inductive and capacitive VARs to control its output current over the rated maximum capacitive or inductive range, independent of the AC System voltage **(Figure 2)** [5].

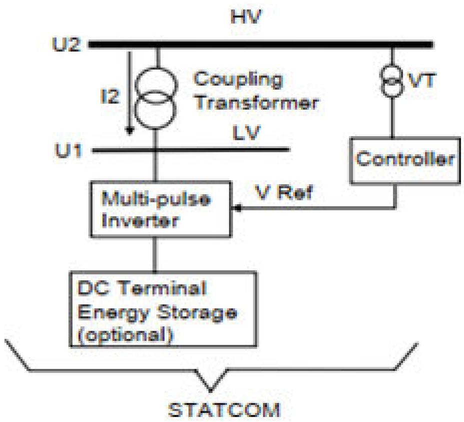

Figure 2: STATCOM Circuit representation

In the linear control range the functional capability of STATCOM is analogous to that of the SVC. Operation at the limits is however different: The SVC becomes an uncontrolled shunt reactance for which the current falls in proportion to the voltage whereas the STATCOM at full output behaves like a current source **(Figure 3)**.

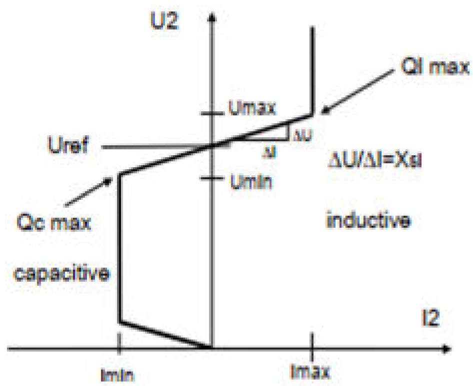

Figure 3: STATCOM V-I Characteristic Curve.

Steady state load flow

The power network consists of synchronous generators and loads interconnected through. The net active and reactive power injected at the PV and load buses are specified but the calculated value of P and Q are determined using: transmission lines (impedances). The entire system is modeled as a set of nodes (buses) interconnected (generators) injecting complex powers and/or (loads) absorbing complex powers may be connected. The generators produce complex powers that flow through the transmission lines for consumption by the loads. A small fraction of the complex power produced by the generators is also absorbed by the transmission lines as line losses (real loss) and reactive drops in the lines.

The Newton Raphson load flow analysis technique is the most efficient load flow analysis technique of large power system including FACTS devices due to its fast convergence and low storage requirement. The load flow solution using Newton Raphson technique is based on Taylor series expansion approach and the Jacobean matrix.The iterative values of the voltage phase angle, ⍰ is computed for n-1 buses (for both PV and load buses) whereas the magnitude of the bus bar voltage is computed for the n-m buses (load bus) for a n-bus power system network containing m- generators where bus one is slack bus, m-1 buses are PV buses and n-m buses are load buses [6-8].

The deviation of the voltage and phase angle are calculated using the inverse of the matrix in and its updated value of V and ⍰ at every (p+1) iteration is calculated using equation

INR load flow model of FACTS

The complexities of software codes, load flow. The Jacobean matrix elements J1, J2, J3 and J4 are calculated using equation. Equation and Jacobean matrix are increased manifold when FACTS are modeled in an existing Newton-Raphson power flow algorithm. In FACTS controllers, there are one or more representative voltage sources for the shunt and series converters. Contributions from these voltage sources necessitate modifications in the existing power flow equations for the sending end (SE) and receiving end (RE) buses of the line incorporating the FACTS controller [9].

UPFC power flow model

For proper utilization of the UPFC in power system planning, operation, and control, a power flow solution of the network incorporating UPFC is a fundamental requirement. An n-bus power system network in which a UPFC is connected between buses i and j of the network.

The UPFC is connected in series at the sending end (SE) of the transmission line represented using two voltage sources, Vse and Vsh.

STATCOM power flow model

For maximum utilization of STATCOMs in power system planning, operation, and control, power flow solution of the network containing them is a fundamental requirement. In previous research works, it is observed that the voltage source(s) representing the shunt converter of the STATCOM contribute new terms to the expressions for the power injections at the concerned buses, the real power of the STATCOM(s), and the associated **(Table 1)**. The expression for the real power delivered by any STATCOM connected at bus. The NR load flow model of an n-bus power system network incorporating STATCOM is expressed using equation. Jacobean blocks. These new terms increase the complexity of the NR load flow model of STATCOM. Vbus is the magnitude of the sending end bus bar voltage where the STATCOM is connected. If m numbers of STATCOMs are connected at the m buses, the deviation of the voltage error for each consecutive iteration accounting the STATCOM [9-11].

Implemented system

The IEEE-5 bus power system implemented using the most power full power system analysis software tool; PSAT Simulink model was used for system simulation. The base values of the system were set at 100 MVA and 100 KV to incorporate the simulation of the system with and without FACTS controller **(Table 2)**.

Bus	Bus type	V [pu]	Phase [deg.]	Pgi [pu]	Qgi [pu]	Pdi [pu]	Qdi [pu]
1	slack	1.06	0	0	0	0	0
2	PV	1	0	0.4	0	0.2	0.1
3	PQ	1	0	0	0	0.45	0.15
4	PQ	1	0	0	0	0.4	0.05
5	PQ	1	0	0	0	0.6	0.1

Table 1: Bus, Load and Generator Data.

From Bus	To Bus	R [pu]	X [pu]	B [pu]
1	2	0.02	0.06	0.06
1	3	0.08	0.24	0.05
2	3	0.06	0.18	0.04
2	4	0.06	0.18	0.04
2	5	0.04	0.12	0.03
3	4	0.01	0.03	0.02
4	5	0.08	0.24	0.05

Table 2: Transmission Line Data.

Simulation result

Simulation result without facts

The voltage profile and transmission line active and reactive power flow of the IEEE_5 bus power system based on Newton Raphson load flow model simulated in PSAT.

Simulation result with STATCOM

STATCOM is connected at bus 3 in order to keep the bus voltage at 1.0 p.u. From the simulation result we can observe that, the STATCOM injects 20.47 MVAR reactive power to the network at bus 3 to push the voltage from 0.987 p.u to unity. A DG unit must be connected at the bus where the STATCOM is connected in order to effectively utilize the STATCOM and initialize its operation.

Simulation result with UPFC

The UPFC is connected at the sending end of bus 3 through the line L23 and L34 (the line connected bus 2 &3, and bus 3 & 4). The UPFC compensates the series impedance of the line to effectively control the active and reactive power flow through the branches and independently controls the voltage at the buses also. The simulation result dictates the UPFC boosts the capacity of the transmission line 2_3 and 3_4 good enough. It was observed from the power flow simulation results presented.

5.7 with 25%, 50% and 75% series compensation that UPFC produced 24.3 MVAR, 25.1 MVAR and 26.1 MVAR respectively of reactive power to keep the voltage regulation at 1 p.u at the connected bus and to improve also the transmission line capacity. Since the UPFC is placed between the load buses (bus_3) and bus_4 having the lowest impedance (R=0.01 p.u and X=0.03 p.u), the UPFC improves the line capacity a maximum of 10.5% without violating the thermal constraints as shown in. The active power loss in the branch connecting bus_3 and 4 is reduced to 0 MW by the incorporation of the UPFC. The results showed that the use of UPFC in the 5 bus IEEE power system could improve the voltage profile and the power transferable capacity of the transmission line. At 100% series compensation of the UPFC the system blackout happen due to the power transfer capability of the line violating its thermal limit. It was observed from the power flow simulation results presented in with 25%, 50% and 75% series compensation the UPFC improve the voltage profile almost close to unity in the network. In addition to that the UPFC also provide a relief to the generating units by supplying sufficient reactive power for the efficient operation of the IEEE 5_bus power system network. When the percentage of series compensation increase, the voltage profile; power transfer capacity of the transmission line and the relief of the generating unit is proportionally improved. Since the UPFC is placed between the load bus (bus_3) and generator bus (bus_2), it controls the power flow in the network effectively. It improves the line capacity by 21%, 50% and 96% of the connected branch with 25%, 50% and 75% series compensation of the UPFC. Due to thermal constraints of the transmission line, 50% series compensation enhances the power transfer capacity by 50%, so the UPFC should be tuned at 50% series compensation in order to operate the system without violating the thermal limit as shown. The active power loss in the branch connecting bus_3 and 2 is reduced to 0 MW by the incorporation of the UPFC. The results shows that the use of UPFC in the 5 bus IEEE power system is improving the voltage profile and the power transferable capacity of the transmission line.

Results and Discussion

The simulation results were presented here one with respect to the other FACTS technology to asses which technology is more effective in voltage control and which one is also more attractive in line capacity improvement. The voltage profile, active power flow and active power losses of the IEEE 5_bus system without FACTS devices, with STATCOM at bus_3, and with UPFC at line 3_2 and line 3_4 connected from bus_3 side are presented graphically to visualize their impacts on the system [12,13].

As we have seen from both UPFC and STATCOM are effectively control the voltage as their respective buses, refer bus_3 in the graph and also boosts the voltage profiles of the other buses in the network. As most of the power is flow through line 1_2 because of the slack bus generator at bus_1 and its lower line impedance as compared with line 1_3. We have seen that, the UPFC controller enhances the line capacity connected with that branch by reducing the power loss through the corresponding branch but the transmission line parameter (impedance) is a big matter during compensation. The transmission network power loss is also greatly reduced [13-15].

Conclusion

As we have seen from the simulation result, UPFC is the best line capacity enhancer and loss absorber, whereas STATCOM is a better voltage regulator FACTS controller. Overall the simulation result shows, FACTS controllers are improving the capacity of the transmission line, the controllability of power system parameters, and effectively controlling the system voltage magnitude and phase angle.

References

1. Hingorani NG, Gyugyi L, Hawary MEL (2000) Understanding FACTS: Concepts and technology of flexible ac transmission systems. IEEE press.
2. Varma V, Kumar P (2017) Load flow analysis in IEEE 14 Bus system using facts device in MATLAB. IJSART 3.
3. Padiyar KR (2007) FACTS controllers in power transmission and distribution. New Age International (P) Limited.
4. Miller TJ (1982) Reactive Power Control in Electric Systems. John Wiley.
5. Olwegard A (1981) Improvement of transmission capacity by thyristor controlled reactive power. IEEE Trans 100: 3930-3939.
6. Mathur RM (1984) Static compensators for reactive power control. Canadian Electrical Association. Cantext Publications.
7. Padiyar KR, Varma RK (1990) Concepts of static var system control for enhancing power transfer in long transmission lines. Electric Machines and Power Systems.
8. Brien MO, Ledwich G (1987) Static Reactive Power Compensator Controls for Improved System Stability. IEEE Proc.
9. Hammad AE (1986) Analysis of power system stability enhancement by static var compensators. IEEE Trans PWRS-1: 222-227.
10. Zhang XP (1996) Fast three phase load flow method IEEE transaction on power systems. 11.
11. Glover JD, Sarma MS, Overbye TJ (2007) Power System: Analysis and design, Fourth Ed. Thomson Learning, India.
12. Bergen AR, Vittal V (2004) Power Systems Analysis, Pearson Education.
13. Grainger JJ, Stevenson WD (1994) Power systems analysis. Tata Mc GrawHill.
14. Pai MA (2006) Computer techniques in power systems analysis. Tata Mc GrawHill.
15. Arabi S, Kundur P (1996) A versatile FACTS device model for power flow and stability simulations, IEEE transactions on power systems. 11: 1944-1950.