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Anju Gupta

YMCA university of Science & Technology, Faridabad, Haryana (India), anjugupta112@gmail.com

P. R. SHARMA

YMCA university of Science & Technology, Faridabad, Haryana (India), prsharma1966@gmail.com

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OPTIMAL PLACEMENT OF FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEM (FACTS) DEVICES FOR STATIC VOLTAGE STABILITY ENHANCEMENT

ANJU GUPTA¹ & P. R. SHARMA²

^{1,2}Department of Electrical and Electronics Engg., YMCA university of Science & Technology, Faridabad, Haryana (India).
anjugupta112@gmail.com; prsharma1966@gmail.com

Abstract: This Voltage stability problems increasing day by day because of demand increase. It is very important to analyze the power system with respect to voltage stability. Location of FACTS devices is important for the enhancement of voltage stability. This paper investigates the voltage stability analysis of 14 bus systems by optimally locating Flexible AC Transmission System (FACTS) devices. Shunt and series FACTS controllers are introduced in the weakest bus and its effectiveness is assessed by comparing voltage profile and loading margins enhancement. It is shown that best location for static voltage stability margin is the “weakest bus” of the system. Continuation power flow (CPF) is done with PSAT (power system stability analysis Toolbox).

Keywords: CPF, FACTS, PSAT.FACTS

1. INTRODUCTION

In planning and operating today's stressed power systems, the ability to maintain voltage stability has become a growing concern. Voltage stability is the ability of a electrical power system to maintain acceptable voltages at all buses of system being subjected to disturbance from a given initial operating conditions. The expansion of the conventional power system allows for indices where unexpected contingencies to go unconsidered. It is important to maintain the stability, security and efficiency of power systems. Due to disturbances in the system, the power consumed by loads tends to be restored and this increases the stress on the high voltage network by increasing power consumption beyond the capacity of transmission network for power transfer and voltage support lead to most common form of voltage instability. The voltage drop of some buses may lead to voltage collapse. The major reasons of voltage collapse are based on increasing loads, line disturbance and line outage.

A number of methods for voltage stability analysis have been suggested such as P-V curve, V-Q curve, and Modal analysis. The application of P-V curve is to evaluate the voltage stability of a power system for various loading conditions.

FACTS are new devices emanating from recent innovative technologies that are capable of altering phase angle, voltage at particular points in power systems. Their fast response offers a high potential for power system stability enhancement apart from steady state flow control. Among the FACTS controllers, Static Var Compensator (SVC) provides fast acting dynamic compensation for voltage support during contingency events which would otherwise depress the voltage support for a significant length of

line. SVC also dampens power swings and reduces system losses by optimized reactive power control. Unified Power Flow Controller (UPFC) plays a important role in improving voltage stability compared to SVC and Static Synchronous Compensator (STATCOM). The best location for reactive power compensation for improving steady state voltage stability margin is the weakest bus in the system. The performance of shunt FACTS controller connected to the weakest bus is assessed by comparing voltage profile and steady state stability margin of the system.

2. CONTINUATION POWER FLOW

The conventional power flow has a problem in the Jacobian matrix which becomes singular at the voltage stability limit. This problem can be overcome by using continuation power flow. Figure1 shows the predictor –corrector scheme used in continuation power flow

From the Newton-Raphson, load flow equations can be written as:

$$P_i - \sum_{j=1}^n Y_{ij} V_i V_j \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (1)$$

$$Q_i - \sum_{j=1}^n Y_{ij} V_i V_j \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (2)$$

The new load flow equations consist of load factor(λ) are expressed as:

$$= + \lambda(\quad) \quad (3)$$

$$= + \lambda(\quad) \quad (4)$$

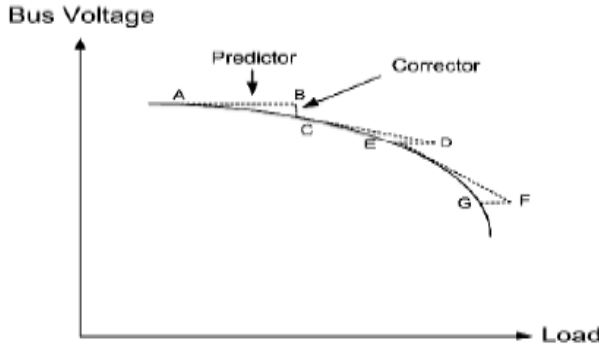


Figure 1: The predictor – corrector scheme
Where

, =original load at bus i, active and reactive power respectively

= multiplier to designate the rate of load change at bus i as λ changes

=a given quantity of apparent power which is chosen to provide appropriate scaling of λ

F(

(5)

Then the active power generation term can be modified to

$$\lambda \quad (6)$$

Where

The initial value of active power generation

=The active power generation at bus i

=the constant of changing rate in generation

To solve the problem, the continuation algorithm starts from a known solution and uses a predictor-corrector scheme to find subsequent solutions at different load levels.

2.1 Modeling of Unified Power Flow Controller (UPFC)

The UPFC consists of two switching converters operated from common DC link. Series converter injects an AC voltage with controllable voltage and phase angle in series with the transmission line. Shunt converter injects or absorbs an independently reactive power to bus. UPFC schematic diagram is shown in figure 2.

The active and reactive power equations can be written as

At bus k

$$P_k = V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] + V_k V_{cr} [G_{km} \cos(\theta_k - \delta_{cr}) + B_{km} \sin(\theta_k - \delta_{cr})] + V_k V_{vr} [G_{vr} \cos(\theta_k - \delta_{vr}) + B_{vr} \sin(\theta_k - \delta_{vr})]$$

$$Q_k = -V_k^2 B_{kk} - V_k V_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] + V_k V_{cr} [G_{km} \sin(\theta_k - \delta_{cr}) - B_{km} \cos(\theta_k - \delta_{cr})] + V_k V_{vr} [G_{vr} \sin(\theta_k - \delta_{vr}) + B_{vr} \cos(\theta_k - \delta_{vr})]$$

At bus m

$$P_m = V_m^2 G_{mm} + V_k V_m [G_{mk} \cos(\theta_m - \theta_k) + B_{mk} \sin(\theta_m - \theta_k)] + V_m V_{cr} [G_{mm} \cos(\theta_m - \delta_{cr}) + B_{mm} \sin(\theta_m - \delta_{cr})]$$

$$Q_m = -V_m^2 B_{mm} + V_k V_m [G_{mk} \sin(\theta_m - \theta_k) - B_{mk} \cos(\theta_m - \theta_k)] + V_m V_{cr} [G_{mm} \sin(\theta_m - \delta_{cr}) - B_{mm} \cos(\theta_m - \delta_{cr})]$$

Series converter

$$P_{cr} = V_{cr}^2 G_{mm} + V_{cr} V_k [G_{km} \cos(\delta_{cr} - \theta_k) + B_{mk} \sin(\delta_{cr} - \theta_k)] + V_m V_{cr} [G_{mm} \cos(\delta_{cr} - \theta_m) + B_{mm} \sin(\delta_{cr} - \theta_m)]$$

$$Q_{cr} = -V_{cr}^2 B_{mm} + V_{cr} V_k [G_{km} \sin(\delta_{cr} - \theta_k) - B_{mk} \cos(\delta_{cr} - \theta_k)] + V_m V_{cr} [G_{mm} \sin(\delta_{cr} - \theta_m) - B_{mm} \cos(\delta_{cr} - \theta_m)]$$

Shunt converter

$$P_{vr} = -V_{vr}^2 G_{vr} + V_{vr} V_k [G_{vr} \cos(\delta_{vr} - \theta_k) + B_{vr} \sin(\delta_{vr} - \theta_k)]$$

$$Q_{vc} = V_{vr}^2 B_{vr} + V_{vr} V_k [G_{vr} \sin(\delta_{vr} - \theta_k) - B_{vr} \cos(\delta_{vr} - \theta_k)]$$

2.2 Modeling of Static Synchronous Compensator (STATCOM)

STATCOM is a self commutated switching power converter supplied from an appropriate energy source and operated to produce a set of adjustable multiphase voltage, which may be coupled to an AC power system for the purpose of exchanging independently real and reactive power. STATCOM schematic diagram is shown in figure 3

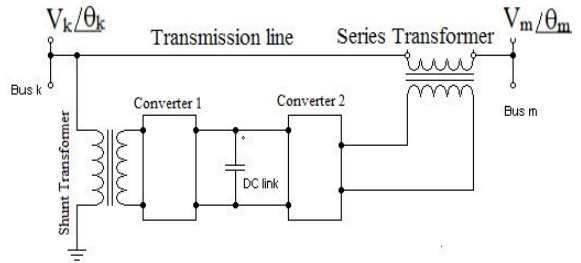


Figure 2

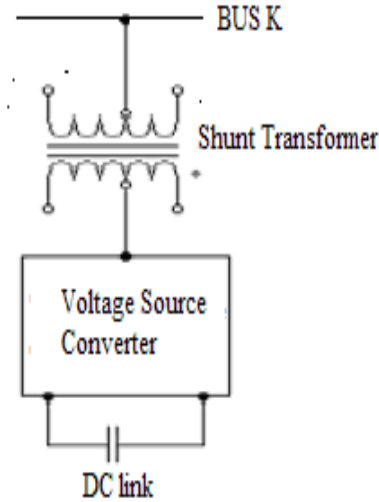


Figure 3

The following active and reactive power equations are obtained for the converter at bus k

$$P_{vr} = V_{vr}^2 G_{vr} + V_{vr} V_k [G_{vr} \cos(\delta_{vr} - \theta_k) + B_{vr} \sin(\delta_{vr} - \theta_k)]$$

$$Q_{vr} = -V_{vr}^2 B_{vr} + V_{vr} V_k [G_{vr} \sin(\delta_{vr} - \theta_k) - B_{vr} \cos(\delta_{vr} - \theta_k)]$$

$$P_k = V_k^2 G_{vr} + V_k V_{vr} [G_{vr} \cos(\theta_k - \delta_{vr}) + B_{vr} \sin(\theta_k - \delta_{vr})]$$

$$Q_k = -V_k^2 B_{vr} + V_k V_{vr} [G_{vr} \sin(\theta_k - \delta_{vr}) - B_{vr} \cos(\theta_k - \delta_{vr})]$$

3. CASE STUDIES

An IEEE 14 bus system is modeled in PSAT software shown in Figure 4.

4. SIMULATION RESULTS

Simulation is done using PSAT software and the results are compared with MATLAB M-file outputs. It was found from PV curve analysis that and bus 14 was the weakest bus for IEEE 14 bus system.

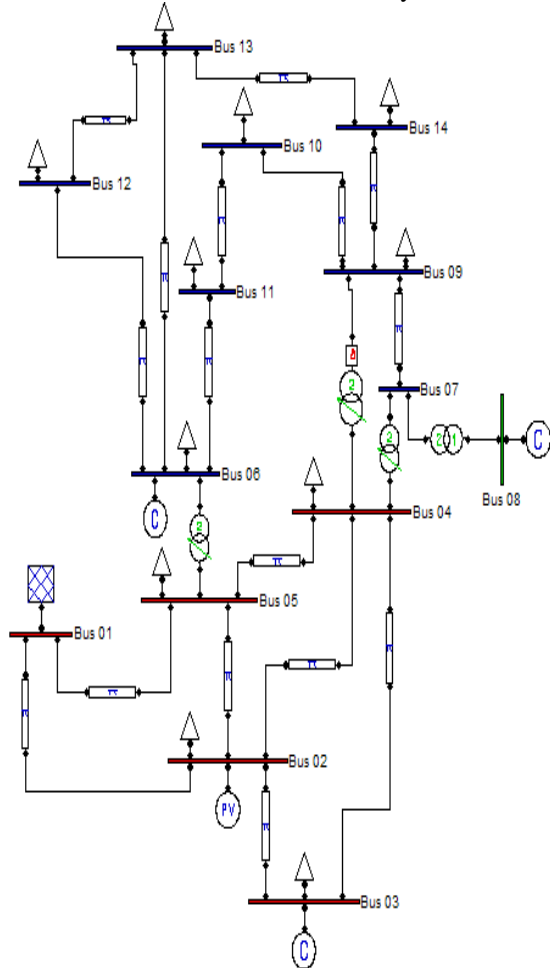


Figure 4 IEEE 14 bus system

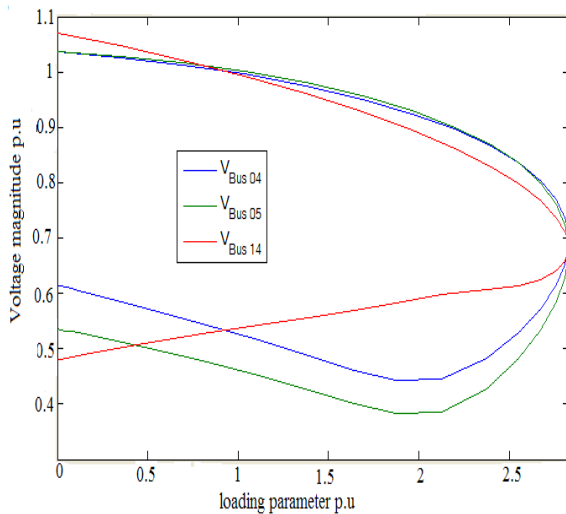


Figure 5. Lowest three voltage P-V curve for IEEE 14 bus system without FACTS

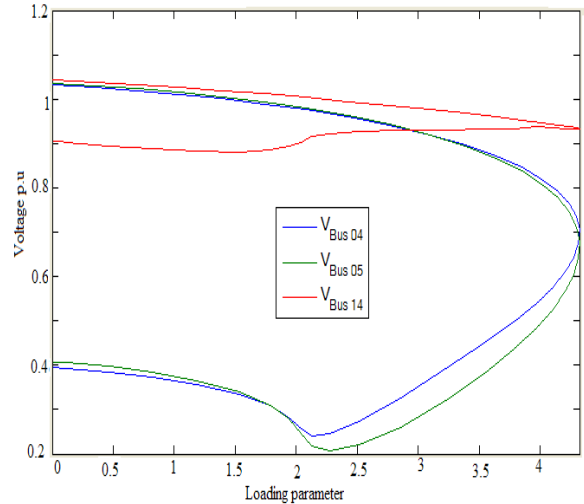


Figure 6 voltages with UPFC at Bus 14

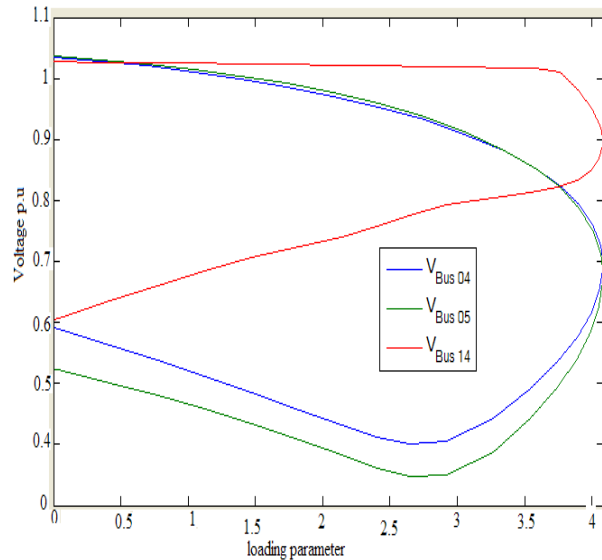


Figure 7 Voltages with STATCOM at Bus 14

UPFC gives better results as compared to SVC and STATCOM. UPFC is connected between 14 and 9 bus and STATCOM is connected at weakest bus 14. Voltage magnitude and angles are shown in Table1 and system losses are shown in Table2 .Voltage magnitude at bus 14 is increased using UPFC as compared to STATCOM. System losses are also get reduced much more with the insertion of UPFC as compared to STATCOM when located at the weakest bus in the system. P-V curves for the voltages with and without FACTS controller are shown in Figure 5, 6 and 7.

5. CONCLUSION

Static voltage stability analysis of IEEE 14 bus system is done. Continuation power flow technique is used identify weakest bus in the system. UPFC and STATCOM are employed and voltage profile of the system is enhanced. The transmission losses are also reduced using UPFC and load ability margin is also increased. Further research will be done on the

optimal location of FACTS devices using Artificial Intelligence like neural and GA.

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Bus No	Voltage magnitude $p.u$ (without FACTS)	Angle (rad) without FACTS	Voltage $p.u$ with UPFC	Angle (rad) with UPFC	Voltage $p.u$ with STATCOM	Angle (rad) with STATCOM
1	1.06	0	1.06	0	1.06	0
2	1.045	-0.135	1.045	-0.087	1.045	-0.354
3	1.01	-0.331	1.01	-0.222	1.01	-0.0331
4	.9977	-0.263	1.0117	-0.178	1.0022	-0.264
5	1.0024	-0.227	1.0159	-0.152	1.0041	-0.227
6	1.07	-0.379	1.07	-0.250	1.07	-0.376
7	1.034	-0.353	1.048	-0.231	1.042	-0.355
8	1.09	-0.353	1.09	-0.231	1.09	-0.355
9	1.011	-0.401	1.046	-0.259	1.027	-0.402
10	1.010	-0.404	1.054	-0.262	1.023	-0.405
11	1.034	-0.395	1.0468	-0.288	1.041	-0.393
12	1.046	-0.401	1.0545	-0.264	1.052	-0.399
13	1.0362	-0.403	1.0498	-0.265	1.047	-0.405
14	.9956	-0.428	1.0282	-0.2767	1.045	-0.444

Table 1. Voltage magnitude and angles of IEEE 14 bus system

Losses	System losses $p.u$ without FACTS	System losses $p.u$ With UPFC	System losses with $p.u$ STATCOM
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