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Placement of FACTS Devices for Voltage Profile Improvement and Loss Reduction

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***Abstract*— Flexible Alternating Current Transmission System (FACTS) devices are solid state converters that have the capability of controlling various electrical parameters such as reactance, power angle and voltage in a power system. Optimal selection and location of FACTS devices play a vital role in improving the static and dynamic performance of the power system. In this paper, the location of FACTS devices has been determined the use of simple methods by utilization of bus voltage responses in an IEEE 14 bus system. The methods used are static and the buses with the lowest voltage magnitudes are the best locations for placing the devices. The methods used are OPF using MATLAB® Matpower Toolbox Version 5.1, CPF via MATLAB®PSAT Toolbox and faulted bus method. The paper further discusses the bus voltage stability enhancement and loss reduction by use of UPFC, SSSC and IPFC FACTS in an IEEE 14 bus system with fault applied at bus 04.**

***Keywords*— MATLAB®PSAT, FACTS, Optimal, placement, PSAT , CPF, Matpower , Reactive and Active Power, Voltage Stability, Transient Stability**

I. INTRODUCTION

Interconnected electrical network comprises of numerous generators, transmission lines, variety of loads and transformers. The term Flexible Alternating Current Transmission System (FACTS) devices or controllers describe a wide range of controllers, many of which incorporate large power electronic converters that can increase the flexibility of power systems making them more controllable and stable. FACTS devices stabilize transmission systems with increased transfer capability and reduced risk of line trips [A. Kumar and S. B. Dubey 2013]. The major problem in power system is upholding steady acceptable system parameters like transients and voltage under normal operating and anomalous conditions, which is usually referred as voltage regulation problem and regaining synchronism after a major fault [C. Makkar and L. Dewan 2010]. This results in system overloading. Overloading may also due to faults, heavy loading, long transmission lines with uncontrolled buses at the receiving end, radial transmission lines, and shortage of local reactive power, intrinsic factors, and small generation reserve margins[A. Satheesh and T. Manigandan 2013] .

This leads to the introduction of FACTS such as Static Var Compensator (SVC), SSSC, STATCOM, UPFC and IPFC [M.Karthik and P.Arul 2013] for system support. In stable power system, the synchronous machines when disturbed, synchronism will either go back to their original state if there is no net change of power or will reach a new state without loss of synchronism. Due to FACTS devices, the power can be flown through the chosen routes with consideration on an increase in transmission line capability and improvement for the security, reliability and economy of the power system. UPFC and IPFC, for instance, are very versatile FACTS controllers. Optimal selection and location of FACTS devices play a vital role in improving the static and dynamic performance of the power system. However, finding the suitable location and selection of FACTS devices simultaneously is a complex and challenging task. There are several Artificial Intelligent (AI) approaches proposed concerning the location and selection of FACTS devices [M. Krishna and P. K. Rao 2012].

Proper placement of FACTS devices enables the transmission system to obtain one or more of the following general benefits [J. Machowski, J. W. Bialek and J. R. Bumby 1997]:

a) Control of power flow. This is the main function of FACTS devices. The use of power flow control may be to meet the utilities' own needs, ensure optimum power flow during contingency conditions.

b) Reduction of generation cost. One of the principal reasons for transmission interconnections is to utilize the lowest cost of generation. When this cannot be achieved, it follows that there is not enough cost-effective transmission and generation capacity.

c) Dynamic stability enhancement. This FACTS peripheral function includes the transient stability improvement, power oscillation damping and voltage stability control.

d) Increase in loading capability of lines to their thermal capabilities both in short term and long term demands.

e) Provide secure tie-line connections to neighbouring and regional utilities thereby decreasing overall generation reserve capacity on both sides.

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II. FACTS DEVICES

The development of FACTS devices started with the growing capabilities of power electronic components. Devices for high power levels have been made available in converters for different voltage levels. The overall starting points are network elements influencing the reactive power the parameters of power system. FACTS devices boost power system operation through their control attributes and injection models [B. Singh et al 2012]. The devices are mainly grouped as:

1. Series controllers such as Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Angle Regulators (TCPAR or TCPST), and Static Synchronous Series Compensator (SSSC)

2. Shunt controllers such as Static Var Compensator (SVC), and Static Synchronous Compensator (STATCOM).

3. Combined series-series controllers and combined series-shunt controllers such as Interline Power Flow Controller (IPFC), Unified Power Flow Controller (UPFC).

III. PLACEMENT OF FACTS DEVICES

a) *Determination Of Location Of Facts Using Optimal Power Flow Via* MATLAB® *Matpower Toolbox*

An electrical power system with improved voltage profile and better reactive power margin can be operated at higher load levels. To obtain voltage profiles an OPF using MATLAB® Matpower Toolbox Version 5.1 computer program. The power flow study is also referred to as the load flow study. The main information obtained from the load flow study consists of magnitudes, phase angles of load bus voltages, reactive power flows on transmission lines [R. D. Zimmerman C. E. Murillo-S_anchez 2015].

The generators real and reactive power is allowed to vary within certain limit.

$$PGi\ (min) < PGi < PGi\ (max) \qquad (1)$$

The operating cost is the important factor of the optimal power flow. The total controllable system production cost will be

$$C_i=(a+bPG_i+cPG_i^2)\$/hr. \qquad (2)$$

Where –

C_i – Total generation cost
a, b, c – cost function coefficients of unit *"i"*
PG_i – is the active power generation of unit *"i"*.

The generators real and reactive power is allowed to vary within certain limit.

$$PGi\ (min) < PGi < PGi\ (max) \qquad (3)$$

Where

The operating cost is the important factor of the optimal power flow. The total controllable system production cost will be:

$$Ci = (a + b\ PGi + c\ PGi2)\ \$s/hr. \qquad (4)$$

Where –

Ci – Total generation cost
a, b, c – cost function coefficients of unit *"i"*
PGi – active power generation of unit *"i"*

System stability is necessary to maintain the voltage at each bus of power system within a permissible limit.

$$V_{imin} < V_i < V_{imax} \qquad (5)$$

Where – *Vimin, Vimax* are the minimum & maximum value of the voltages. OPF solved with Matpower 5.1 on the IEEE 14 bus is used to determine the best location of FACTS by identification of weak buses using voltage profile of the buses [R. D. Zimmerman C. E. Murillo-S_anchez 2015].

b) *Location Of Facts Devices Using Psat CPF*

CPF employs a predictor corrector scheme to find a solution path. It adopts locally parameterized continuation. Local parameterization allows not only the added load parameter, but also the state variables to be used as continuation parameters. Continuation power flow finds successive load flow solutions according to a load scenario. From a known base solution, a tangent predictor is used so as to estimate next solution for a specified pattern of technique as shown in figure 3.1 below. It includes state variable load parameter, and step length for load parameter.

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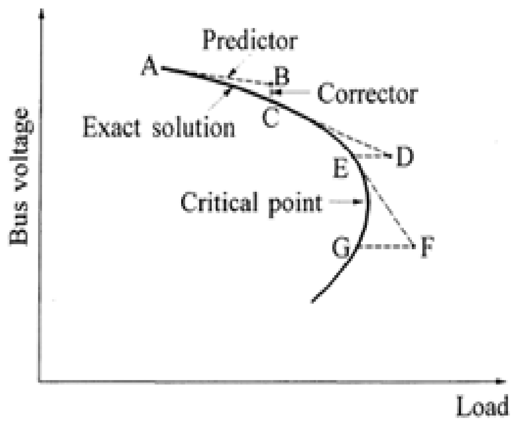

Figure 3.1 CPF Prediction step illustration.

From a known base solution, a tangent predictor is used so as to estimate next solution for a specified pattern of load increase. The corrector step then determines the exact solution using Newton Raphson technique employed by a conventional power flow. After that a new prediction is made for a specified increase in load based upon the new tangent vector. Then corrector step is applied. This process goes on until critical point is reached. The critical point is the point where the tangent vector is zero. Continuation power flow analysis without in IEEE 14 bus system considering load parameter variation is done establish the bus with lowest voltage magnitude. This is the weakest bus and the best location of the FACTS device [F. Milano 2014].

c) Location Of Facts Devices Using Via Faulted Bus

The analysis of power systems under faulted provides information regarding circuit breaker selection, relay setting and the stability of the system operation. It is important to determine the values of system voltages and currents during faulted conditions, so that protective devices may be set to minimize the harmful effects of such contingencies. In this research a three phase fault is applied at Bus 4. The voltage magnate profile of the faulted and the weakest bus is determined. This is optimal location of FACTS device placement is utilized for stability enhancement studies.

IV. Results And Discussion

A. Location Of Facts Using Opf Via MATLAB® *Matpower Toolbox*

The constrained OPF results, corrected to decimal places showed static voltage magnitudes of Bus 04 (0.998 p.u.) and Bus 14(0.996p.u.) as the buses with lowest voltage profiles as shown in the table 3.1 below. It was further observed that Bus 14 was the weakest bus for IEEE 14 bus system.

Table 3.1:
Optimal power flow with Matpower for IEEE 14 bus System

OPTIMAL POWER FLOW RESULTS		
Bus	V[p.u.]	Phase[rad]
Bus 01	1.060	0
Bus 02	1.045	-0.136
Bus 03	1.010	-0.332
Bus 04	0.998	-0.263
Bus 05	1.002	-0.227
Bus 06	1.070	-0.380
Bus 07	1.035	-0.356
Bus 08	1.090	-0.354
Bus 09	1.011	-0.402
Bus 10	1.011	-0.405
Bus 11	1.035	-0.395
Bus 12	1.046	-0.401
Bus 13	1.036	-0.403
Bus 14	0.996	-0.429

B. Location Of Facts Devices Using Psat Version 2.1.9 Continuation Power Flow

Continuation Power Flow simulation was done using PSAT Version 2.1.9 software and the results were obtained as displayed in table 4.3 and figure 4.1. Table 4.3 showed that the buses with lowest voltage magnitudes are 04, 05 and 14 with 0.693p.u, 0.675p.u and 0.681p.u respectively.

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From figure 3.2 it was found out from P-V nose curves for the 14-bus test system that bus 14 was the weakest bus for IEEE 14 bus system. Continuation power flow technique has been used to successfully identify weakest bus in the system. Therefore, the best location for placing FACTS is/or close to Bus 14.

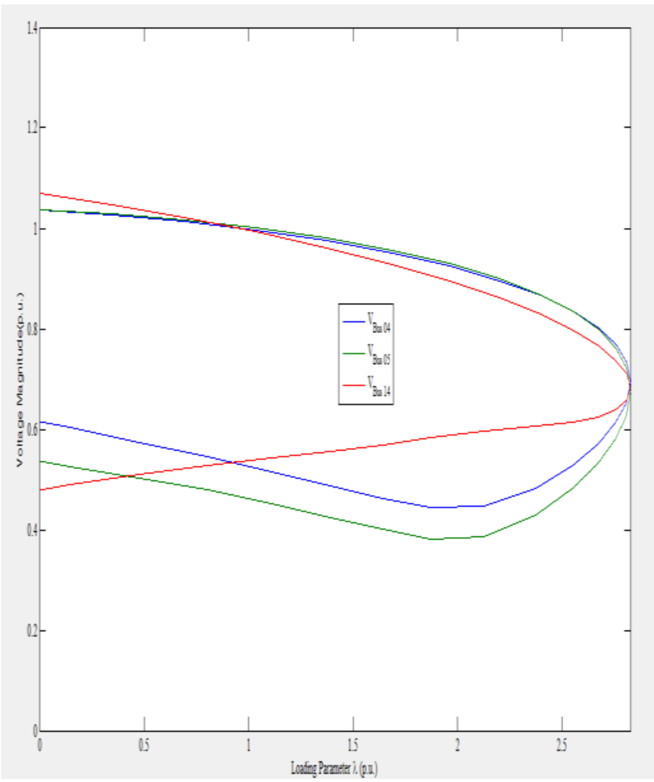

Figure 3.1: Voltage P-V nose curves IEEE 14 bus system

V. Voltage Profile Enhancement With FACTS

Table 3.2:
Continuation power flow with results PSAT Version 2.1.9 for IEEE 14 bus System

POWER FLOW RESULTS (Voltage and Angle)		
Bus	V[p.u.]	Phase[rad]
Bus 01	1.060	0
Bus 02	1.045	-0.657
Bus 03	1.010	-1.529
Bus 04	0.693	-1.260
Bus 05	0.675	-1.077
Bus 06	1.070	-1.894
Bus 07	0.791	-1.678
Bus 08	1.090	-1.679
Bus 09	0.697	-1.897
Bus 10	0.720	-1.931
Bus 11	0.875	-1.919
Bus 12	0.976	-1.963
Bus 13	0.926	-1.965
Bus 14	0.681	-2.069

FACTS controllers: SSSC, IPFC and UPFC significantly enhance voltage stability. It is evident that IPFC provides better voltage support than UPFC and SSSC as shown in table 3.4 and figure 4.46 below. All the three FACTS reduce power losses in power networks with SSSC and UPFC by 0.03 p.u and IPFC by 0.14p.u hence IPFC is best placed for loss reduction applications than the other three FACTS controllers.

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Table 3.4
Voltage Magnitude with fault applied a Bus 04 for SSSC, UPFC and IPFC FACTS

VOLTAGE MAGNITUDE					
Bus No.	Without fault and Device	Fault at Bus 4 Without Device	Fault at Bus 4 With SSSC	Fault at Bus 4 With UFPC	Fault at Bus 4 With IPFC
	[p.u.]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 01	1.062	1.057	1.060	1.060	1.060
Bus 02	1.049	1.045	1.045	1.045	1.045
Bus 03	1.006	1.003	1.010	1.010	1.010
Bus 04	0.978	0.975	0.992	0.992	0.992
Bus 05	0.987	0.984	0.999	0.999	0.999
Bus 06	1.061	1.058	1.070	1.070	1.070
Bus 07	1.022	1.020	1.033	1.033	1.032
Bus 08	1.082	1.080	1.090	1.090	1.090
Bus 09	0.999	0.996	1.010	1.010	1.008
Bus 10	1.000	0.997	1.010	1.010	1.008
Bus 11	1.025	1.022	1.035	1.035	1.034
Bus 12	1.037	1.034	1.046	1.046	1.047
Bus 13	1.027	1.024	1.036	1.036	1.039
Bus 14	0.986	0.983	0.995	0.995	1.005
REAL POWER LOSSES		0.294	0.291	0.291	0.280

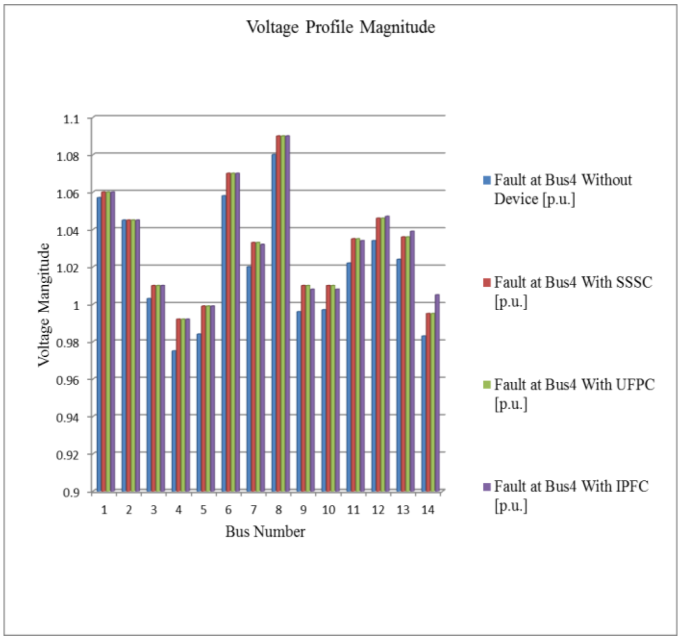

Figure 3.2: Voltage magnitude profiles with and without FACTS controller

VI. Conclusion

Simple techniques have been used to successfully identify weakest bus in the system. Therefore, the best location for placing FACTS is/or close to Bus 14. This is the best location of FACTS for stability studies. The methods used are Optimal Power Flow in MATLAB® Matpower Toolbox Version 5.1 and Continuation Power Flow via MATLAB®PSAT Toolbox. The location of FACTS devices has been effectively determined the use of various methods by observation of bus voltage profiles. The methods used are static and the buses with the lowest voltage magnitudes are the best locations for placing the devices. It's further deduced after placing the FACTS best location that IPFC provides better voltage stability enhancement than UPFC and SSSC. All the three FACTS reduce power losses in poor networks with SSSC and UPFC by 0.03 p.u and IPFC by 0.14p.u hence IPFC is best placed for loss reduction applications than the other two FACTS controllers.

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