REGULATION OF POWERFLOW BY UNIFIED POWER FLOW CONTROLLER

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ABSTRACT- The unified power flow controller (UPFC) is one of the most flexible alternating current transmission systems(FACTS) device in a power network. The UPFC is the shunt series equipment interconnected by DC link, with shunt converter and series converter. The objective of this paper is to use UPFC injection model which can be incorporated in power flow algorithm for power flow control in a powernetwork. The location of UPFC is done by active power loss sensitivity factor(APLSF) and online voltage stability index(OLVSI) in order to increase voltage level and reduce power losses. Programming is carried out in MATLAB to check the performance of UPFC in IEEE 5 bus system. The results of power system network with and without using UPFC are compared in terms of active power flows in the line and also power loss to analyze the performance of UPFC .

KEYWORDS- **injection model, power flow, sensitivity factor, stability index**

INTRODUCTION

With increasing demand of power industry , the existing transmission network in a power system are found to be weak which results in a poor quality of power supply. In order to expand or enhance the power transfer capability of existing transmission network and to overcome serious issues related to power system network like power quality, voltage instability, transmission capability etc concepts of FACTS (Flexible AC transmission system) is developed by the Electric Power Research Institute (EPRI) in the late 1980s. FACTs means alternating current transmissions systems consisting of power electronic based and other static controllers to improve controllability and enhance power transfer capability [1-2]. Facts controllers may be series, shunt or their combination. Shunt controllers inject current into the system and may be variable impedance or variable source or both for ex: Static Synchronous Compensator (STATCOM) , static var compensator (SVC) etc. Series controllers inject voltage in series with the line for ex: Static Synchronous Series Compensator (SSSC), Thyristor controlled Series Capacitor (TCSC), Thyristor switched series Capacitor (TSSC), Thyristor Controlled Series Reactor (TCSR), Thyristor Switched Series Reactor (TSSR). A combination of static synchronous compensator (STATCOM) and static series compensator **(**SSSC) which are coupled via a common dc link to allow bidirectional flow of real power between series o/p terminals of SSSC and shunt o/p terminals of STATCOM is called UPFC (unified Power Flow Controller).

Among different kinds of FACTS devices the UPFC is the most versatile and effective device which was introduced in 1991. The UPFC consist of voltage source converters, one connected in series and other in shunt and both are connected back to back through a D.C capacitor [3-5]. In this paper stability index and sensitivity method is used to find the location of UPFC and injection model of UPFC is incorporated in power flow algorithm in order to observe the control of power flow in transmission systems. Newton Raphson power flow algorithm which is having fast computational speed, high degree of accuracy and good convergence rate is used in this paper.

OPERATING PRINCIPLE OF UPFC

UPFC consists of two back to back AC to DC voltage converters operated from common DC link capacitor as shown in Fig 1. Shunt converter is connected in shunt and second converter i.e, series converter is in series with the transmission line. Shunt converter is mainly used to supply active power demand of series converter via DC link. It can also absorb or generate reactive power, if desired and provides independent shunt reactive compensation for the line. Series converter performs main function of UPFC by injecting an ac voltage with controllable magnitude and phase angle in series with transmission line via a series transformer[6-8]. By inserting a variable ac voltage, the UPFC controls the magnitude and phase angle of transmission line voltage at its series terminal to achieve the desired active and reactive power in the line.

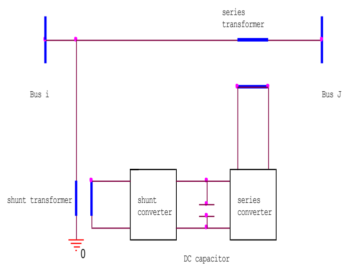

Fig 1: Operating principle of upfc

INJECTION MODEL OF UPFC

With dc link the two voltage source converters of the UPFC are connected and figure 2 shows two ideal voltage sources, one connected in series and the other in shunt between the two buses. The output coming from series voltage source Vseandθse are adjustable of magnitude and phase angle between the limits $V_{semax} \leq V_{se} \leq V_{semin}$and $\theta \leq \theta se \leq 2\pi$respectively and of the shunt voltage source is V_{sh} and θ_{sh}adjustable between $V_{shmax} \leq V_{sh} \leq V_{shmin}$and $\theta \leq \theta sh \leq 2\pi$.

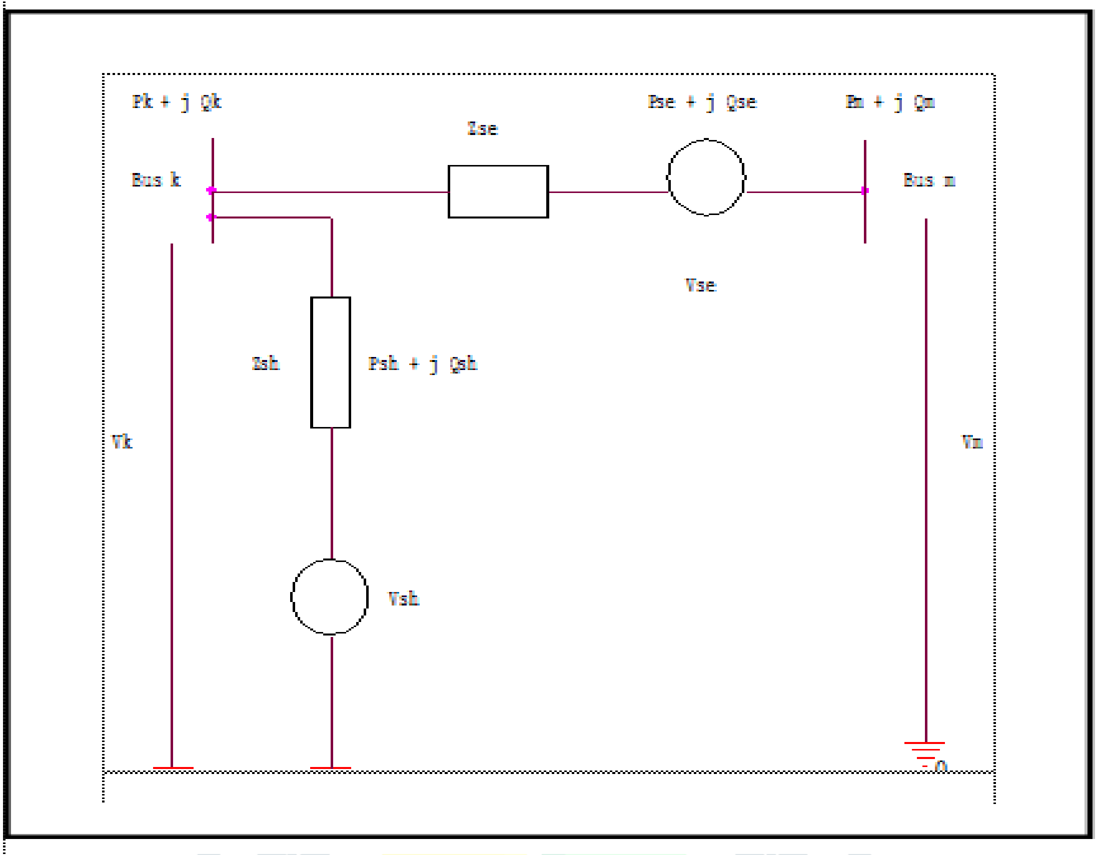

Fig 2:injection model of UPFC

Z_{se} and $Z_{sh}$are theimpedances of the two coupling transformers one connected in series and other in shunt between the line and UPFC

The two ideal voltage sources of the UPFC can be mathematically represented as

$\mathbf{V}_{se}= V_{se}(\cos\theta_{se} + j\sin\theta_{se})$ (1)

$V_{sh}= V_{sh}(\cos\theta_{sh}+ j \sin\theta_{sh})$ (2)

UPFC is connected between two buses *k* and *m* in the power system. Applying the kirchoff's current and voltagelaws for the network in Fig. 2 gives

$I_k= (y_{se}+y_{sh})V_k+ (-y_{se})V_m+ (-y_{se})V_{se}+ (-y_{sh})V_{sh}$

$I_m=(-y_{se})V_k+ (y_{se})V_m+ (y_{se})V_{se}+ (0)V_{sh}$ (3)

Where $y_{se}= 1/z_{se}$and$y_{sh}= 1/z_{sh}$

The element of transfer admittance matrix can be put as

$Y_{kk}= G_{kk}+ jB_{kk}= y_{se}+ y_{sh}$

$Y_{mm}= G_{mm}+ jB_{mm}= y_{se}$

$Y_{km}= Y_{mk}+ G_{km}+ jB_{km}= -y_{se}$ (4)

$Y_{sh}=G_{sh}+ jB_{sh}= -y_{\underline{sh}}$

Lossless UPFC converters are assumed in this model. Then the following equality constraint has to be guaranteed.

$P_{se}+ P_{sh}= 0$ (5)

From Figure 2 and by Eq. (1), (2), (3) for the series and shunt sources the power equations of UPFC can bewritten

At bus k

$P_k = V_k^2 G_{kk} + V_k V_m(G_{km}\cos(\theta k-\theta m) + B_{km}\sin(\theta k-\theta m)) + V_k V_{se}(G_{km}\cos(\theta_k-\theta_{se}) + B_{km}\sin(\theta_k-\theta_{se})) + V_k V_{sh}(G_{sh}\cos(\theta_k-\theta_{sh}) + B_{sh}\sin(\theta_k-\theta_{sh}))$
$Q_k = -V_k^2 B_{kk} + V_k V_m(G_{km}\sin(\theta k-\theta m) - B_{km}\cos(\theta k-\theta m)) + V_k V_{se}(G_{km}\sin(\theta k-\theta se) - B_{km}\cos(\theta k-\theta se)) + V_k V_{sh}(G_{sh}\sin(\theta_k-\theta_{sh}) - B_{sh}\cos(\theta_k-\theta_{sh}))$

At bus m

$P_m = V_m^2 G_{mm} + V_m V_k(G_{mk}\cos(\theta m-\theta k) + B_{mk}\sin(\theta_m-\theta_k)) + V_m V_{se}(G_{mm}\cos(\theta_m-\theta_{se}) + B_{km}\sin(\theta_k-\theta_{se}))$
$Q_m = - V_m^2 B_{mm} + V_m V_k(G_{mk}\sin(\theta_m-\theta_k) - B_{km}\cos(\theta_m-\theta_k)) + V_m V_{se}(G_{mm}\sin(\theta_m-\theta_{se}) - B_{mk}\cos(\theta_m-\theta_{se}))$

Series converter equation is

$P_{se} = V_{se}^2 G_{mm} + V_{se} V_k(G_{km}\cos(\theta_{se}-\theta_k) + B_{km}\sin(\theta_{se}-\theta_k)) + V_{se} V_m(G_{mm}\cos(\theta_{se}-\theta_m) + B_{mm}\sin(\theta_{se}-\theta_m))$(6)
$Q_{se} = - V_{se}^2 G_{mm} + V_{se} V_k(G_{km}\sin(\theta se-\theta k) - B_{km}\cos(\theta_{se}-\theta_k)) + V_{se} V_m(G_{mm}\sin(\theta_{se}-\theta_m) - B_{mm}\cos(\theta_{se}-\theta_m))$

Shunt converter equation is

$P_{sh} = -V_{sh}^2 G_{sh} + V_{sh} V_k(G_{sh}\cos(\theta_{sh}-\theta_k) + B_{sh}\sin(\theta_{sh}-\theta_k))$ (7)
$Q_{sh} = V_{sh}^2 G_{sh} + V_{sh} V_k(G_{sh}\sin(\theta_{sh}-\theta_k) - B_{sh}\cos(\theta_{sh}-\theta_k))$

PLACEMENT OF UPFC

Placement of UPFC can be determined by following sensitivity factor and stability index

Active power loss sensitivity factor is $\frac{\partial P_L}{\partial V_{ij}} = 2 V_i V_j\cos(\delta_i - \delta_j) + 2 V_i V_j\sin(\delta_i - \delta_j)$
V_i ,V_j sending and receiving end voltages respectively
An online voltage stability index in terms of line active power and bus voltage is formulated as
OLVSI= $\frac{(4P_j * R)}{(v_i\cos(\theta-\delta))^2}$
R= transmission line resistance
P_j = receiving end active power
For stable operation it should be less than 1

NR LOAD FLOW METHOD

NR load flow method is fastest and most reliable method when compared to other load flow methods. Load flow algorithm is given below.

1. Read system data and form bus admittance matrix Y_{bus}
2. Assume flat voltage profile for all buses except slack bus
3. set convergence point ε
4. set iteration count k=0 and bus count p=1
5. calculate active power P_i and reactive power Q_i for i= 2,…n with UPFC and shunt and series converter powers.
6. calculate change in active and reactive power for i=2,…n i.e.,ΔP_i and ΔQ_i
7. calculate maximum absolute value of residue i.e., $|\Delta P_i|$ and $|\Delta Q_i|$
8. check if residue ≤ ε then go to step 14 else go to step 9
9. Form conventional jacobian matrix
10. Modify jacobian matrix for incorporating UPFC Parameters
11. solve for Δ|V|, Δδ using load flow equations |
12. Update bus voltages and UPFC output voltages
13. check if voltage magnitude of converter is out of limit then set voltages at limit values and advance iteration count and go to step 5
    else advance iteration count and go to step 5
14. calculate line flows and bus powers and it ends the program.

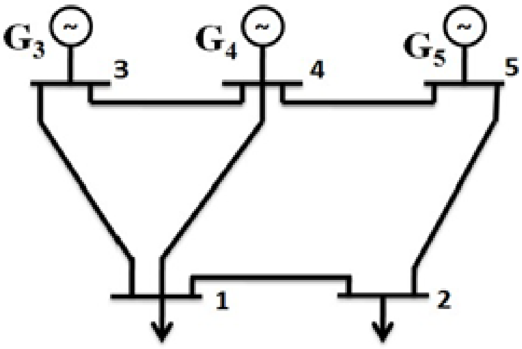

Fig 3: IEEE 5 BUS SYSTEM

Table 1. Bus data

Bus no	Bus type	Voltage(p.u)	Angle(deg)	Gen MW	Gen MVAR	Load MW	Load MVAR	Q_{min} MVAR	Q_{max} MVAR
1	0	1	0	0	0	1500	750	0	0
2	0	1	0	0	0	500	250	0	0
3	2	1.05	0	1000	0	0	0	-750	750
4	2	1.05	0	750	0	0	0	-750	750
5	1	1.05	0	309	0	0	0	-500	500

Table 2. Line data

Line no	Line designation	Resistance p.u	Reactance p.u	Line charging p.u
1	1-2	0.002	0.01	0.002
2	1-3	0.004	0.02	0.004
3	1-4	0.002	0.01	0.002
4	2-5	0.004	0.02	0.004
5	3-4	0.004	0.02	0.004
6	4-5	0.004	0.02	0.004

RESULTS

Sensitivity and stability indices are shown in table 3. Generally facts device is located where OLVSI is high and APLSF is low hence line 2 and 3 are considered as sensitive lines. For NR algorithm maximum power flow is specified as 8.0 p.u on all lines and without facts line 3 is observed to carry 8.97 p.u. Hence facts device is placed in line 3

Table 3.sensitivity and stability indices for each line

Line no	Line designation	OLVSI	APLSF
1	1-2	-0.9878	1.9175
2	1-3	**36.8908**	**0.8622**
3	1-4	**4.4125**	**0.9196**
4	2-5	3.1375	1.9012
5	3-4	1.7818	0.9463
6	4-5	0.9642	2.1607

As shown in table 4 after placing facts device UPFC, voltage at bus 1 is improved to specified value of 1 p.u and in table 5 , real power loss is decreased from 0.23 p.u to 0.1852 p.u and real power is controlled to 8.0 p.u.

Table 4.voltage profile with and without facts device

Bus no	Voltage Without facts device in p.u	Angle without facts device in deg	UPFC(line3) Voltage in p.u	UPFC(line3) Angle in deg
1	0.974	-3.295	1.0000	-4.2204
2	0.974	-3.908	0.9920	-4.4736
3	1.05	4.138	1.05	3.9747
4	1.05	1.139	1.05	1.6096
5	1.05	0	1.05	0.0000

Table 5. Real power flows with and without facts device

Line no	Line designation	Without facts P_{line}	Without facts P_{loss}	UPFC line3 P_{line}	UPFC line3 P_{loss}
1	1-2	0.9634	0.0021	0.5734	0.0016
2	1-3	-6.9911	0.221	-7.5733	0.2302
3	1-4	**-8.9722**	**0.2300**	**-8.0000**	**0.1852**
4	2-5	-4.0386	0.1008	-4.4281	0.0933
5	3-4	2.7874	0.0290	2.1963	0.0181
6	4-5	1.056	0.0041	1.4931	0.0084

CONCLUSION

Injection model of UPFC is used in this paper to investigate the functioning of UPFC in power flow control. The model is incorporated in NR power flow Algorithm for load flow studies. The programming results for the standard 5 bus network has been presented with and without UPFC and compared. It was found that the UPFC is properly located by on line voltage stability index method, Active power loss sensitivity factor and it regulates the active and reactive power of the buses and the lines within specified limits. The algorithm is capable of regulating the power flow in any power system network. Hence UPFC with NR algorithm performed better in a network and programming results demonstrate that the proposed method is successfully used for control of active power, reactive power in a line and in a bus in a power system network.

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