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Research Paper

Implementation of Steady State Modal of UPFC in bus system

Engineering

KEYWORDS : Power Flow, Newton-Raphson based load flow, UPFC, MATLAB, IEEE 14 bus.

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ABSTRACT

Controlling power flow in modern power systems can be made more flexible. The paper presents a reliable method to meet the requirements by developing a Newton-Raphson based load flow calculation through which control settings of UPFC (Unified Power Flow Controller) can be determined for the pre-specified power flow between the lines. A MATLAB program has been developed to calculate the control settings of UPFC and the power flow between the lines after the load flow is converged. Case studies have been performed on IEEE 14-bus system to show that the proposed method is effective.

I. INTRODUCTION

As the power systems are becoming more complex it requires careful design of the new devices for the operation of controlling the power flow in transmission system, which should be flexible enough to adapt to any momentary system conditions. The operation of an ac power transmission line, is generally constrained by limitations of one or more network parameters and operating variables By using FACTS technology such as STATCOM (Static Synchronous Compensator), Thyristor Controlled Series Capacitor (TCSC), UPFC etc., the bus voltages, line impedances, and phase angles in the power system can be regulated rapidly and flexibly. FACTS do not indicate a particular controller but a host of controllers which the system planner can choose based on cost benefit analysis.

The UPFC is an advanced power system device capable of providing simultaneous control of voltage magnitude and active and reactive power flows in an adaptive fashion. Owing to its instantaneous speed of response and unrivalled functionality, it is well placed to solve most issues relating to power flow control in modern power systems.

The UPFC can control voltage, line impedance and phase angles in the power system[9] which will enhance the power transfer capability and also decrease generation cost (and improve the security and stability) of the power system. UPFC can be used for power flow control, loop flow control, load sharing among parallel corridors.

A Load flow problem

In this paper the load flow problems are solved by using N-R method in polar co-ordinate form is an iterative method which approximates the set of linear simultaneous equations using Taylor's series expansion and the terms are limited to first approximation. In the power flow of the transmission line the complex power injected at the ith bus with respect to ground system is

$S_i = P_i + jQ_i$ .... (3.1)

$= V_i\, I_i^*$ .... (3.2)

Where i=1, 2, 3………..n.

Where V_i is the voltage at the i^{th} bus with respect to ground and I_i is the source current injected into the bus.

$P_i + jQ_i = V_i\, I_i^*$ .... (3.3)

Substituting for

$I_i = \sum_{k=1}^{n} Y_{ik} V_k$ .... (3.4)

Equating real and imaginary parts

$P_i = Real\,[V_i^* \sum_{k=1}^{n} Y_{ik} V_k]$ .... (3.5)

$Q_i = -imag\,[V_i^* \sum_{k=1}^{n} Y_{ik} V_k]$ .... (3.6)

$V_i = |V_i| e^{j\delta_i}$ .... (3.7)

$Y_{ik} = |Y_{ik}| e^{j\theta_{ik}}$ .... (3.8)

Real power reactive power can now be expressed as

P_i*(Real power)=*

$|V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i)$; … (3.9)

Q_i *(Reactive power)=*

$|V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k\ \delta_i)$; … (3.10)

i=1, 2, 3, 4……………….n-;i≠slack bus

B UPFC modified Jacobian matrix elements

In power flow the two power injections (Pi, Qi) and (Pj, Qj) of a UPFC can be treated as generators however because they vary with the connected bus bar voltage amplitudes and phases the relevant elements of Jacobin matrix at each iteration.

The formation of Jacobian matrix

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix} H & N \\ J & L\end{bmatrix} \begin{bmatrix}\Delta\delta \\ |\Delta V|\end{bmatrix}$$

Where H, N, J, L are the elements of Jacobian matrix.

$H_{im} = \frac{\partial P_i}{\partial \delta_m}$;

$N_{im} = \frac{\partial P_i}{\partial |V_m|}$;

$J_{im} = \frac{\partial Q_i}{\partial \delta_m}$;

$L_{im} = \frac{\partial Q_i}{\partial |V_m|}$;

The elements of Jacobian matrix can be calculated as follows

case1:

m≠i

$H_{im} = L_{im} = a_m f_i - b_m e_i$;

$N_{im} = -J_{im} = a_m e_i - b_m f_i$;

Where

$Y_{im} = G_{im} + jB_{im}$;

$V_i = e_i - jf_i$;

$(a_m + jb_m) = (G_{im} + jB_{im}) * (e_i - jf_i)$;

Case 2:

m=i

$H_{ii} = -Q_i - B_{ii}|V_i|^2$;

$N_{ii} = P_i + G_{ii}|V_i|^2$;

$J_{ii} = P_i - G_{ii}|V_i|^2$;

$L_{ii} = Q_i - B_{ii}|V_i|^2$

C Optimal power flow Algorithm:

In this paper Optimal power flow algorithm is adopted as it offers a number of advantages that is to detect the distance

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between the desired operating point and the closest unfeasible point. Thus it provides a measure of degree of controllability and it can provide computational efficiency with out destroying the advantages of the conventional power flow when used error feedback adjustment to implement UPFC model. The proposed model and algorithm as follows.

1. Assume bus voltage V_p except at slack bus i.e. p=1, 2, 3……….n; p $\neq$ s Where n is the number of buses.
2. Form Y-bus matrix.
3. Set iteration count k=0.
4. Set the convergence criterion, $\in$
5. Calculate the real and reactive power P_p and Q_p at each bus where p=1, 2, 3…….n; p $\neq$ s.
6. Evaluate $\Delta P_p = P_{spe} - P_p$ and $\Delta Q_p = Q_{sps} - Q_p$ at each bus where p=1, 2, 3…….n; p $\neq$ s.
7. Compare each and every residue with $\in$ and if all of them are $\leq \in$ then go to step 13.
8. Calculate the elements of Jacobian matrix.
9. Calculate increments in phase angles and voltages.
10. Calculate new bus voltages and respective phase angles $V_p^{k+1} = V_p^k + \Delta V_p^k$ and $\theta_p^{k+1} = \theta_p^k + \Delta\theta_p^k$ where p=1, 2, 3…….n; p $\neq$ s.
11. Replace V_p^k by V_p^{k+1} and θ_p^k by θ_p^{k+1} where p=1, 2, 3…….n; p $\neq$ s.
12. Set k=k+1 and go to step 5.
13. Print the final values of voltage magnitudes and corresponding phase angles.

III UPFC IMPLEMENTATION IN POWER FLOW STUDIES

The Implementation of UPFC models in power flow is essentially a controlled power flow problem. The UPFC modeling needs the change of relevant elements of Jacobian matrix however the user defined power flow software do not allow users to directly modify the Jacobian matrix and only provide the facilities for the iteration between the main program and user defined model. This iteration some times diverges especially when the system is heavily loaded.

A Control Strategies of UPFC

In this section the UPFC represented by two voltage sources of series path and shunt path is often transformed in to a pair of power injections (Pi, Qi), (Pj, Qj) at both sides of UPFC locations in order to be incorporated into power flow algorithm. From the view point of effects of these power injections on the system Qi can be independently regulated to support bus bar voltage connected at the shunt path Pi and Pj are used to manipulate line active power with equal magnitude but at reverse direction and Qj can control both j bus bar voltage and line reactive power based on this analysis the philosophy of the UPFC local control strategy is described.

After modifying all the UPFC connected branches, the load flow equations can be written as follows

$$P_i + jQ_i = V_i^* \sum_{k=1}^{n} Y_{ik} V_k \qquad i \neq l, m$$

$$P_l + jQ_l = V_l^* \sum_{k=1}^{n} Y_{lk} V_k + (P_{lm} + jQ_{lm})$$

$$P_m + jQ_m = V_m^* \sum_{k=1}^{n} Y_{mk} V_k + (P_c + jQ_c)$$

With the above modifications the load flow studies should be done, after convergence the control settings of UPFC can be determined as follows .

1. Use Qi to control bus voltage Vi
2. Use Pi and Pj to control the line power.
3. Set Qj= 0 (i.e. better to use Qi to control Vi since it is closer to the bus).
4. The feedback information of power injections (Pi, Qi) (Pj, Qj) derived from the above closed-loop controllers is then converted into UPFC control parameters.

IV CASE STUDY AND CONCLUSION

A Case Study

In order to investigate the feasibility of the proposed technique, a large number of power systems of different sizes and under different system conditions has been tested. It should be pointed out that the results are under so-called normal power flow, i.e. the control parameters of UPFC are given and UPFC is operated in an closed -loop form. All the results indicate good convergence and high accuracy achieved by the proposed method. In this section, the IEEE 14-bus system have been presented to numerically demonstrate its performance. It have been used to show quantitatively, how the UPFC performs. The original network is modified to include the UPFC. This compensates the line between any of the buses. The UPFC is used to regulate the active and reactive power flowing in the line at a pre specified value. The load flow solution for the modified network is obtained by the proposed power flow algorithm and the Matlab program is used to find the control setting of UPFC for the pre specified real and reactive power flow between any buses and the power flow between the lines are observed the effects of UPFC. The same procedure is repeated to observe the power flow between the buses. (Depending on the pre specified value of

the active and reactive power the UPFC control setting is determined after the load flow is converged.).

B Test results for IEEE 14 bus system

The single line diagram of IEEE 14 bus system is shown in fig.4.

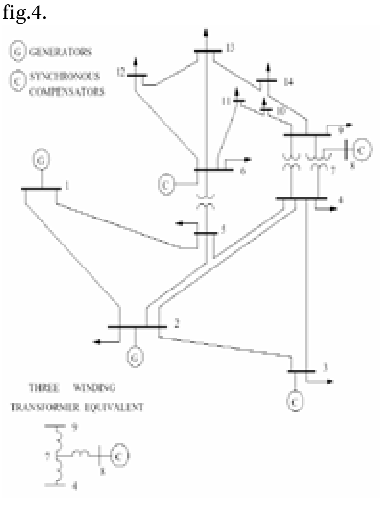

Fig 4 IEEE 14 bus system

Test results without UPFC

The voltage profile of the system is tabulated below:

Bus code	Voltage(p.u)	Angle(rad)	Angle(deg)
1	1.060000	0.000000	0.000000
2	0.179331	-2.288247	-131.106867
3	3.003445	2.569834	147.240670
4	0.801914	1.153725	66.103578
5	0.557927	2.134085	122.274079
6	0.361504	0.632530	36.241286
7	1.205262	0.493703	28.287102
8	0.029187	0.237284	13.595389
9	0.200750	-1.509105	-86.465347
10	0.088059	1.616350	92.610029
11	0.095862	-1.698440	-97.313422
12	0.398357	1.836755	105.238306
13	1.116873	-0.412811	-23.652326
14	0.632956	2.982683	170.895172

The Power flow profile of the system

Bus code	Real power(p.u)	Reactive power(p.u)	Loss(p.u)
1-2	8.427942	18.311464	7.027357
1-5	-0.640964	6.581140	2.119981
2-3	2.496023	-0.825690	10.097645
2-4	0.503510	0.794991	1.601668
2-5	0.601350	0.152012	0.681603
3-4	29.240393	39.059395	17.718054
4-5	-5.324704	11.044104	3.120731
4-7	2.833800	-0.576041	0.000000
4-9	0.133342	1.413121	-0.000000
5-6	0.798388	1.179781	0.000000
6-11	0.404998	0.583696	0.366826
6-12	-0.306318	0.456276	0.284050
6-13	1.908977	-1.520838	3.015375
7-8	0.050649	8.053528	0.000000
7-9	1.997330	14.125655	0.000000
9-10	0.223268	0.602056	0.325453
9-14	0.472542	0.029734	0.707077
10-11	0.023820	0.073490	0.063149
12-13	1.870098	0.124471	4.890334
13-14	2.607364	4.269854	3.429823

2) *Test results with UPFC (between bus 3 & 4)*

The voltage profile of the system is tabulated below:

Bus code	Voltage(p.u)	Angle(rad)	Angle(deg)
1	1.060000	0.000000	0.000000
2	1.138315	0.088483	5.069689
3	1.198760	0.192627	11.036737
4	1.187929	0.172307	9.872480
5	1.169031	0.147799	8.468233
6	1.208460	0.225223	12.904324
7	1.210613	0.212923	12.199564
8	1.210613	0.212923	12.199564
9	1.223324	0.233666	13.388092
10	1.227042	0.235883	13.515074
11	1.220824	0.232344	13.312348
12	1.221141	0.236528	13.552028
13	1.225306	0.237447	13.604730
14	1.238980	0.247866	14.201670

The Power flow profile of the system

Bus code	Real power(p.u)	Reactive power(p.u)	Loss(p.u)
1-2	-2.018832	-0.691634	0.077856
1-5	-0.877515	-0.272669	0.039915
2-3	-0.748037	-0.161029	0.020930
2-4	-0.666420	-0.095772	0.020161
2-5	-0.465231	-0.057668	0.009567
3-4	0.173033	0.000639	0.001401
4-5	0.890799	0.260604	0.008149
4-7	-0.279235	-0.123186	0.000000
4-9	-0.160222	-0.070683	0.000000
5-6	0.433578	-0.166104	-0.000000
6-11	-0.072151	-0.040478	0.000445
6-12	-0.076222	-0.022915	0.000533
6-13	-0.173205	-0.067466	0.001565
7-8	0.000000	0.000000	0.000000
7-9	-0.279235	-0.136990	0.000000
9-10	-0.052213	-0.034117	0.000083
9-14	-0.092244	-0.026903	0.000784
10-11	0.037704	0.023663	0.000108
12-13	-0.015755	-0.008025	0.000046
13-14	-0.055572	-0.020614	0.000400

The choice of "P_c" and "Q_c" are valid

The control settings of UPFC are:

Voltage(U_T U_T in p.u)	Phase angle(φ_T φ_T in rad)
0.049953	1.317874

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V CONCLUSIONS

Unified power flow controller provides simultaneous or individual controls of basic system parameters like transmission voltage, impedance and phase angle, thereby controlling transmitted power.

In this paper an IEEE 14-bus system is taken into consideration to observe the effects of UPFC. Load flow studies were conducted on given system to find the nodal voltages, and power flow between the nodes. The MATLAB program is run with and without incorporation of UPFC. The UPFC is incorporated between buses (3, 4) to improve the power flow between the lines to a pre-specified value. From the results it has been observed that the power flow between the lines is improved to a pre-specified value. Depending on the pre-specified value the UPFC control settings were determined. The real power losses between the lines were decreased after the incorporation of UPFC.

So, it can be concluded that after the incorporation of UPFC the voltage profile and power flow between the lines improves. Also by using this program, control setting of UPFC for different pre-specified power flows can be obtained.

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