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Implementation of UPFC for Improving the Power flow and Voltage Profile

Ishit Shah [1], Neha Srivastava[1], Yogesh Prajapati [2], Jigar Sarda[3]
[1](Electrical, M.E. Student at Birla Vishvakarma Mahavidyalaya, V.V.Nagar, India),
[2](Electrical, Asst. Professor at Birla Vishvakarma Mahavidyalaya, V.V.Nagar, India),
[3](Electrical, Asst. Professor at Charotar University of Science and Technology, Changa, India).

ABSTRACT
As the present scenario of Power system network is getting huger and complex, it's giving rise to the need of an effective tool to incorporate in the system so that the power flow can be maintained at an optimum level. This not only helps to maintain the voltage stability but also helps to reduce the losses. Thus, the main objective of this paper is to enhance the Power flow using UPFC controller. The UPFC which is a type of FACTS device controller has been used here which proves to be an effective tool that improves power transfer capability of the system and at the same time keep the system, stable and reliable. The UPFC model has been implemented here and is also included in the N-R load flow algorithm to minimize the losses of the system and thus improve the Voltage stability. The analysis has been performed on IEEE-14 bus system.

Keywords: Enhancement of Power flow; Improvement of Voltage Level; Newton-Raphson Load flow; Unified Power Flow Controller (UPFC); MATLAB.

I. INTRODUCTION
Today's Power system network is a complex network which are frequently prone to disturbances and faults. At the same time, the Unpredictable Power demand is creating a need for a faster, accurate and reliable system that can overcome the present day power system problems.

At present voltage stability issue is one of the major concerns in the power system network. It can be configured by using the FACTS devices. The FACTS devices can be grouped into three categories: Series, Shunt and combination of Series-Shunt controllers. The series controllers are used to inject voltage in series with the line, shunt controllers are used to inject current and a combination of these two helps to inject voltage through the series part and inject current through the shunt part of the system at the point of connection.

The Unified Power Flow Controller (UPFC) (a type of series-shunt combination) , which was proposed by GyuGyi in the year 1991[7], is a type of FACTS device which utilizes Voltage Source Converters (VSC) to control the parameters like voltage, phase angle, impedance, that mostly affects the power flow in a transmission line. It can be used to control power flow, enhance the voltage, mitigate the oscillation in the system, etc. Thus, it is capable of controlling both active and reactive power. Hence to meet the ever increasing power demand and solve the major concerns of today's power system network scenario, UPFC proves to be an effective device that can control the comprehensive power flow efficiently [8]. IEEE-14 bus system is used for the system under

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consideration and the implementation is done in MATLAB software. This paper has been organized in the following manner. Section II discusses the operation and modelling of UPFC. Section III presents the power flow algorithm using N-R method. Section IV presents results of load flow for IEEE-14 bus system with and without the UPFC.

II. Unified Power Flow Controller

A. Structure and Operation of UPFC[1], [3]

Among the all FACTS devices UPFC is most versatile device [8]. It has all encompassing capabilities of series compensation, voltage regulation and phase shifting. It can rapidly and independently control both real and reactive power flows in transmission line. The configuration is shown in figure 1. In UPFC two voltage source converters (VSC) are back-to-back connected which labeled as Converter - 1 and Converter – 2 in figure 1[9].

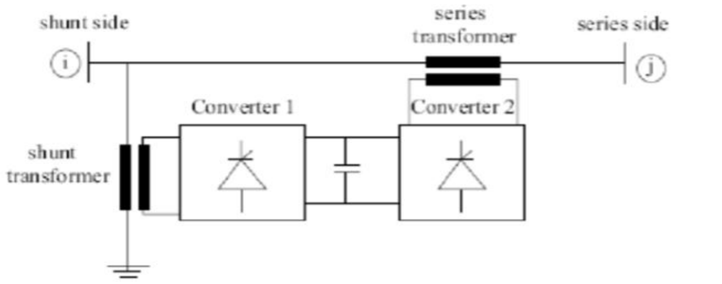

Figure 1: UPFC with back-to-back VSC

They are operated from a common dc link which is provided by dc storage capacitor.VSC convereter-1 is connected in shunt through coupling transformer with the line and VSC convereter-2 is inserted in series through interface transformer with the transmission line. This arrangement functions as an ideal ac-to-ac power converter. The real power can flow in either direction between the ac terminals between the two converters. Each converter can independently absorb (or generate) reactive power at its own ac terminal. The working of Converter-2 is to control voltage phasor V_{pq} in series with the line. The phase angle V_{pq} can independently varied from 0^0 to 360^0. So VSC-2 exchanges both reactive and real power with line. The reactive power is generated/absorbed internally by the converter-2. The real power exchanged from the ac terminal which is converted into dc power and it appears at the dc link as a positive or negative real power demand. Converter-1 is used mainly to supply the real power demanded by converter-2, it derives from the transmission line. It helps to maintain constant voltage of the dc link. The net real power drawn from the line is equivalent to the losses of both converters and their coupling transformers. Converter-1 is shunt connected and it is operated as STATCOM and independently controls the terminal voltage of interconnected bus by generating/absorbing proper reactive power.

B. Power injection Model of UPFC[1], [2]

The UPFC equivalent circuit consists of two coordinated synchronous voltage sources for the purpose of fundamental frequency steady state analysis. Such an equivalent circuit is shown in Figure 2[16].

The UPFC voltage sources are:

$$E_{vR}=V_{vR}(\cos_{vR}+j\sin_{vR}) \quad (1)$$

$$E_{cR}=V_{cR}(\cos_{cR}+j\sin_{cR}) \quad (2)$$

Where, V_{vR} and δ_{vR} are the controllable magnitude ($V_{vRmin} \leq V_{vR} \leq V_{vRmax}$) and phase angle ($0 \leq \delta_{vR} \leq \delta 2\Pi$) of the voltage source representing the shunt converter. The magnitude V_{cR} and phase angle δ_{cR} of the voltage source representing the series converter are controlled between limits ($V_{cRmin} \leq V_{cR} \leq V_{cRmax}$) and ($0 \leq \delta_{cR} \leq \delta 2\Pi$), respectively. The phase angle of the series injected voltage determines the mode of power flow control.

If δ_{cR} is in phase with nodal voltage angle θ_k, the UPFC regulates the terminal voltage. If δ_{cR} is in quadrature with θ_k, it controls active power flow, acting as a phase shifter. If δ_{cR} is in quadrature with line current angle then it controls active power flow, acting as a variable series compensator. At any other value of δ_{cR}, the UPFC operates as a combination of voltage regulator, variable series compensator and phase shifter. The magnitude of the series injected voltage determines the amount of power flow to be controlled.

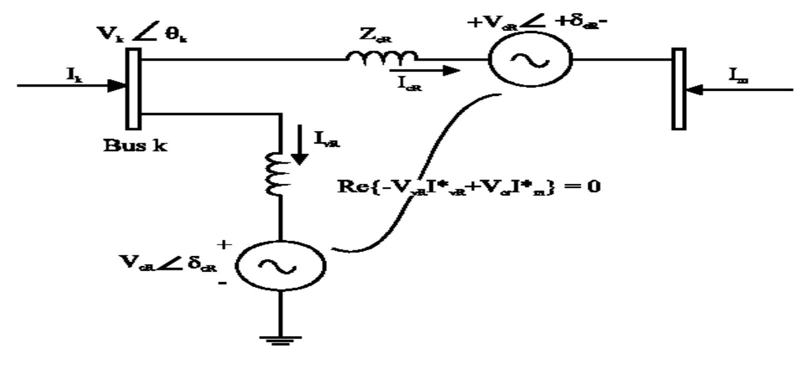

Figure 2: Unified Power flow controller equivalent circuit

The active and reactive power equations are [11], [12], [13]:

At bus K:

$$\begin{aligned} P_k &= V_k^2 G_{kk} + V_k V_m [G_{km}\cos(\theta_k-\theta_m)+B_{km}\sin(\theta_k-\theta_m)] \\ &+ V_k V_{cR}[G_{km}\cos(\theta_k-\delta_{cR})+B_{km}\sin(\theta_k-\delta_{cR})] \\ &+ V_k V_{vR}[G_{vR}\cos(\theta_k-\delta_{vR})+B_{vR}\sin(\theta_k-\delta_{vR})] \end{aligned} \quad (3)$$

$$\begin{aligned} Q_k &= -V_k^2 B_{kk} + V_k V_m [G_{km}\sin(\theta_k-\theta_m)-B_{km}\cos(\theta_k-\theta_m)] \\ &+ V_k V_{cR}[G_{km}\sin(\theta_k-\delta_{cR})-B_{km}\cos(\theta_k-\delta_{cR})] \\ &+ V_k V_{vR}[G_{vR}\sin(\theta_k-\delta_{vR})-B_{vR}\cos(\theta_k-\delta_{vR})] \end{aligned} \quad (4)$$

At bus m:

$$P_m = V_m^2 G_{mm} + V_m V_k [G_{mk} \cos(\theta_m - \theta_k) + B_{mk} \sin(\theta_m - \theta_k)]$$
$$+ V_m V_{cR} [G_{mm} \cos(\theta_m - \delta_{cR}) + B_{mm} \sin(\theta_m - \delta_{cR})] \quad (5)$$

$$Q_m = -V_m^2 B_{mm} + V_m V_k [G_{mk} \sin(\theta_m - \theta_k) - B_{mk} \cos(\theta_m - \theta_k)]$$
$$+ V_m V_{cR} [G_{mm} \sin(\theta_m - \delta_{cR}) - B_{mm} \cos(\theta_m - \delta_{cR})] \quad (6)$$

Series converter:

$$P_{cR} = V_{cR}^2 G_{mm} + V_{cR} V_k [G_{km} \cos(\delta_{cR} - \theta_k) + B_{km} \sin(\delta_{cR} - \theta_k)]$$
$$+ V_{cR} V_m [G_{mm} \cos(\delta_{cR} - \theta_m) + B_{mm} \sin(\delta_{cR} - \theta_m)] \quad (7)$$

$$Q_{cR} = -V_{cR}^2 B_{mm} + V_{cR} V_k [G_{km} \sin(\delta_{cR} - \theta_k) - B_{km} \cos(\delta_{cR} - \theta_k)]$$
$$+ V_{cR} V_m [G_{mm} \sin(\delta_{cR} - \theta_m) - B_{mm} \cos(\delta_{cR} - \theta_m)] \quad (8)$$

Shunt converter:

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_k [G_{vR} \cos(\delta_{vR} - \theta_k) + B_{vR} \sin(\delta_{vR} - \theta_k)] \quad (9)$$

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_k [G_{vR} \sin(\delta_{vR} - \theta_k) - B_{vR} \cos(\delta_{vR} - \theta_k)] \quad (10)$$

III. Power flow Algorithm

1. Using the given line data and Bus data, form the Admittance Matrix [4].
2. Calculate the Jacobian elements using N-R method [5], [6] (without UPFC).
3. Form the modified Jacobian matrix (with UPFC).
4. Amend the mismatch power equation.
5. Revise the previous Bus bars Voltages.
6. Check for convergence otherwise repeat the previous steps.
7. Print the Load flow information, generations, line flows, bulbar voltages, and transmission line losses.

Modification in Jacobian Matrix:

The two power injections (P_k, Q_k) and (P_m, Q_m) of a UPFC can be treated as generators as they vary with the connected bus bar voltage amplitudes and phases the relevant elements of Jacobin matrix at every iteration.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta v \end{bmatrix} \quad (11)$$

Where H, N, J, L are the elements of jacobian matrix is given by [4], [5], [13]

$$H_{km} = \frac{\partial Pk}{\partial \delta m} \quad (12)$$

$$N_{km} = \frac{\partial Pk}{\partial Vm} \quad (13)$$

$$J_{km} = \frac{\partial Qk}{\partial \delta m} \quad (14)$$

$$L_{km} = \frac{\partial Qk}{\partial Vm} \quad (15)$$

Case 1: k and m are not equal,

$$H_{km} = L_{km} = a_m f_k - b_m e_k \quad (16)$$

$$N_{km} = -J_{km} = a_m e_k - b_m f_k \quad (17)$$

$$Y_{km} = G_{km} + jB_{km} \quad (18)$$

$$V_k = e_k - jf_k \quad (19)$$

$$(a_m + jb_m) = (G_{km} + jB_{km}) * (e_k - jf_k) \quad (20)$$

Case 2: k and m are equal,

$$H_{kk} = -Q_k - B_{kk} V_k^2 \quad (21)$$

$$N_{kk} = P_k + G_{kk} V_k^2 \quad (22)$$

$$J_{kk} = P_k - G_{kk} V_k^2 \quad (23)$$

$$L_{kk} = Q_k - B_{kk} V_k^2 \quad (24)$$

IV. Case Study and Results

Fig. 3 shows IEEE-14 bus system. In this paper, I used MATLAB software for programming of N-R load flow to calculate the losses of the system and Power flow of the lines without the UPFC controller. After placing the UPFC between the line 2-5 load flow is done and the losses and Power flow of the line is calculated again.

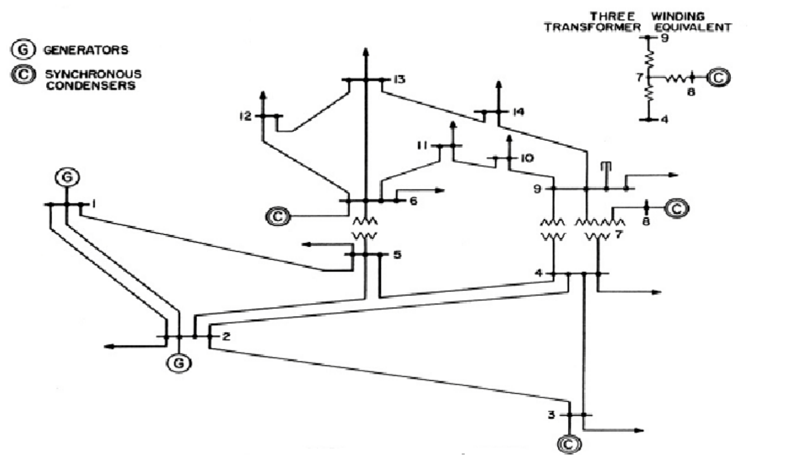

Figure 3. IEEE-14 Bus System

Results:

Table 1. Voltage Profile without UPFC

Bus	Voltage	Angle(Degree)
1	1.0600	0.0000
2	0.9100	-3.3464
3	0.8500	-13.4751
4	0.8857	-10.6369
5	0.8964	-8.6538
6	0.8800	-15.7271
7	0.9407	-14.9096
8	1.0400	-14.9096
9	0.8992	-17.1717
10	0.8870	-17.3469
11	0.8795	-16.7606
12	0.8645	-16.9912
13	0.8613	-17.1772
14	0.8610	-18.6191

Table 2. Voltage Profile with UPFC

Bus	Voltage	Angle (degree)
1	1.06	0
2	1.027	-5.180387
3	0.993	-13.121144
4	1.032	-12.146982
5	1.047	-10.769517
6	1.024	-14.224093
7	1.052	-15.291714
8	1.041	-15.291714
9	1.020	-16.917602
10	1.014	-16.774039
11	1.016	-15.781236
12	1.007	-15.221978
13	1.004	-15.527325
14	0.998	-17.241038

Table 3. Power Flow between lines without UPFC

Bus Code	Real Power(MW)	Reactive Power(MVar)
1-2	166.249	217.045
1-5	79.447	63.351
2-3	72.612	16.434
2-4	57.154	-2.584
2-5	41.889	-4.596
3-4	-24.733	-7.497
4-5	-65.465	-0.707
4-7	30.352	-22.712
4-9	16.818	-1.271
5-6	41.356	8.819
6-11	5.825	-2.499
6-12	7.439	1.827
6-13	16.892	4.270
7-8	0.000	-53.015
7-9	30.352	36.076
9-10	6.811	10.425
9-14	10.859	7.713
10-11	-2.250	4.463
12-13	1.246	0.033
13-14	4.373	-2.011

Table 4. Power Flow between lines with UPFC

Bus Code	Real Power(MW)	Reactive Power(MVar)
1-2	169.6973	4.9388
1-5	91.2434	-12.7003
2-3	72.4590	0.7821
2-4	66.2272	-24.2590
2-5	51.7886	-29.3772
3-4	-16.5094	-19.5389
4-5	-66.3562	-16.1084
4-7	28.4969	-9.2381
4-9	15.7470	2.8563
5-6	25.6256	10.4914
6-11	13.1912	-2.1278
6-12	8.2501	2.5580
6-13	20.4330	4.8871

7-8	0.000000	6.7250
7-9	27.6938	31.1586
9-10	-0.3890	7.1196
9-14	5.0128	6.1420
10-11	-8.1020	2.7983
12-13	1.9750	-0.6543
13-14	7.7553	-1.7444

Table 5. Total Loss of IEEE-14 bus system

IEEE-14 System	Total Losses(MW)
Without UPFC	26.695
With UPFC	17.55

CONCLUSIONS

Now a days the load requirement is increasing because of industrialization and urbanization. It results in high dependency on electrical energy. The rapid growth of power requirement leads to some uncertainty in the system which results in contingency and outages. This causes the overloading of the other lines and makes them to reach to their thermal limit.

It also affects the quality of power delivered. So after inserting the UPFC device in IEEE-14 bus system the total loss of the system is reduced by 34.26% and power transfer capability of the system is improved. So we can use the same line for transferring more power without any extra cost. Simultaneously the voltage profile of the system is also improved.

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