International Conference on Innovative Applications of Computational Intelligence on Power, Energy and Controls with their Impact on Humanity (CIPECH14) 28 & 29 November 2014

Allocation of UPFC in Distribution System to Minimize the Losses

Shiva Pujan Jaiswal
Department of Electrical Engineering
UEC, RTU, Kota, INDIA

Vivek Shrivastava, *IEEE Member*
Department of Electrical Engineering
UEC, RTU, Kota, INDIA

***Abstract*-FACTS technology was introduced into the distribution system (then called FACDS) to improve the distribution system performance.UPFC (Unified Power Flow Controller) is considered to be one of the best suited for power flow control as it controls all the three parameters of distribution line (i.e. impedance, voltage and phase angle). This paper presents a method for minimizing the distribution losses and improving the node voltage profile using UPFC. MATLab program was developed for power flow analysis using Newton-Raphson algorithms and to obtain the optimal location of UPFC using minimum loss as objective function. The proposed method is tested on the IEEE 33 RDS (radial distribution system) standard network.**

***Keywords: FACDS, UPFC, injection model,distributed generation, radial distribution system, optimal location*.**

I. INTRODUCTION

With the development of power distribution systems, especially the opening of electric energy trading, it becomes more important to control the power flow through the distribution line, so that change in operation and design standards for distribution network is necessary. Voltage regulation and line loss minimization are important challenging issues that have to be addressed by the power engineers. Distribution network can be of radial type or loop type. Radial distribution systems are more desirable than loop because of simple and inexpensive protection schemes[1]. However, in heavy loaded feeders the voltage at the far end point may be beyond the allowed voltage limit which causes high power loss and stability problems.

Recent development in distribution systems has been focused on Distributed Generation (DG).Integration of DG into network changes the operating conditions of the existing power network [2]. DG may result reverse power flow, node voltage may be beyond the permissible limits or even may lead to protection system failure [2]-[4].Conventional solutions for the distribution problems[5] like on-load tap changer (OLTC) to control the voltage, OLTC with LDC, generator power factor control, power curtailment, energy storage, reconfiguration of the radial network to loop using the existing infrastructure, shunt capacitor are no longer viable because the nature of distribution network will change from passive network to an active network thus the voltage profile cannotbe anticipated [6]. Therefore new control concepts and devices like high-power semiconductor will be required. FACTS devices are a well known technology, numbers of papers discuss the application of FACTS, using these devices to maintain the voltage profile of the transmission system. The UPFC, which was developed by L.Gyugyi in 1991, is one of the most versatile FACTS devices in a power system [7]. It is mainly used to control real and reactive power independently. Conventional devices or other FACTS devices such as a Static Var Compensator (SVC), a Thyristor Controlled Series Capacitor (TCSC), a phase shifter, etc. are not competent to control all parameters that influence real and reactive power flow in the line, i.e. the line impedance, voltage magnitudes at the terminals of the line or power angle simultaneously.However, the UPFC allows simultaneous control of these parameters to transfer from one control scheme to another in real time [8]. Also, UPFC can be used for voltage improvement, transient stability enhancement and damping of low frequency power system oscillations. Because of its attractive features, modelling and controlling of UPFC have come into exhaustive examination in the recent years.
Several references in technical literature can be found on the development of UPFC steady state, dynamic and linear models [9]. A mathematical model of UPFC known as UPFC injection model is developed and incorporated in steady state power flow model. UPFC is modelled as a series resistance together with the dependent loads injected at each end of the series reactance. The model is easy and helpful in understanding the UPFC impact on the distribution system.

In this paper author wishes to deal with Newton Raphson algorithm to solve the power flow without UPFC and with UPFC.A program is developed in MATLAB to find the optimal location of UPFC to minimize losses [10],and also to find the operating policy of the distribution system having UPFC so that the voltage-stability limit is maximized.Power balance constraints and steady state security limits are also satisfied. The IEEE 33 bus system is presented to illustrate some of the important properties of the UPFC at optimal location.This paper is organized as follows: section II develops a steady state model of UPFC. Section III discusses the implementation of the model for power flow studies. Section IV proposes a method to find optimal location. Section V demonstrates the application of UPFC through IEEE 33 RDS bus system.

II. UPFC MODEL

The unified power flow controller consists of two voltage source inverter connected with a DC link and connected to the power system through coupling transformers [11]. Basic electrical model of UPFC is shown in figure 1 which represents a lossless UPFC-embedded distribution line. The active power absorbed by shunt convertor is equal to that injected into the line by series convertor i.e. net active power exchange between UPFC and the system is zero.

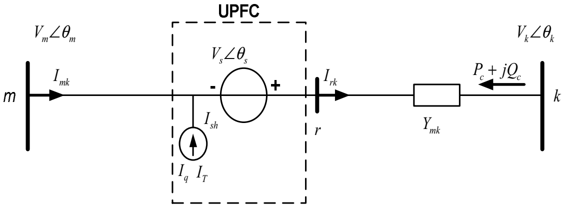

Fig :1: Electrical model of UPFC

The line connects nodes m and k. The output of the series voltage source $V_s$and θs are controllable magnitude and angle between the limits $V_s^{min}\le V_s\le V_s^{max}$and $0 \le \theta_s \le 2\pi$ respectively, and the shunt branch is equivalent to an ideal current source I_{sh}The variable $I_{sh}$of shunt current source also is controllable within $0 \le I_{sh} \le I_{sh}^{max}$,$I_{sh}^{max}$ is current capacity limit of shunt converter.

The steady-state model of UPFC can be broadly classified into two main categories: decoupled model and coupled model. The coupled model consists of two major kinds: Voltage (or Current) Source Model (VSM) and Power (or Current) Injection Model (PIM).This paper deal only in injection model.

*Power Injection Model:*A series connected voltage source is located between nodes *m* and *k* in the given power system.

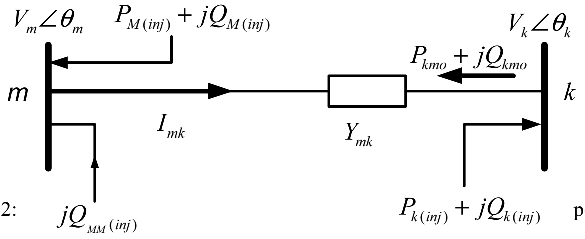

Fig :2: power injection model

$P_{m(inj)} + jQ_{m(inj)}$are power injected into node m by UPFC, as oppose to $P_{k(inj)} + jQ_{k(inj)}$which are injected into node k by UPFC. These additional injection powers are used to control the power flow through the line between node *m* and node *k*. The new mismatch equations when UPFC is installed in distribution line are expressed below:

$$P_{Gi} - P_{Li} = \sum_{j\in i} V_i V_j \left(G_{ij}cos\theta_{ij} + B_{ij}sin\theta_{ij}\right) \quad \text{----- (1)}$$

$$Q_{Gi} - Q_{Li} = \sum_{j\in i} V_i V_j \left(G_{ij}sin\theta_{ij} + B_{ij}cos\theta_{ij}\right) \quad \text{-----(2)}$$

$$i = 1, 2, 3, \dots\dots n\,;\;\; i \neq m, k$$

Where, n is the total numbers of buses in the power systemP_{Gi} and Q_{Gi} are active and reactive power injected to the bus i by generator.P_{Li} and Q_{Li} are active and reactive power extracted from bus *i* by load. $V_i$is magnitude of voltage of bus *i*. V_j is magnitude of voltage of bus j. $\theta_{ij} = \theta_i - \theta_j$is the phase angle difference between bus i and j, G_{ij}, B_{ij} denote the element $Y_{ij}$of admittance matrix of system network

Thus the four new mismatch equations are

$$P_{Gm} - P_{Lm} + P_{m(inj)} = \sum_{j\in m} V_m V_j (G_{mj}cos\theta_{mj} + B_{mj}sin\theta_{mj}) \quad \text{----- (3)}$$

$$Q_{Gm} - Q_{Lm} + Q_{m(inj)} + Q_{mm(inj)} = \sum_{j\in m} V_m V_j \left(G_{mj}sin\theta_{mj} + B_{mj}cos\theta_{mj}\right) \quad \text{----- (4)}$$

$$P_{Gk} - P_{Lk} + P_{k(inj)} = \sum_{j\in k} V_k V_j \left(G_{kj}cos\theta_{kj} + B_{kj}sin\theta_{kj}\right) \quad \text{----- (5)}$$

$$Q_{Gk} - Q_{Lk} + Q_{k(inj)} = \sum_{j\in k} V_k V_j \left(G_{kj}sin\theta_{kj} + B_{kj}cos\theta_{kj}\right) \quad \text{-----(6)}$$

The UPFC injection model can easily be incorporated in a load flow program. If UPFC is located between node *m*andnode *k*in a power system Linearized load flow model can be represented as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V/V \end{bmatrix} \quad \text{---- (7)}$$

III. POWER FLOW ANALYSIS WITH UPFC

Load flow problem is formulated as a set of nonlinear algebraic equations which can be solved by a number of mathematical methods such as Gauss Shidel, Newton-Raphson(NR), Fast Decoupledetc. Out of this N-R is a very efficient and reliable method [12]-[13]. The nodal voltage equations of power system without UPFC is expressed as

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \quad \text{---- (8)}$$

$$j = 1, 2, \dots\dots\dots n;$$

First conjugateI_i and then multiply by V_j.Through simple deduction the power system nodal power equations are obtained:

$$P_{Gi} - P_{Li} = \sum_{j\in i} V_i V_j \left(G_{ij}cos\theta_{ij} + B_{ij}sin\theta_{ij}\right) \quad \text{---- (9)}$$

$$Q_{Gi} - Q_{Li} = \sum_{j\in i} V_i V_j \left(G_{ij}sin\theta_{ij} + B_{ij}cos\theta_{ij}\right) \quad \text{---- (10)}$$

$$\text{i}= 1, 2, \dots\dots\dots n;$$

The UPFC embedded distribution line between node-kand node-*m* the load flow power mismatch equations can be expressed equations (8)and (9)for i= $1, 2, \dots\dots\dots n; buti \neq m, k$.Mismatch equations areexpressed by equation 3, 4, 5 and 6. Thus, the relationship is obtained for small variations in *V* and θ, by forming the total differentials

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = J_1 \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} + J_2 \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \quad \text{----- (11)}$$

$$J = J_1 + J_2 \qquad \text{----- (12)}$$

Where $J_1$is the normal N-R power flow Jacobian matrix and J_2 is the partial derivative matrixes of injected power with respect to the variables. When bus-m and bus-k are PQ buses, the matrix J_2 may have 10 nonzero elements as if bus-m is a PV bus corresponding elements of row and column will not exist.

IV. PROBLEM FORMULATION

To optimize the steady state performance of the distribution system,candidate integrates UPFC at the optimal location, minimum power loss as objective function while satisfying several equality and inequality constrains [14]-[16].

*Objective function:*Minimization of power loss in network:

$$S = [(\sum_{l=1}^{L} P_{iloss})^2 + (\sum_{l=1}^{L} Q_{iloss})^2]^{1/2} \qquad \text{----(13)}$$

Equality constraints: Power flow equations with corresponding to both active and reactive power must be satisfied as mention below:

$$P_{Gi} + P_{UPFC} + P_{Li} = P_i \qquad \text{----- (14)}$$

$$Q_{Gi} + Q_{UPFC} + Q_{Li} = Q_i \qquad \text{----- (15)}$$

*Inequality constrains:*These include the operating limits on the various variables of the system and UPFC parameters

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}$$

$$|V_i^{min}| \le |V_i| \le |V_i^{max}|$$

$$V_S^{min} \le V_S \le V_S^{max}$$

$$0 \le \theta_s \le 2\pi$$

$$0 \le I_{sh} \le I_{sh}^{max}$$

$$\text{----- (16)}$$

CASE STUDY

In order to demonstrate the effectiveness of UPFC to minimize the loss and for improves the voltage profile, the proposed method is applied to Fig.3 IEEE 33 bus radial system embedded with a UPFC at the most favourable site.

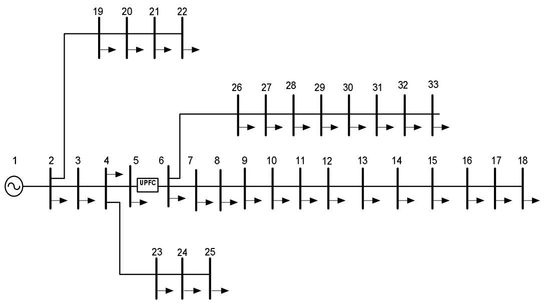

Fig :3: Line diagram of IEEE 33 RDS intregated with UPFC

Line (5-6) is a most favourable location for minimization of loss and with minimum the voltage deviation.UPFC control parameters are $V_s = 0.06$, $\theta_s = 0.05$, $I_{sh} = 0.02$which play an important role in effective system operation.Fig. 4 shows that the system loss with different location of UPFC in the system. Due of wide range of values of losses author, considerthe logarithm scale onthe Y-axis for reasonable visualization,from the graph we can easily find that UPFC with line 5-6 give minimum apparent loss.

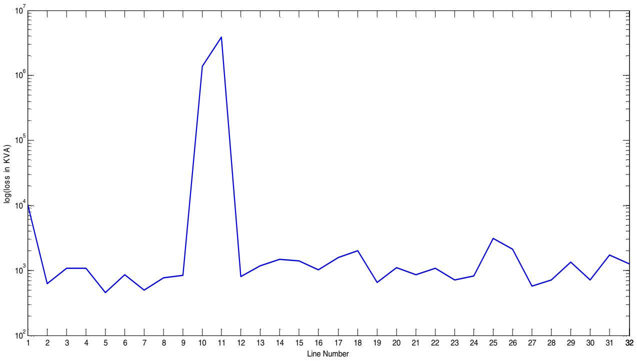

Fig: 4: Losses vs Line number

Fig. 5 Establish capability of UPFC to improvethe voltage profile of a system. In the base case without UPFC voltage range 0.84p. u. to 1.0 p.u., with UPFC on line number (5-6) the voltage range is 0.92 pu to 1.0 p.u and envlope of voltage profile is also narrow.

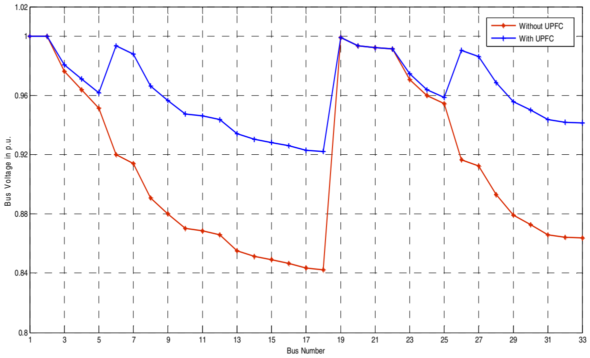

Fig:5: Voltage in p.u. vs Bus number

Figure 5 also displays that more voltage enchantment to near buses to line 5-6 than the far buses. Table 1 discuss the losses with and without integration of UPFC and express that the considerable reduction in active and reactive losses.

TABLE: I: Comparison of losses

Case/ losses	Without UPFC	With UPFC
Active power loss (KW)	423.00	384.00
Reactive power loss (KVAR)	280.00	254.00
Apparent power loss (KVA)	507.27	460.40

V. CONCLUSION

This paper has proposed a scheme to minimize line loss and to regulate the voltage within the permissible range. The location of UPFC is an important factor for optimal operation of radial distribution system because the radial structure is more prone to voltage decay at the far end than loop connection. Voltage strengthening is more at closer buses to UPFC than far buses.More than one UPFC may be integrated in system with economical consideration. The proposed technique is an efficient method to identifythe best suitable location of UPFC with minimum loss and minimum deviations in voltage contour without contravene the limits. The results demonstrate the great ability of UPFC to regulate the voltage profile underline loss minimization condition in radial distribution system.The loss comparison table shows that UPFC can reduce the active as well as reactive losses,both at the same time.

REFERENCES

[1] H. Saadat, Power System Analysis. Tata McGraw-Hill, India, p. 210, 2002.

[2] G. Pepermans, J. Driesen, D. Haeseldonckx, R. Belmans, W. D'haeseleer, "Distributed generation: definition, benefits and issues", Energy Policy Vol. 33, p.p. 787–798, 2005

[3] El-Kattam, W., Salama, M.M.A, "Distributed Generation Technologies:and benefits". Electric Power Research, 71, pp. 119-128, (2004).

[4] K.Tsukahara, C. Ishibashi, A. Kontani, Y. Yamada. "Present situation ofdistribution system in Japan and a proposed for new method of distribution

[5] T. Xu, P. C. Taylor "Voltage Control Technique for Electrical Distribution Network Including Distributed Generation" 17th IFAC world congress Seoul, korea, July 2008 pp.11967-11971.

[6] Masters, C.L. "voltage rise: the big issue when connecting embedded to long 11KV overhead line" Power Engineering Journal, Vol.16 No.1 pp5-12, 2002.

[7] L.Gyugi, "Unified power flow controller concept for flexible AC transmission system,"IEE Proceeding – C Vol.139 No. 4 pp323-331, July1992

[8] L. Gyqyi T. R Rietman A. Edris,' The Unified Power flow Controller: A New Approach to Power Transmission Control, IEEE Transactions on Power Delivery, Vol. 10, No. 2, April 1995.

[9] M. Mashayekh, A. Kazemi, S. Jadid "A New Approach for Modelling of UPFC In Power Flow and Optimum Power Flow Studies", IEEE Trans.2006,pp :7803-9514

[10] M. Ssyed, T. Takeshita, "All node voltage regulation and line loss inimization in loop distribution system using UPFC",IEEE Transaction on power electronics, Vol. 26 No. 6 pp. 1694-1703June2011.

[11] W.L.Fang and H.W.Ngan. " Control setting of unified power flow through a robust load flow calculation". IEEE Proceedings, Generation, Transmission & Distribution, Vol. 146, No. 4, pp: 365-369, July 1999

[12] C.R.Fuerte-Esquivel & E.Acha. "Unified Power Flow Controller: A Critical Comparison of Newton-Raphson UPFC Algorithms in Power Flow Studies. IEEE Proceedings. Generation,Transmission & Distribution 1997 pp :437-44

[13] Xiao-Ping Zhang and Keith R Godfrey. "Advanced Unified Power Flow Controller Model for Power System Steady State Control". IEEE International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT 2004), pp 228-233

[14] M.Noroozian , L.Angquist , M.Ghandhari & G.Andersson. " Use of UPFC for Optimal Power Flow Control". IEEE Trans.on Power Delivery:1997pp:1629-1634.

[15] M.Huneault, FD. Galiana, "A servey of the optimal power flow literature," IEEE Trans Power System 1991 Vol. 2, pp. 70-76.

[16] V.Bhadoria,N.S.Pal,V.Shrivastava,"Installation of DG for Optimal Demand Compensation" ICICT-2014,pp821-824

Shiva Pujan Jaiswal born in 1982. He had completed his B.Tech and M.Tech degree in Electrical engineering from Faculty of Engineering, Dayalbagh Educational Institute Agra, and pursuing PhD. from Department of Electrical Engineering, UEC, Rajasthan Technical University Kota, India. His main fields of research are power system, Flexible AC Transmission systems. HVDC and renewable energy

Vivek Shrivastava (M' 2007) born in 1977 and currently Associate Professor in Rajasthan Technical University Kota. Prior to this assignment he had worked as Associate Professor and Academic In charge at National Institute of Technology Delhi. He had completed his B.Tech in Electrical Engineering from RGPV Bhopal and Ph. D. from Indian Institute of Technology Kharagpur.

He had carried out industrial assignment at SanDisk Semiconductors at Shanghai and USA. He has published more than 25 papers on System Reliability, probabilistic Power System Planning and Test Analysis in reputed International Journals & Conferences. He is a member of IETE India and IEEE USA