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Novel Optimal Placement of UPFC Based on Sensitivity Analysis and Evolutionary Programming

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Abstract: In this study, optimal placement of UPFC is proposed based on the sensitivity analysis and evolutionary programming technique. The guidance for the selection of the location of UPFC is made according to the sensitivity analysis performed on the transformer model of UPFC. From the point of view of operational planning, this analysis is superior when compared to the others as this analysis gives the best possible installation location. As the screening technique for locating UPFC is made on the sensitivity analysis and evolutionary programming, computation time for determining optimal location of UPFC is greatly reduced. On selection of the location of UPFC, performance of UPFC in reducing the generation cost is analysed using the evolutionary programming technique and the coding was done using matlab. The effectiveness of the proposed algorithm is tested and illustrated on IEEE 9 bus system.

Key words: UPFC, optimal power flow, evolutionary programming, UPFC location, sensitivity analysis, ideal transformer model of UPFC

INTRODUCTION

Modern electric power utilities are facing challenges due to their increasing complexity in structure and operation. Flexible AC Transmission Systems (FACTS) controllers have large potential to operate power systems in a more flexible and economical way. These FACTS controllers (Hingorani, 1993; Gyugi, 1992) provide new control facilities both in steady state power flow control and dynamic stability control.

Recently, the interest on these FACTS devices has geared up due to the cost effectiveness (Larsen *et al*., 1992) of these devices which was made possible by the recent developments in Power Electronics. The studies on FACTS are concerned with controller deployment optimally, deciding their number and placement in the power system with respect to power flow control. The optimal power flow problem of minimizing the generation cost has been solved by classical optimization methods. The constraints involved are the physical laws governing the power generation and transmission systems and the operating limitations of the equipment. There are several papers citing the solution for optimal power flow problem with the objective of minimising the production cost using classical optimization methods (Dommel and Tinney, 1968; Lee *et al*., 1985; Sasson, 1969; Bouktir *et al*., 2000). To overcome the problem of high dimensionality of power systems and the computation time involved, artificial intelligence techniques have been in use for solving the same problem.

Genetic algorithm based solution for finding the optimum location and choice of FACTS controllers has been reported as far as by Cai and Erlich (2003).

A non convex approach using tabu search to optimally locate UPFC was proposed in Mori and Goto (2000). In Cai and Erlich (2003), work was based on the basic model of UPFC. UPFC injection model and uncoupled model (Seungwon *et al*., 2007) have been proposed for steady state power flow analysis. These models can be made use of in OPF problems as reported in Cai and Erlich (2003). In this model, OPF problem formulation becomes complex in nature as the degrees of freedom in computing the objective of generation cost minimisation is reduced. Hence based on the planning point of view, recently reported UPFC transformer model (Seungwon *et al*., 2007) seems to be the best option for location of UPFC. This model is used in efficiently screening the locations by solving only the base case. The optimal power flow problem of minimizing the generation cost with the equality and inequality constraints being met had been solved using evolutionary programming.

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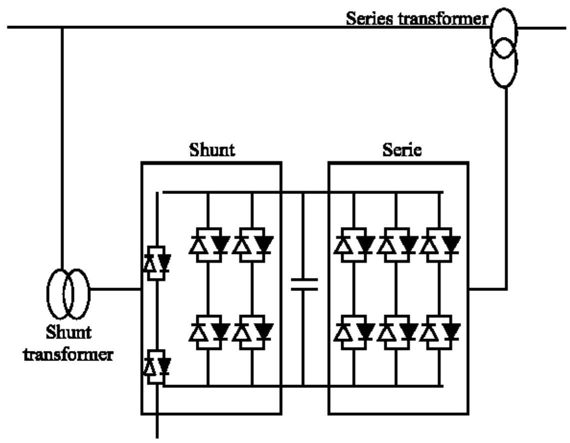

Fig. 1: UPFC model

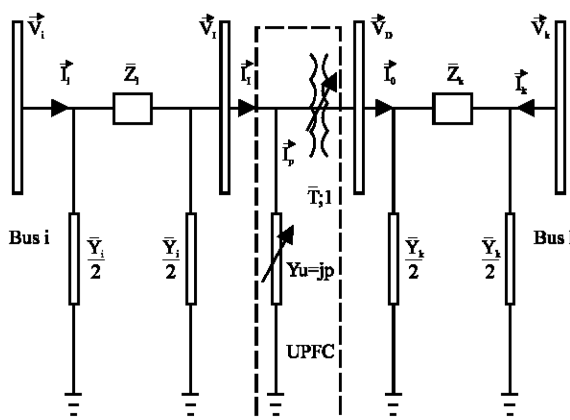

Fig. 2: Transformer model

Operating principles: Unified power flow controller has the ability to control the voltage and phase angle with the additional capability to provide positive and negative reactive power injections. UPFC consists of a shunt transformer, series transformer and a DC link as shown in the Fig. 1.

Shunt inverter acts like a Static VAR compensator when series inverter is not connected and series inverter performs that action of Advanced series compensator when shunt inverter is not connected.

The transformer model of UPFC (Seungwon *et al.*, 2007) is based on the ABCD matrix which represents the cascaded networks. Let us divide a transmission line between buses i and k with a UPFC into three different blocks as shown in the Fig. 2. The ABCD parameters for the transmission line can be obtained as below (Seungwon *et al.*, 2007). The UPFC variables for this model are

T : Transformer turns ratio,
Φ : Phase shifting angle
ρ : Shunt susceptance

The voltage equations governing this model are given by

$$\begin{bmatrix} \vec{I}_i \\ \vec{I}_k \end{bmatrix} = \overline{Ybus}_{ik} \begin{bmatrix} \vec{V}_i \\ \vec{V}_k \end{bmatrix} \quad (1)$$

Where:

$$\overline{Ybus}_{ik} = \begin{bmatrix} D_{ik}/B_{ik} & C_{ik} - A_{ik}D_{ik}/B_{ik} \\ -1/B_{ik} & A_{ik}/B_{ik} \end{bmatrix} \quad (2)$$

$$\begin{aligned} A_{ik} &= TA_iA_k + j\ TB_i\ A_k\rho + (1/T^*)B_i\ C_k \\ B_{ik} &= TAiB_k + j\ TB_i\ B_k\rho + (1/T^*)B_i\ D_k \\ C_{ik} &= TC_iA_k + j\ TD_i\ A_k\rho + (1/T^*)D_i\ C_k \\ D_{ik} &= TCiBk + j\ TD_i\ B_k\ \rho + (1/T^*)D_i\ Dk \end{aligned} \quad (3)$$

Where, [$Ybus_{ik}$] comprises ABCD parameters. Since the UPFC is embedded in the Ybus matrix, the size of the Ybus matrix is not changed, so UPFC sensitivity analysis can be performed using this model.

PARAMETRIC OPTIMAL POWER FLOW FORMULATION

We consider the OPF problem of a power system with n buses. Taking into consideration the variable real power generation and reactive power generation, bus voltage magnitudes, bus angles and transformer tap ratios, the mathematical formulation of OPF can be expressed as

$$\min C\ (y, xik) \quad (4)$$

Where:

n : Number of buses
m : Number of generator buses
C (y, xik) : Total generation cost
y : Decision variables
xik : UPFC control variables
hi : Equality constraints
gi : Inequality constraints

The Lagrangian for the OPF problem is given by

$$\partial L_{ik}/\partial x_{ik} = 0 \quad (5)$$

$$\lambda_x{}^*(x_0) = \left[\partial C(y^*, x_{ik})/\partial x_{ik} + \sum_{j\in A} \lambda_j{}^* \partial h_j(y^*, x_{ik})/\partial x_{ik} \right]$$

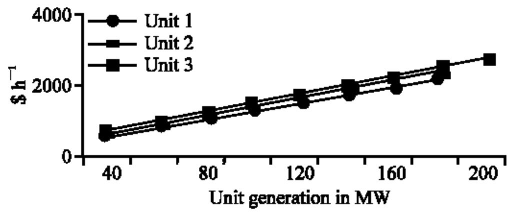

Fig. 3: Generation cost curves

Equality constraints: The constraints include the power flow equations of the UPFC controlled system

$$Pgi(k) - Pli(k) = \sum_{j \in i} [(Vi(k)\,Vj(k)\,[Gij(k)\cos\delta ij(k) + Bij(k)\sin\delta ij(k)] \quad (6)$$

$$Qgi(k) - Qli(k) = \sum_{j \in i} [(Vi(k)\,Vj(k)\,[Gij(k)\sin\delta ij(k) + Bij(k)\cos\delta ij(k)]$$

Where:

I = 1…n
k = 1…nc
nc- Total operating conditions

Inequality constraints: The operational system constraints including maximum line current, bus voltage levels, limits of reactive power generation, ratios of tap changers and operating region of UPFC.

$$-Iq\min \le Iq \le Iq\max$$
$$Qg(k)\min \le Qg(k) \le Qg(k)\max$$
$$Pg(k)\min \le Pg(k) \le Pg(k)\max$$
$$V(k)\min \le V(k) \le V(k)\max$$
$$S\min(l) \le S(l) \le S\max(l)$$

Where:

k : Operating condition
l : Lines
i and j : Both ends of the line where UPFC is connected

Cost function: The generation cost function measured in \$ h^{-1}, is defined by

$$C(P_G) = \alpha + \beta^* P_G + \gamma^* P_G^2 \quad (7)$$

Where:

P_G- Unit's real power generation in MW
α, β and γ are constants. The generation cost curves for the system considered is given in Fig. 3.

SENSITIVITY ANALYSIS

First order sensitivity analysis is performed in this study in order to identify the location of UPFC for minimisation of generation cost. The study consists of deriving the marginal values of the UPFC to be installed in a line which is nothing but the exact amount of deviation in the total cost when the control variables of UPFC are changed. In order to find the marginal values the new lagrangian of the problem is formulated and is given by

$$L_{ik}(y,\lambda,\mu,x_{ik}) = C(y,x_{ik}) + \sum_{j\in A}^{n} \lambda_i h_j(y,x_{ik}) + \lambda_x^T(x - x_{ik}) \quad (8)$$

Where: $\lambda_x = [\lambda_T, \lambda_\phi, \lambda_\rho]$

$\lambda^*(x)$ is the optimal value of the Lagrangian multiplier on the constraint $x_{ik}=x$. In order to find out the optimal value of λ with the control parameter $x = x_0$, we use the first order condition

$$\partial L_{ik} / \partial x_{ik} = 0 \quad (9)$$

Hence marginal value is given by

$$\lambda_x{}^*(x_0) = \left[\partial C(y^*, x_{ik}) / \partial x_{ik} + \sum_{j\in A} \lambda_j{}^* \, \partial h_j(y^*, x_{ik}) / \partial x_{ik} \right] \quad (10)$$

Thus the deviation in the cost function with respect to UPFC control variables for each transmission line can be found by solving only the base case OPF.

When compared to other models, this transformer model is ideal for location identification based on sensitivity analysis as the UPFC model is embedded in the Ybus matrix itself and the variables T, Φ and ρ are independent of the UPFC input and output voltages and currents unlike in other models. Irrespective of the sign of λ_x*, the absolute value of the multiplier determines the marginal change in the total generation cost as the constraint is varied.

OPF PROCEDURE USING EVOLUTIONARY PROGRAMMING

The programming technique can be classified into the following subsections.

Initial population: An initial population of parent individuals pi, i = 1, 2, ……….k is generated randomly within a feasible range in each dimension and the distribution of initial trial parents is uniform. Assume population size, maximum number of populations and scaling factor for the given test system. Population factor is set to zero. Run power flow for the base case using Newton Raphson algorithm and the load flow results are determined.

Mutation: Each parent vector Pi generates an offspring vector by adding a Gaussian random variable with zero mean and pre-selected standard deviation to each individual of Pi. The K parents create K offspring thus resulting in 2K individuals in the competing pool.

Selection: Each individual in the competing pool is evaluated for its fitness. All individuals compete with each other for selection. The best K individuals with maximum fitness values are retained to be parents of the next generation. The process of creating offspring and selecting those with maximum fitness which fulfils the objective of minimising the fuel cost subject to the equality and inequality constraints are repeated until there is no appreciable improvement in the maximum fitness value or it is repeated up to a pre specified number of iterations. If all the constraints are satisfied, the individual of the new population becomes valid. Find the maximum fitness (minimum cost) among all the individuals.

RESULTS

The sensitivity method was tested on a 9 bus system (subsection of IEEE 14 bus system) to establish its effectiveness. The input data for the system under consideration is given in Peter and Pai (1997). The test system consists of three generators and eleven lines. One of these generator is a reactive power controlled one (at bus 7). Sensitivity analysis helps in screening the location of UPFC prior to installation and the method proves to be a good choice in locating the controller as shown by the results.

On selection of the best location the optimal power flow is carried to provide solution for achieving the objective of minimisation of fuel cost. A population size of 10 is chosen for analysis. The values of λ_T, λ_ϕ, λ_ρ show how much deviation would occur in the generation cost if the control variables of UPFC are changed. There seems to be a maximum deviation in the line 5-6 as indicated by the Table 1.

From the above results, in line 7 (connecting bus 5 and bus 6), the deviation of the UPFC variables seems to be the maximum when compared to other locations. Line 6 follows closely line 7 on comparison of marginal values of control variables. Line 7 proves to be a better choice for installation of UPFC on comparing Lambda phi and lambda rho values. The lines with low marginal values are ignored and full optimal power flow is run for lines with higher marginal values.

Table 1: Sensitivity factors of UPFC variables

Line no.	Lambda T	Lambda phi	Lambda rho
1	0.098295	0.000822173	0.33316
2	0.450431	0.056074367	0.379867
3	0.711666	0.099775375	0.954366
4	0.430889	0.090291373	1.529668
5	0.269745	0.21963	2.352432
6	0.081222	0.390633718	4.0555
7	1.421906	0.503521552	4.38313
8	1.664755	0.409048866	2.90483
9	2.446592	0.34570639	3.336114
10	1.92245	0.223534	2.837347
11	0.01.76863604	0.2677661	3.775938

Table 2: Cost benefit with UPFC

UPFC Position	Generation cost($ h^{-1})
No UPFC	3054.75
Line 1	3050.535
Line 2	3046.535
Line 3	3043.91
Line 4	3044.80
Line 5	3046.98
Line 6	3044.81
Line 7	3043.91
Line 8	3046.19
Line 9	3049.22
Line 10	3048.12
Line 11	3047.32

The base case optimal power flow returns the solution for generation cost. With UPFC installed in line 7, the generation cost reaches a minimum when compared to other locations as indicated in the Table 2. For verification purpose, optimal power flow is run for all the lines for the system considered and tabulated below to prove the effect of screening the location using sensitivity analysis.

CONCLUSION

Identification of optimal location of UPFCs is a practical concern when it comes to their implementation in modern power systems. This study uses the recently proposed ideal transformer model of UPFC which facilitates the easy implementation of sensitivity analysis for screening and identifying the possible locations of installations of UPFC. As demonstrated by the case study performed, the computational burden in determining the optimal location to obtain the cost savings is greatly reduced on using this technique.

APPENDIX A

Cost functions:

A $ h^{-1}	B $/hr/MW	C $/hr/MW^2
240	6.7	.009
220	6.1	.005
240	6.5	.008

REFERENCES

Bouktir, T., M. Belkacemi and K. Zehar, 2000. Optimal power flow using modified gradient method. Proceeding ICEL, U.S.T. Oran, Algeria, 2: 436-442.

Cai, L.J. and I. Elrich, 2003. Optimal choice and allocation of FACTS devices using Genetic algorithms, ISAP Conference, Lemnos, Greece.

Dommel, H.W. and W.F. Tinney, 1968. Optimal Power Flow Solutions. IEEE. Trans. Power Apparatus and Sys., 87: 1866-1876.

Gyugi, L., 1992. A unified Power flow control concept for flexible AC transmission systems. IEEE. Proc. Part C, 139: 323-331.

Hingorani, N.G., 1993. Flexible AC Transmission. IEEE Spectrum, pp: 40-45.

Larsen, E., N. Miller, S. Nilsson and S. Lindgren, 1992. Benefits of GTO based compensation systems for electric utility applications. IEEE. Trans. Power Delivery, 7: 2056-2064.

Lee, K.Y., Y.M. Park and J.L. Ortiz, 1985. A United Approach to Optimal Real and Reactive Power Dispatch. IEEE. Trans. Power Sys., 104: 1147-1153.

Mori, H. and Y. Goto, 2000. A parallel tabu search based method for determing optimal allocation of facts in power systems. In: Proc. Int. Conf. Power Sys. Technol., 2: 1077-1082.

Peter, W.S. and M.A. Pai, 1997. Power Systems Dynamics and Stability. Prentice Hall.

Sasson, M., 1969. Non linear Programming Solutions for load flow, minimum loss and economic dispatching problems. IEEE Transaction Power Apparatus and Systems, Vol. PAS-88.

Seungwon A.N. *et al.*, 2007. An Ideal Transformer model, OPF First order sensitivities and application to screening for optimal UPFC locations. IEEE. Transactions on Power Systems, Vol. 22.