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Optimal Location of FACTS Devices by Evolutionary Programming Based OPF in Deregulated Power Systems

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Abstract

This paper presents an Evolutionary Programming (EP) based approach for solving the optimal power flow with Flexible Alternating Current Transmission (FACTS) device to eliminate transmission line congestion in deregulated power system. Congestion in the transmission lines is one of the technical problems that appear particularly in the deregulated environment**.** In the deregulated power industry, private power producers are increasing rapidly to meet the increase demand. The purpose of the transmission network is to pool power plants and load centres in order to supply the load at a required reliability, maximum efficiency and at lower cost. As power transfer increases, the power system becomes increasingly more difficult to operate and insecure with unscheduled power flows and higher losses. The objective of FACTS devices is to control power flow so that it flows through the designated routes, increase transmission line capability to its maximum thermal limit, and improve the security of transmission system with minimal infrastructure investment and environmental impact. Thyristor Controlled Series capacitor (TCSC) is an emerging FACTS device used in this paper to reduce the congestion. The proposed approach introduces performance index parameter to locate TCSC optimally for relieving the congestion. In congestion management, the objective function is nonlinear. Hence an EP based approach is applied to solve the Optimal Power Flow (OPF) problem. IEEE 14 bus system is considered to demonstrate the suitability of this algorithm and the results are appreciably good.

Keywords: Congestion; Deregulated power system; EP; FACTS; OPF.

1 INTRODUCTION

Electric power systems, around the world, have been forced to operate to almost their full capacities due to the environmental and/or economic constraints to build new generating plants and transmission lines. The amount of electric power that can be transmitted between two locations through a transmission network is limited by security and stability constraints. Power flow in the lines and transformers should not be allowed to increase to a level where a random

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event could cause the network collapse because of angular instability, voltage instability or cascaded outages. When such a limit reaches, the system is said to be congested. Managing congestion to minimize the restrictions of the transmission network in the competitive market has, thus, become the central activity of systems operators. It has been observed that the unsatisfactory management of transactions could increase the congestion cost which is an unwanted burden on customers.

In regulated power system, Transmission Companies (TRANSCOs), Generation Companies (GENCOs) and Distribution Companies (DISCOs) come under one sector i.e government. Not only the expenditure but also the earned revenue is taken over by the government. On the other hand in deregulated power systems TRANSCOs, GENCOs, DISCOs are under different organizations (Keshi Reddy et al., 2006). The structure of deregulated industry is shown in (Fig. 1). To maintain the coordination between them there is one system operator in all types of deregulated power system models, generally he is Independent System Operator (ISO). In deregulated environment all the GENCOs and DISCOs make the transactions ahead of time, but by the time of implementations there may be congestion in some of the transmission lines. Hence ISO has to relieve that congestion to maintain the security of the system. To relieve the congestion ISO uses the following method. They are

1. Price Area Congestion Management
2. Available Transfer Capability (ATC) based Congestion Management
3. OPF based Congestion Management.

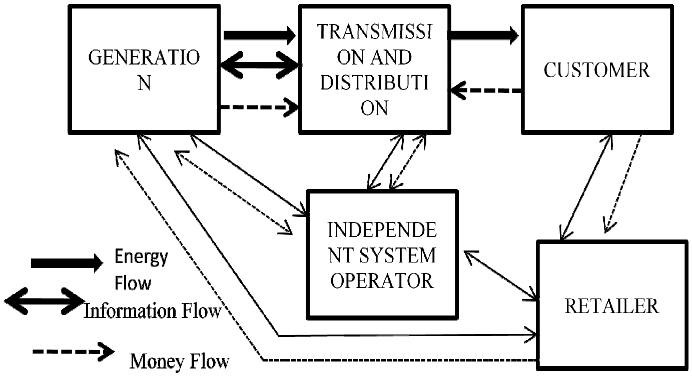

Fig. 1: Structure of deregulated power system

This paper presents the congestion relief by OPF based congestion management**.** Optimization is performed to minimize generator-operating cost with the set of constraints. They represent a model of the transmission system within which the generators operate.

2 OPTIMAL LOCATION OF FACTS CONTROLLERS

More attention has been given to the application of FACTS controllers in power systems in the recent past, as these controllers are proven to be a promising solution for various power system problems. One pertinent solution issue related to FACTS application is the selection of appropriate location. Proper location is a key to maximize the benefits of the expensive FACTS controllers. This paper deals with the location of the series FACTS controllers, especially to mange congestion in the deregulated electricity markets.

2.1 Location of Facts Controllers

The location of FACTS controllers is based on static or dynamic performance of the system. The best placement of FACTS controllers is to improve the dynamic performance which requires the Eigen value analysis and time domain simulation with proper dynamic modelling of FACTS controllers. For improving static performance, sensitivity factor method is generally used with the static modelling of FACTS controllers. In static modelling, series FACTS controller like TCSC is modelled simply as a series capacitor, which greatly simplifies the computation. Either the congested link or the neighborhood lines are the potential locations for installing series FACTS controllers to reduce the level of congestion. This forms the basis of this paper. The objective in the deregulated markets is to maximize the social welfare (or minimize the total generation cost to reduce the level of congestion). The set point for the TCSC can be determined by incorporating TCSC in the OPF problem.

2.2 Modelling of Facts Controllers

For static applications, FACTS controllers are designed by power injection model (Seyad Abbas Taher et al., 2008). The injection model describes the FACTS as a device that injects a certain amount of real and reactive power to a node, so that the FACTS controller is represented as PQ elements. The advantage of this model is that it does not destroy the symmetrical characteristic of the admittance matrix and allows efficient and convenient integration of FACTS into existing power system analytical tools.

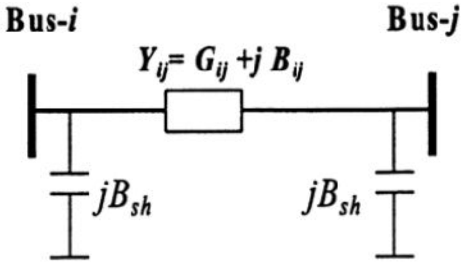

Fig.2: Model of transmission line

The simple transmission line represented by its lumped л-equivalent parameters connected between bus-i and bus-j is shown in (Fig.2). The real power flow from bus-i to bus-j (P_{ij}) is given by Eq. (1) and the reactive power flow from bus-I to bus-j (Q_{ij}) is given by Eq.(2).

$$P_{ij}= V_i^2 G_{ij} - V_i V_j \left[G_{ij}\cos\left(\delta_{ij}\right)+B_{ij}\sin\left(\delta_{ij}\right)\right] \tag{1}$$

$$Q_{ij}= -V_i^2\left(B_{ij}+B_{sh}\right)-V_i V_j \left[G_{ij}\sin\left(\delta_{ij}\right)-B_{ij}\cos\left(\delta_{ij}\right)\right] \tag{2}$$

2.3 Thyristor Controlled Series Capacitor

The model of transmission line with a TCSC connected between bus-i and bus-j is shown in (Fig. 3). During steady state, the TCSC can be considered as a static reactance $-jx_c$ (Singh et al., 2000). The controllable reactance x_c directly used as the control variable in the power flow equations.

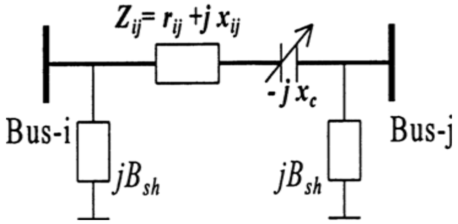

Fig. 3: Model of TCSC

The real and reactive power flow from bus-i to bus-j of a line having series impedance z_{ij} and a series capacitor reactance ($-jx_c$) are given by Eq. (3) and Eq. (4) respectively.

$$P_{ij}{}^{c} = V_j^2 G_{ij}{}^{c} - V_i V_j \left[G_{ij}{}^{c} \cos\left(\delta_{ij}\right) + B_{ij}{}^{c} \sin\left(\delta_{ij}\right)\right] \tag{3}$$

$$Q_{ij}{}^{c} = -V_i^2\left(B_{ij}{}^{c} + B_{sh}\right) - V_i V_j \left[G_{ij}{}^{c} \sin\left(\delta_{ij}\right) - B_{ij}{}^{c} \cos\left(\delta_{ij}\right)\right] \tag{4}$$

where

$$G_{ij}^{c} = \frac{X_C R_{ij} (X_{TCSC} - 2X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{TCSC})^2)} \tag{5}$$

$$B_{ij}^{c} = \frac{-X_{TCSC} (R_{ij}^2 - X_{ij}^2 + X_{TCSC} X_{ij})}{(R_{ij}^2 + X_{ij}^2)(R_{ij}^2 + (X_{ij} - X_{TCSC})^2)} \tag{6}$$

The change in the line flow due to series capacitance can be represented as a line flow without series capacitance with additional power (complex) injections at the receiving (S_{jc}) and sending (S_{ic}) ends as shown in (Fig. 4) .

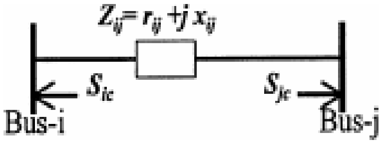

Fig. 4: Injection model of TCSC

2.4 Methods for Finding Optimal Location for TCSC

The TCSC is placed in a line which is over loaded. It is located optimally in a line such that the overall fuel cost of the system is minimum. The optimal location of TCSC is done in two ways (Seyad Abbas Taher et al., 2008). They are as follows:

2.4.1 Reduction of total system reactive power loss

When TCSC is placed between buses i and j, the loss sensitivity with respect to control parameter of TCSC placed between buses i and j can be written as

$$a_{ij} = \frac{\partial Q_L}{\partial x_{ij}} = [V_i^2 + V_j^2 - 2V_i V_j \cos\delta_{ij}] \frac{r_{ij}^2 - x_{ij}^2}{(r_{ij}^2 + x_{ij}^2)^2} \tag{7}$$

2.4.2 Real power flow performance index sensitivity indices

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index as given below.

$$PI = \sum_{m=1}^{N_L} \frac{W_m}{2n} \left(\frac{P_{Lm}}{P_{Lm}^{\max}} \right)^{2n} \tag{8}$$

Where

P_{Lm} is the real power flow,

$P_{Lm}^{\max}$ is the rated capacity of line-m & n is the exponent,

W_m a real non-negative weighting coefficient which may be used to reflect the importance of lines.

3 EVOLUTIONARY PROGRAMMING

Evolutionary Programming (EP) searches for the optimal solution by evolving a population of feasible solution over a number of generations or iterations. The evolution of solution is carried out through mutation (using Gaussian distribution) and competitive selection. The major steps involved in evolutionary programming approach are discussed as follows (Vijayakumar et al., 2007).

3.1 Initialization of Parent Population

An initial population of parent individuals I_{pi} (pi, i=1,2,…N_p) is generated randomly within a feasible range in each dimension. Assume population size, maximum number of populations and scaling factor for the given test system. Population factor is set to zero.

3.2 Creation of Offspring (Mutation)

Each parent I_{pi} vector generates an offspring vector I_{oi}^{m} (oi=N_{p+1},N_{p+2},…2N_p) by adding a Gaussian random variable with zero mean and pre-selected standard deviation to each element of I_{pi}. The N_p parent creates N_p offspring, thus resulting in 2N_p invitations in the competing pool.

3.3 Competition and Selection

Each individual in the competing pool is evaluated for its fitness. All individuals compete with each other for probabilistic selection. The first N_p individuals with minimum fitness values (for a minimization problem) are retained to be the parents of the next generation. This process of creating offspring and selecting those with minimum fitness are repeated until there is no appreciable improvement in the minimum fitness value.

4 EP BASED ALGORITHM OF OPF FOR CONGESTION MANAGEMENT

The steps for solving optimal power flow with TCSC controller for congestion management using EP are given as follows (Mosaad et al., 2010).

1. The objective function to execute the base case OPF (Wood et al. 1996) is to minimize total production cost (F_T) subject to real and reactive power flow constraints.

$$F_T = \min\left(\sum_{i=1}^{N_G} C_{Gi}(P_{Gi})\right) \tag{9}$$

where

C_{Gi} is the cost of generation for generator power
P_{Gi} is the power output of generator i in MW
a_i, b_i, c_i are the cost coefficients of the ith generator.

The constraint are given by Eq.(10) and Eq. (11)

$$P_{gi} - P_{di} = \sum_{j=1}^{N_B} |v_i||v_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}) \tag{10}$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{N_B} |v_i||v_j||Y_{ij}|\sin(\delta_i - \delta_j - \theta_{ij}) \tag{11}$$

2. The congestion in all line is checked with the calculated line flow from step 1.

3. The congestion is relieved by optimally locating TCSC in the line with most positive reactive power loss sensitivity index which is calculated for all lines with the help of Eq (7).

4. Run OPF with the inclusion of TCSC using evolutionary programming with the objective function

$$F_T = \min \left(\sum_{i=1}^{N_G} C_{Gi}(P_{Gi}) \right) + C_{TCSC} \tag{12}$$

where C_{TCSC} is the cost of TCSC which is given by Eq. (13)

$$C_{TCSC} = 0.0015S^2 - 0.7130S + 153.75 \text{ (\$/MVar)} \tag{13}$$

where S is the operating range of TCSC.

5. Check whether the congestion gets relieved. If the congestion is relieved stop the iteration and print results. Else go to step 1.

5 RESULTS AND DISCUSSION

The proposed method has been implemented on IEEE 14-Bus system as shown in (Fig.5). The results obtained have been found satisfactory. The test system has 5 generators, 14 buses and 20 lines. The generator and transmission line data relevant to the system are taken from (Rich Christie 1993).

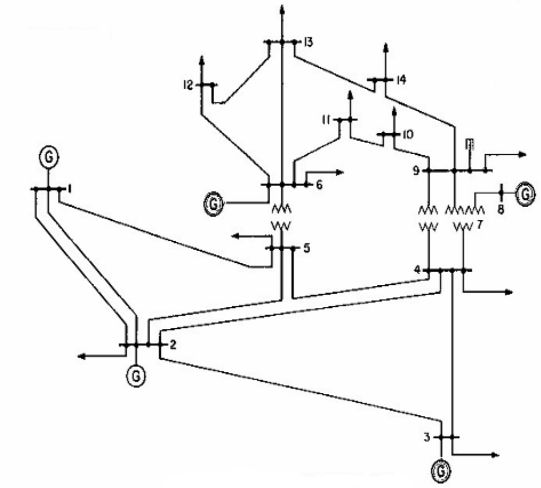

Fig. 5: Single line diagram of IEEE 14 Bus system

For the base case conditions, load flow is executed and the line flows are calculated. It is seen from the Table 1 that, the real power flow in line 5-6 is 32.8151 MW which is more than its line loading limit. Hence this line is considered as the congested line.

The Sensitivity indices are calculated placing TCSC in every line one at a time for the same operating conditions. The sensitivities of real power flow performance index with respect to

TCSC control parameter are given in Table 2 and it is clear that the highest positive sensitivity index is obtained for line 19. Hence by placing TCSC in line 19 relieves congestion.

Table 1: Base case line flows and their limits

Sending bus	Receiving bus	Line flow maximum limit	Actual line flow	Line over flow
1	2	130.00	52.8387	0
1	5	130.00	38.9051	0
2	3	65.00	28.2462	0
2	4	130.00	38.4958	0
2	5	130.00	30.7940	0
3	4	65.00	10.8617	0
4	5	90.00	33.8107	0
4	7	70.00	26.5942	0
4	9	130.00	13.9418	0
5	**6**	**32.00**	**32.8151**	**0.8151**
6	11	65.000	8.7731	0
6	12	32.00	8.2392	0
6	13	65.00	19.4648	0
7	8	65.00	20.4294	0
7	9	65.00	30.7126	0
9	10	65.00	6.6591	0
9	14	32.00	9.7801	0
10	11	32.00	4.8493	0
12	13	32.00	1.8259	0
13	14	16.00	6.3477	0

Table 2: Reactive power loss sensitivity index for each line

Line No	Between Buses	Sensitivity index	Line No	Between Buses	Sensitivity index
1	1-2	-0.204119	11	6-11	-0.004226
2	1-5	-0.122829	12	6-12	-0.003705
3	2-3	-0.068680	13	6-13	-0.019525
4	2-4	-0.109190	14	7-8	-0.035129
5	2-5	-0.070381	15	7-9	-0.083301
6	3-4	-0.007649	16	9-10	-0.002978
7	4-5	-0.088819	17	9-14	-0.005451
8	4-7	-0.064568	18	10-11	-0.001453
9	4-9	-0.017420	**19**	**12-13**	**0.000030**
10	5-6	-0.088914	20	13-14	-0.002231

The results of optimal dispatch with TCSC placement in line 19 is given in Table 3. It is seen that congestion gets relieved by the placement of TCSC.

Table 3: Result after locating TCSC

Sending bus	Receiving bus	Line maximum limit	Actual Line flow	Line flow
1	2	130.0000	65.7368	0
1	5	130.0000	35.4874	0
2	3	65.0000	39.2542	0
2	4	130.0000	34.0264	0
2	5	130.0000	22.2622	0
3	4	65.0000	9.8232	0
4	5	90.0000	50.6633	0
4	7	70.0000	24.2295	0
4	9	130.0000	10.3864	0
5	**6**	**32.0000**	**13.9543**	**0**
6	11	65.0000	18.9646	0
6	12	32.0000	8.8767	0
6	13	65.0000	24.4573	0
7	8	65.0000	19.1176	0
7	9	65.0000	20.7941	0
9	10	65.0000	11.7146	0
9	14	32.0000	7.9949	0
10	11	32.0000	15.5943	0
12	13	32.0000	2.5582	0
13	14	16.0000	12.7882	0

6 CONCLUSION

In this paper, reduction of reactive power loss sensitivity-based method has been developed for determining the optimal location of TCSC in an electricity market. The developed method is implemented on IEEE 14 bus system and the results reveal that the proposed method is simple, reliable and efficient for the practical implementation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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