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A NEW METHOD TO INCORPORATE TCSC IN OPTIMAL POWER FLOW USING GENETIC ALGORITHM

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ABSTRACT

In this work, Genetic Algorithm (GA) for the solution of the optimal power flow (OPF) with use of Thyristor Controlled Series Compensator (TCSC) is studied. The specified power flow constraints due to use of TCSC are included in the OPF in addition to the normal conventional constraints. The sensitivity analysis is carried out for the location of TCSC. This method provides an enhanced economic solution. Traditionally, classical optimization methods were used to effectively solve OPF. But more recently due to incorporation of Flexible A.C. Transmission System (FACTS) devices and deregulation of a power sector, the traditional concepts and practices of power systems are superimposed by an economic market management. So OPF have become complex. In recent years, Artificial Intelligence methods (GA etc) have emerged which can solve highly complex OPF problems. 5-bus system has been studied to show the effectiveness of the algorithm.

Keywords: optimal power flow, GA, thyristor controlled series compensator, flexible A.C. transmission system.

INTRODUCTION

Deregulation of the electricity supply system becomes an important issue in many countries. Flexible AC Transmission System devices become more commonly used as the power market becomes more competitive. They may be used to improve the transient responses of power system and can also control the power flow (both active and reactive power). The main advantages of FACTS are the ability in enhancing system flexibility and increasing the load ability [1].

In steady state operation of power system, unwanted loop flow and parallel power flow between utilities are problems in heavily loaded interconnected power systems. These two power flow problems are sometimes beyond the control of generators or it may cost too much with generator regulations. However, with the FACTS controllers, the unwanted power flow can be easily regulated [2, 3].

In OPF the main objective is to minimize the cost of meeting the load demand for the power system while satisfying all the security constraints. Since OPF is a non-linear problem, decouple of the control parameter of the FACTS device is a highly nonlinear problem [4] so that Genetic algorithm is used as a methodology to solve. In this context, more control facilities may complicate the system operation. As control facilities influence each other, a good coordination is required in order to bring all devices to work together, without interfering with each other. Therefore, it becomes necessary to extend available system analysis tools, such as optimal power flow to represent FACTS controls. It has also been noted that the OPF problem with series compensation may be a non-convex and non-linear problem, which will lead the conventional optimization method stuck into local minimum.

Genetic algorithms [5] offer a new and powerful approach to these optimization problems made possible by the increasing availability of high performance computers. These algorithms have recently found extensive applications in solving global optimization searching problems when the closed-form optimization technique cannot be applied. Genetic algorithms are parallel and global search techniques that emulate natural genetic operators. The GA is more likely to converge toward the global solution because it, simultaneously, evaluates many points in the parameter space. The method is not sensitive to the starting points and capable to determining the global optimum solution to the OPF for range of constraints and objective functions. In this paper a simple genetic algorithm is applied to the problem of optimal power flow. To accelerate the processes of GAOPF, the controllable variables are decomposed to active constraints that effect directly the cost function are included in the Genetic algorithms process and passive constraints which are updating using a conventional load flow program.

PROBLEM FORMULATION

The economic dispatch problem [6] is to simultaneously minimize the overall cost rate and meet the load demand of a power system. The power system model consists of *n* generating units already connected to the system. The economic dispatch problem can be expressed as the most commonly used objective in the OPF problem formulation is the minimization of the total cost of real power generation. The individual costs of each generating unit are assumed to be function, only of active power generation and are represented by quadratic curves of second order. The objective function for the entire power system can then be written as the sum of the quadratic cost model at each generator.

$$Min \sum_{i=1}^{n} F_i(P_i)$$

$$F_i(P_i) = \left(a_i + b_i P_i + c_i P_i^2\right) \quad (1)$$

where a_i, b_i and c_i are the cost coefficients of i-th generator and n is the number of generators committed to the operating system. P_i is the power output of the i-th generator. The economic dispatch problem subjects to the following constraints

$$P_{i\,(min)} \leq P_i \leq P_{i\,(max)} \quad for\ i = 1,\ldots..n \tag{2}$$

$$\sum_{i=1}^{n} P_i - P_D - P_L = 0 \tag{3}$$

Where

$$P_L = [P_1, P_2,\ldots\ldots P_n] \begin{bmatrix} B_{11} & \cdots & B_{1n} \\ \vdots & \ddots & \vdots \\ B_{1n} & \cdots & B_{nn} \end{bmatrix} \begin{bmatrix} P_1 \\ \vdots \\ P_n \end{bmatrix} + [P_1, P_2,\ldots\ldots P_n] \begin{bmatrix} \frac{B_{01}}{2} \\ \vdots \\ \frac{B_{0n}}{2} \end{bmatrix} + B_{oo} \tag{4}$$

where $P_{i(min)}$ and $P_{i(max)}$ are the minimum and maximum generating limits, respectively for the plant i. P_D is the load demand and P_L represents the transmission losses. B_{ii} and B_{oi} are the loss coefficients.

GENETIC ALGORITHM

The genetic algorithm [7] is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. We can apply the genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, nondifferentiable, stochastic, or highly nonlinear.

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population:

- Selection rules select the individuals, called parents that contribute to the population at the next generation.
- Crossover rules combine two parents to form children for the next generation.
- Mutation rules apply random changes to individual parents to form children.

The genetic algorithm differs from a classical, derivative-based, optimization algorithm in two main ways, as summarized in the following table.

Classical algorithm	Genetic algorithm
Generates a single point at each iteration. The sequence of points approaches an optimal solution.	Generates a population of points at each iteration. The best point in the population approaches an optimal solution.
Selects the next point in the sequence by a deterministic computation.	Selects the next population by computation which uses random number generators.

To find minimum of function using genetic algorithm:

Syntax

x = ga (fitnessfcn,nvars,A,b,Aeq,beq,LB,UB)

Description

- Implements the genetic algorithm at the command line to minimize an objective function.
- Finds a local unconstrained minimum, x, to the objective function, fitnessfcn. nvars is the dimension (number of design variables) of fitnessfcn. The objective function, fitnessfcn, accepts a vector x of size 1-by-nvars, and returns a scalar evaluated at x.
- Finds a local minimum x to fitnessfcn, subject to the linear inequalities A*x $\leq$ b. fitnessfcn accepts input x and returns a scalar function value evaluated at x. If the problem has m linear inequality constraints and nvars variables, then A is a matrix of size m-by-nvars. b is a vector of length m.
- Finds a local minimum x to fitnessfcn, subject to the linear equalities Aeq*x = beq as well as A*x $\leq$ b. (Set A = [] and b = [] if no inequalities exist.). If the problem has r linear equality constraints and nvars variables, then Aeq is a matrix of size r-by-nvars. beq is a vector of length r.
- Finds a local minimum x to fitnessfcn subject to a set of lower and upper bounds on the design variables, x, so that a solution is found in the range LB $\leq$ x $\leq$ UB. Use empty matrices for LB and UB if no bounds exist. Set LB (i) = -Inf if x (i) is unbounded below; set UB (i) = Inf if x (i) is unbounded above.

Genetic Algorithm finds the minimum for the Optimum power flow problem, where problem is a structure containing the following fields:

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fitnessfcn	Fitness function = Cost function
nvars	Number of design variables = No. of generators
Aeq	A matrix for linear inequality constraints Aeq = [],
beq	b vector for linear inequality constraints beq = []
A	A matrix for linear equality constraints A = [1,1,….1]
b	b vector for linear equality constraints b = [P_D + P_L]
LB	Lower bound on x LB=[lower limits of generators]
UB	Upper bound on x LB=[upper limits of generators]

FACTS DEVICES

The flexible ac transmission systems are designed to overcome the limitations of the present mechanically controlled ac power transmission systems [8]. By using reliable, high speed power electronic controllers, the FACTS technology provides the utilities with five opportunities for increased efficiency.

i Greater control of power so that it flows on the prescribed transmission routes.
ii Secure loading of transmission lines to levels nearer to their thermal limits.
iii Greater ability to transfer between controlled areas.
iv Prevention of cascading outages.
v Damping of power system oscillation.

The idea of FACTS is explained in Figure-1 which shows schematic diagram of an ac interconnection between two systems. The active power transmitted between the systems is defined by the given equation where V_1 and V_2 are the voltages at both ends of the transmission. X is the equivalent impedance of the transmission, and δ_1-δ_2 is the phase angle difference between both systems. From the equation it is evident that the transmitted power is influenced by three parameters: voltage, impedance and voltage angle difference. FACTS devices can influence one or more of these parameters as shown in Figure, and thereby influence power flow.

Figure-1 is a list of FACTS controllers which have been realized or are still under development for application. They can be used for load flow control, voltage control and stability improvement in transmission system as well as for additional special applications.

The advantage of FACTS is that combining a variety of different equipment can create different new members of the FACTS family. Advantages of FACTS controllers in ac system are shown in Table-1.

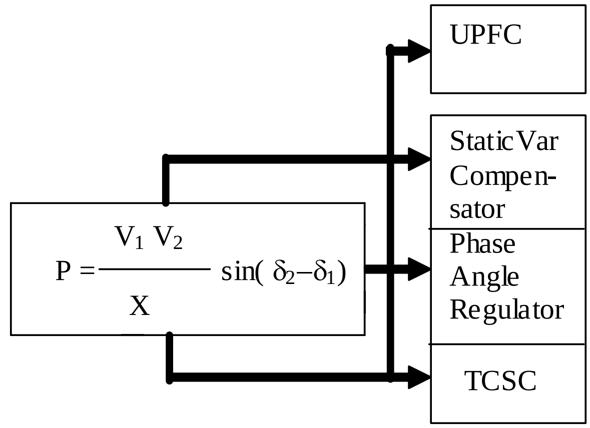

Figure-1. Representation of different controllers.

Table-1. Comparison of advantages of FACTS.

Device name	Load flow control	Voltage control	Transient stability	Oscillation damping
SVC	*	***	*	**
TCSC	**	*	***	**
SSSC	***	**	***	**
UPFC	***	***	***	***

*small** medium*** strong

The first series connected FACTS controllers, TCSC, were put into operation about eight year years ago. As shown in Figure-2, TCSC can vary the impedance continuously to the level below and up to the line natural impedance. TCSC have been realized also in commercial projects. The main task for this type of controller is load flow control and the improvement of stability conditions in the system. A further advantage of TCSC is the ability to damp sub synchronous resonance.

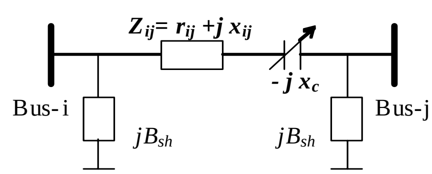

Fig. 2: Model of TCSC

REAL POWER FLOW PI SENSITIVITY INDICES FOR LOCATING TCSC

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index [9], as given below:

$$PI = \sum_{m=1}^{N_l} \frac{w_m}{2n} \left(\frac{P_{lm}}{P_{lm}^{\max}} \right)^{2n} \quad (5)$$

where P_{lm} is the real power flow and $P_{lm}^{\max}$ is the rated capacity of line-*m*, *n* is the exponent and w_m a real non-negative weighting coefficient which may be used to reflect the importance of the lines. N_l is the total number of lines in the network. In this study, the value of exponent has been taken as 2 and w_m =1.0. Real power flow performance index gives good measure of the system congestion during the normal operating condition. The real power flow PI sensitivity factors with respect to the control parameters can be defined as:

$$c_1^k = \left.\frac{\partial PI}{\partial V_T}\right|_{V_T=0} \quad \text{= PI sensitivity with respect to } V_T$$

$$c_2^k = \left.\frac{\partial PI}{V_T \partial \phi_T}\right|_{\phi_T=0} \quad \text{= PI sensitivity with respect to } \phi_T$$

$$c_3^k = \left.\frac{\partial PI}{\partial I_q}\right|_{I_q=0} \quad \text{= PI sensitivity with respect to } Iq$$

APPLICATION STUDY

This paper proposes an application of genetic algorithm to solve the OPF problems. In this paper transmission losses are included by calculating the B coefficients of transmission losses. The 5 bus system has been used to test the effectiveness of the proposed method. A new technique to implement the TCSC in Optimal Power Flow has also been used. The Bus and Line Data of the system is presented below in Tables 2 and 3. The system consists of 7 lines and 3 generators, bus one is taken as reference bus others are taken as load buses. The initial angle at respective buses is assumed as zero degree.

Table-2. Bus data.

Bus No.	Voltage mag.	Angle degree	---Load----		---Generator----			
			MW	Mvar	MW	Mvar	Qmin	Qmax
1	1.06	0.0	0	0	0	0	10	50
2	1.045	0.0	20	10	40	30	10	50
3	1.03	0.0	20	15	30	10	10	40
4	1.00	0.0	50	30	0	0	0	0
5	1.00	0.0	60	40	0	0	0	0

Generator operating costs in $/h, with P_i MW are as follows:

$C_1 = 200 + 7.0P_1 + 0.008P_1^2$
$C_2 = 180 + 6.3P_2 + 0.009P_2^2$
$C_3 = 140 + 6.8P_3 + 0.007P_3^2$

Generator real power limits are:

Generator	Minimum MW	Maximum MW
1	10	85
2	10	80
3	10	70

Table-3. Line data.

Bus No.	Bus No.	R p.u.	X p.u.	1/2 B p.u.	tr. tap at bus
1	2	0.02	0.06	0.030	1
1	3	0.08	0.24	0.025	1
2	3	0.06	0.18	0.020	1
2	4	0.06	0.18	0.020	1
2	5	0.04	0.12	0.015	1
3	4	0.01	0.13	0.010	1
4	5	0.08	0.24	0.025	1

To get Power flow solution, Newton-Raphson Method is applied. The voltage profile at various buses and the total generating cost is obtained as shown in Table-4.

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Table-4.

Bus No.	Voltage mag.	Angle degree	---Load----		---Generator----	
			MW	Mvar	MW	Mvar
1	1.060	0.000	0.000	0.000	83.689	24.615
2	1.035	-1.796	20.000	10.000	40.000	28.104
3	1.030	-1.991	20.000	15.000	30.000	23.396
4	0.999	-4.086	50.000	30.000	0.000	0.000
5	0.976	-4.743	60.000	40.000	0.000	0.000
Total Generating Cost = 1636.02 $/h						

The FACTS device should be placed on the most sensitive lines. With sensitivity indices computed for the FACTS device the TCSC should be placed in a line having largest negative value of sensitivity factor. In 5 bus system case, line 3 to 4 is most suitable line to connect the TCSC.

Modifications required in Load flow to include TCSC:

a) The two main objectives of TCSC are to either compensate the line reactance or to maintain a specified power flow in the line.
b) If the main objective of TCSC is to compensate the line reactance then it can be considered as simple capacitive impedance in series with the line reactance.
c) Hence, only the admittance matrix used in load flow analysis has to be modified.
d) The line impedance of a series compensated line will decrease and this will be reflected in admittance matrix.

A TCSC of 0.10 p.u. capacitive impedance is connected between the lines 3 to 4.

Table-5. Modified line data.

Bus No.	Bus No.	R p.u.	X p.u.	1/2 B p.u.	tr. tap at bus
1	2	0.02	0.06	0.030	1
1	3	0.08	0.24	0.025	1
2	3	0.06	0.18	0.020	1
2	4	0.06	0.18	0.020	1
2	5	0.04	0.12	0.015	1
3	4	0.01	0.03	0.010	1
4	5	0.08	0.24	0.025	1

After incorporating the TCSC parameter, Load flow program in MATLAB is executed. After Load flow, we get the improved voltage profile and reduced total generating cost as shown in Figure-3 and in Table-6.

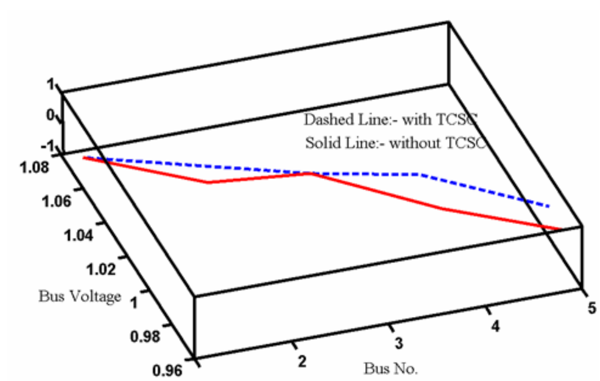

Figure-3. Comparison of the Bus Voltage angle variation with and without the use of TCSC.

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Table-6.

Bus No.	Voltage Mag.	Angle Degree	---Load----		---Generator----	
			MW	Mvar	MW	Mvar
1	1.060	0.000	0.000	0.000	83.689	7.271
2	1.045	-1.782	20.000	10.000	40.000	41.811
3	1.030	-2.664	20.000	15.000	30.000	24.148
4	1.019	-3.243	50.000	30.000	0.000	0.000
5	0.990	-4.405	60.000	40.000	0.000	0.000
Total Generating Cost = 1633.24 $/h						

OPTIMUM POWER FLOW USING GENETIC ALGORITHM INCLUDING TRANSMISSION LOSSES

To find the loss coefficients

- First a power solution is obtained for the initial operating state. This provides the voltage magnitude and phase angles at all buses.
- From these results load currents are obtained.
- Bus matrix is found.
- Transformation matrices are found.
- Finally B coefficients are evaluated.

The B coefficients are the functions of the system operating state. If a new scheduling of generation is not drastically different from the initial operating condition, the loss coefficients may be assumed constant.

B =

0.0218	0.0093	0.0028
0.0093	0.0228	0.0017
0.0028	0.0017	0.0179

B0 =

0.0003	0.0031	0.0015

B00 =
3.0523e-004

Total system loss = 3.05248 MW

Genetic algorithm is used to calculate optimum value of generation taking the condition $P = P_D + P_L$

P1 = 33.7698
P2 = 68.2807
P3 = 51.0010

Total Generating Cost without TCSC = 1636.02 $/h
Total Generating Cost with TCSC = 1633.24 $/h
Total Generating Cost with GAOPF = 1602.70 $/h

Thus it can also be seen that the total generation cost per hour comes down by 1636.02 - 1602.70 = 33.32 $/h as a result of the proposed TCSC usage with GAOPF.

CONCLUSIONS

In this paper a new method with genetic algorithm is presented to solve the optimal power flow problem of power system with flexible AC transmission (FACTS) systems. The proposed method introduces a new method to incorporate FACTS devices into a conventional optimum power flow problem. The merits of this method are that there is no requirement to modify the power mismatch equations to implement the FACTS devices. Application of this technique to Optimal Power Flow has been explored and tested. The simulation results show that this simple algorithm can give a good result using only simple modifications. Case studies on IEEE test system show the potential for application of GA to determine optimal dispatch of generation with FACTS devices.

REFERENCES

[1] G. Breuer. 1991. Flexible AC Transmission Systems: Technology for Future. Proceeding of 20th Annual Electrical/ Electronic Insulation conference. Boston MA.

[2] A.J. Wood and B.F. Wollenberg. 1984. Power Generation Operation and Control. John Wiley and Sons, New York, USA.

[3] Bouktir T., Belkacemi M., Zehar K. 2000. Optimal power flow using modified gradient method. Proceedings ICEL'2000, U.S.T. Oran, Algeria. pp. 436-442.

[4] Galiana G.D. *et al*. 1936. Assesment and control of impact of FACTS devices on Power system Performance. IEEE Tran on Power System. 11(4): 1931-1936.

[5] D. Walters and G.B. Sheble. 1993. Genetic algorithm solution of economic dispatch with valve point loading. IEEE Trans. on Power Systems. 8(3): 1325-1331.

[6] A. Bakirtzis, V. Petrides and S. Kazarlis. 1994. Genetic algorithm solution to the economic dispatch problem. IEE Proc. Gener. Transm. Distrib. 141(4): 377-382.

[7] P.H. Chen and H.C. Chang. 1995. Large-scale economic dispatch approach by genetic algorithm. IEEE Trans. on Power Systems. 10(4): 1919-1926.

[8] N. G. Hingorani. 1993. Flexible AC Transmission. IEEE Spectrum. 30(4): 40-45.

[9] Lie. TT. and Deng W. 1999. Optimal Flexible AC Transmission Systems (FACTS) Devices Allocation. International Journal of Electrical Power and Energy Systems. 19(2): 125-134.

[10] Dommel H.W., Tinney W.F. 1968. Optimal Power Flow Solutions. IEEE Transactions on power apparatus and systems. PAS. 87(10): 1866-1876.

[11] Fletcher R. 1986. Practical Methods of Optimization. John Willey and Sons.

[12] Dorigo M. 1992. Optimization, learning, and natural algorithms, Ph.D. Dissertation (in Italian), Dipartimento di Elettronica, Politecnico di Milano, Italy.