International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 10, October - 2013

Power Flow Control incorporating TCSC using Differential Evolution

Abhishek Bhardwaj
Thapar University, Patiala

Manbir Kaur, *Member IET*
Thapar University, Patiala

***Abstract*— Optimal power flow aims to optimize the generation cost, active power loss via optimal adjustment of power system control variables, while at the same time satisfying various equality and inequality constraints. In recent years FACTS devices have made the power systems operation more flexible and secure. In this paper, the focus is to obtain the optimal solution using differential evolution, when thyristor controlled series capacitors (TCSC) are used at fixed location in the system. The proposed strategy is tested on IEEE 14 bus system and load flow is carried out with Newton Raphson method. The results obtained are compared for the system with and without TCSC. and shows improvement in results.

***Index Terms*— Differential Evolution, Generator Fuel Cost FACTS, Optimal power flow**.**

I. INTRODUCTION

As power industry is moving to a competitive market, its operation is strongly influenced. Optimization methods have been widely used in power system operation, analysis and planning. One of the most significant application is optimal power flow (OPF). So when we consider the case of power system operation and planning, Optimal Power Flow (OPF) plays an important role. The OPF mainly aims to optimize the selected objective function such as fuel cost, active power loss via optimal adjustment of power system control variables, keeping the equality and inequality constraints in limit. Equality constraints are basically the power flow equations, while inequality constraints are the limits on control variables and control variable includes the generator active powers, the generator bus voltage magnitudes, the transformer tap settings and reactive power of VAR sources. Mathematically, OPF is modelled as a nonlinear programming (NLP) problem, which usually minimizes the total generating unit fuel cost and total load bus voltage deviation from a specified point subject to a set of equality and inequality constraints and thus losses can be reduced to a significant amount by keeping the equality and inequality constraints in limit. Now as the demand for the power transfer increases, the power system becomes increasingly more difficult to operate and insecure with unscheduled power flows and thus handling the losses. Rapid development of self-commutated semiconductor devices has made it possible to design power electronic equipment. This equipment is well known aslexible AC Transmission System (FACTS) which has been introduced by Hingorani [1] in 1988. FACTS Technology is concerned with the management of active and reactive power to improve the performance of electrical networks and thus minimizing the losses. FACTS includes various types of series and shunt type VAR compensators. Series and shunt VAR compensators have the capability to change the performance characteristics of electrical networks. In both of them, the reactive power through the system can significantly improve the performance of the power system. So, as discussed earlier OPF is modelled as a nonlinear programming (NLP) problem and when we incorporated FACTS in it and considered as a control variable, it becomes even more nonlinear and complex. Various researchers developed algorithms to solve optimal power flow incorporating FACTS devices. T.S.Chung *et al.* [2] presented a Hybrid Genetic Algorithm (GA) method to solve OPF incorporating FACTS devices. GA is integrated with conventional OPF to select the best control parameters to minimize the total generation fuel cost and keep the power flows within the security limits. TCPS and TCSC are modeled. The proposed method was applied on modified IEEE 14 bus system and it converged in a few iterations. L.J.Cai *et al.* [3] proposed optimal choice and allocation of FACTS devices in multi-machine power systems using genetic algorithm. The objective is to achieve the power system economic generation allocation and dispatch in deregulated electricity market. The locations of the FACTS devices, their types and ratings are optimized simultaneously. UPFC, TCSC, TCPST and SVC are modeled and their investment costs are also considered.

The remaining part of the paper is organized as follows. Section II presents the modeling of TCSC. Section III represents the problem formulation of OPF using TCSC. Section IV gives the brief idea about Differential Evolution. Section V gives overview of proposed algorithm. Implementation of DE to solve OPF problem incorporating TCSC and results is presented in Section VI. Finally conclusion is drawn in Section VII.

II. MODELLING OF TCSC

Transmission lines are invariably represented by π equivalent parameters and is located as lumped component in the entwork. The series compensator Thyristor controlled Series Compensator (TCSC) is a static capacitor/ reactor with impedance X_C. Fig. 1 shows a transmission line incorporating a TCSC. [4][5] between bus nodes *i* and *j* and updated admittance between nodes *i and j* will be expressed as in equation (1):

$$\Delta y_{ij} = y_{ij}^{'} - y_{ij} = (g_{ij}^{'} + jb_{ij}^{'}) - (g_{ij} + jb_{ij}) \quad \text{.....(1)}$$

$$g_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} ; \; b_{ij} = - \frac{x_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}}$$

$$g_{ij}^{'} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + (x_{ij} + x_c)^2}} ; \; b_{ij}^{'} = \frac{r_{ij} + x_{ij}}{\sqrt{r_{ij}^2 + (x_{ij} + x_c)^2}}$$

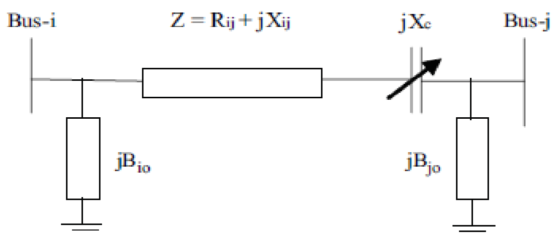

Figure 1: Equivalent circuit of a line with TCSC

With the addition of TCSC in the line between bus i and bus j of a general power system, the new system admittance matrix Y_{bus} can be updated as:

$$Y'_{bus} = Y_{bus} + A \quad \ldots (2)$$

s

$$A=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \Delta y_{ij} & 0 \cdots 0 & & -\Delta y_{ij} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\Delta y_{ij} & 0 \cdots 0 & & \Delta y_{ij} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

III. PROBLEM FORMULATION

The objective function of power flow problem is the minimization of total generation cost. Power flow equations in the OPF problem incorporating flexible ac transmission system is expressed as follows:

$$\sum_{i=1}^{Ng} a_i + b_i P_i + c_i P_i^2 + |d_i * sin\{e_i * (P_i^{min} - P_i)\}| \quad \ldots(3)$$

Subject to

$$P_{Gi} - P_{Di} - \sum_{j=1}^{NB} V_i V_j \, \gamma_{ij} \cos(\theta_{ij} + \delta_i - \delta_j) = 0 \quad \forall_i \in N_B \quad \ldots\ldots\ldots(4)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{NB} V_i V_j \, \gamma_{ij} \sin(\theta_{ij} + \delta_i - \delta_j) = 0 \quad \forall_i \in N_B \quad \ldots\ldots\ldots(5)$$

$$\sum_{i=1}^{NG} P_{Gi} - P_D - P_L \quad \ldots\ldots(6)$$

$$\sum_{i=1}^{NQ} Q_{Gi} - Q_D - Q_L \quad \ldots\ldots(7)$$

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad \forall_i \in N_G \quad \ldots\ldots(8)$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \quad \forall_i \in N_G \quad \ldots\ldots(9)$$

$$V_i^{min} \leq V_i \leq V_i^{max} \quad \forall_i \in N_B \quad \ldots\ldots(10)$$

$$x_{ci}^{min} \leq x_{ci} \leq x_{ci}^{max} \quad \forall_i \in N_{TCSC} \quad \ldots\ldots(11)$$

where,

P_{Gi}	Real power generation at bus i,
Q_{Gi}	Reactive power generation at bus i
P_{Di}	Real power demand at bus i
Q_{Di}	Reactive power demand at bus i
γ_{ij}	magnitude of ij^{th} element in bus x
θ_{ij}	angle of ij^{th} element in bus admittance matrix
V_i	voltage magnitude at bus i
δ_j	phase angle at bus j
x_{ci}	reactance of TCSC i
N_G	set of generator bus indexes
N_Q	set of bus indexes having reactive power source
N_B	set of bus indexes
N_L	set of transmission line indexes
N_{TCSC}	set of TCSC
a_i, b_i, c_i, d_i, e_i	cost coefficient of generator i,

IV. DIFFERENTIAL EVOLUTION

Differential Evolution (DE) is an evolutionary algorithm originally proposed by Price and Storn [6] for optimization problems over a continuous domain. DE is exceptionally simple, significantly faster and robust. The basic idea of DE is to adapt the search during the evolutionary process. Differential Evolution (DE) is a parallel direct search method and selectes the optimal solution from D dimension population. The initial vector population is chosen randomly defioned over the parameter space. The perturbation is assumed as large at the start of evolution. At the start of the evolution, the perturbations are large since parent populations are far away from each other. Over the evolution process the population converges to a small region and the perturbations adaptively become small. As a result, the evolutionary algorithm performs a global exploratory search during the early stages of the evolutionary process and local exploitation during the mature stage of the search. In DE the fittest of an offspring competes one-to-one with that of corresponding parent which is different from other evolutionary algorithms. This one-to-one competition gives rise to faster convergence rate. The optimization process in DE is carried out with three basic operations: mutation, crossover and selection. The DE algorithm is described as follows:

1) Initialization

The initial population X with population size of Np is initialized randomly such that X=[N_1, N_2, N_3..............N_{NP}]. Each solution is given by N_n =[P_{n1},P_{n2},P_{n3},.........P_{nN}](where n = 1, 2 ... Np ,N is the number of real power generations in the problem and Np is the Number of population). The variables shall bound within their upper and lower limits. Let the n^{th} component of the m^{th} population members may be initialized as

$$X_{mn}^0 = X_n^l + rand(0,1) * (X_n^u - X_n^l) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Where X_n^u is the upper bound of the n^{th} variable of the problem , X_n^l is the lower bound of the n^{th} variable of the problem, rand (0,1) is a uniformly distributed number within the limits(0,1), X_{mn}^{0} is the initial nth variable of the mth population.

2) Mutation

Mutant population is generated. Among the DE variants used for mutation in DE, the addition of the weighted difference vector between the two population members to the third member is adopted in this approach. Here three different members namely X_{r1} ,X_{r2} and X_{r3} are chosen from the current population .Then the difference between any two of these members is scaled by a scalar number F, which is then added to the third member. The value of F is usually in between 0.4 and 1. The Mutation operation using the difference between two randomly selected individuals may cause the mutant individual to escape from the search domain. If an optimized variable for the mutant individual is outside of the domain search, then this variable is replaced by its lower bound or its upper bound so that each individual can be restricted to remain within the search domain. mth member of the donor vector $V_n(t)$ is expressed as

$$V_{mn}^{(t+1)} = x_{r1}m(t) + F * \left(x_{r2}m(t) - x_{r3}m(t)\right) \ldots\ldots\ldots\ldots(12)$$

3) Crossover

. A new population is created by suitably combining the parent population and the mutant population. The process of crossover is based on the CR which is in between (0,1). Binomial crossover scheme is used which is performed on all D variables and can be expressed as:

$U_m(t) = V_{mn}(t)$ if rand (0, 1) < CR

$U_m(t) = X_{mn}(t)$ else

where $U_{mn}(t)$ is the child which is obtained after crossover operation where m = 1,2, ... Np, n = 1,2, ... D. Here, rand ensures that the newly generated vector is different for both $V_{mn}(t)$ and $X_{mn}(t)$.

4) Selection

After calculating the objective function F(t) using D number of variables for using initial and crossover population , a new population with the least objective function (minimum fuel cost) is formed foSr the next generation. This is given by

$$X(t+1) = U_n(t) \text{ if } f(U_n(t)) \leq f(X_n(t))$$

$$X(t+1) = X_n(t) \text{ if } f(U_n(t)) > f(X_n(t))$$

The process is repeated until the maximum number of generations or no improvement is seen in the real power generation cost after many generations. The global optimum searching capability and the convergence speed of DE are very sensitive to the choice of control parameters NP, F and CR. The crossover $_{rate}$ CR is between [0.3, 0.9].

V. PROCEDURAL STEPS

Step 1.Intailse the population for decision variables of power system namely: real power generation of the generating units excluding slack bus, voltage magnitude and phase angle of the buses and series capacitors of TCSC. The ith parent vector is as follows:

$p_i = [P_{G1}^{i} \ldots P_{Gm}^{i} \ldots P_{GNg}^{i}, V_1^{i} .. V_m^{i} \ldots . V_{Nb}^{i}, .. \delta_1^{i} \ldots . \delta_m^{i} \ldots . \delta_{Nb}^{i},$ $x_{c1}^{i} \ldots\ldots x_{cm}^{i} \ldots \ldots x_{cNTCSC}^{i} \ ]^{T}.$

Step 2: Run Newton–Raphson load flow for each parent vector p_i. The reactive power generations, transmission loss, slack bus generations and line flows are determined. Cost of generation is calculated for each parent vector p_i.

Step 2. Perform mutation for each target vector.

Step 3. Perform crossover for each target vector and create a trial vector.

Step 4. Perform selection for each target vector, by comparing its cost with that of the trial vector. The vector that has lesser cost of the two would survive for the next generation.

Step5. Stop if the maximum number of generations is reached otherwise go to Step 2.

VI. RESULTS AND DISCUSSIONS

The effectiveness of the proposed algorithm is tested on IEEE 14-bus system. Two branches, (2, 3), (6, 8) are selected and TCSC are installed. Limits of the series capacitors size are taken in such a manner that the ratio of maximum series capacitors limit to line reactor is equal or more than 50% . The results obtained are tabulated in table 1. The values of TCSC capacitances obtained are presented in table 2.

Table 1: Comparison of Results

Generator (MW)	Power Generation with TCSC using DE	Power Generation without TCSC using DE	Power Generation Using Conventional Load flow method
P1	162.81	162.30	232.60
P2	34.95	61.03	40
P3	26.10	21.56	0
P4	20.81	13.82	0
P5	22.58	10.00	0
Cost($/h)	**746.2312**	**754.7656**	**801.0287**
Losses(MW)	**8.2542**	**9.711**	**13.600**

Table 2 Values of TCSC obtained from DE

Position of TCSC	Capacitance values in pu
x_{c2-3}	0.0826
x_{c6-8}	0.0090

Table 3 represents the comparison of conventional load flow solution for bus voltages and phase angles of modified IEEE 14 bus system with and without TCSC.

Table 3: bus Voltage magnitudes and Phase angles

Bus No.	Voltages (pu)	Angle Degree	Voltages (pu)	Angle Degree	Voltages (pu)	Angle Degree
1	1.0000	0	1.0000	0	1.0000	0
2	1.0450	-4.9957	1.0026	-3.9821	0.9874	-3.9624
3	1.0200	-12.8726	0.9981	-11.0747	0.9876	-8.8393
4	1.0600	-14.4096	0.9829	-12.0017	1.0249	-10.1571
5	1.0800	-13.2742	0.9700	-9.8988	1.0343	-6.5195
6	1.0139	-10.2425	0.9643	-8.6329	0.9727	-7.5957
7	1.0444	-13.2742	0.9636	-10.9786	1.0011	-8.7206
8	1.0159	-8.7337	0.9649	-7.2713	0.9742	-6.6609
9	1.0274	-14.8829	0.9500	-12.9502	0.9850	-10.7615
10	1.0255	-15.0875	0.9500	-13.1204	0.9841	-10.9635
11	1.0390	-14.8713	0.9606	-12.7057	1.0005	-10.6886
12	1.0436	-15.2771	0.9653	-13.0401	1.0075	-11.0981
13	1.0375	-15.3247	0.9586	-13.1256	1.0006	-11.1509
14	1.0134	-16.1166	0.9500	-14.2504	0.9726	-12.0589

Fig. 2 and Fig. 3 represents the generation cost with and without TCSC respectively.

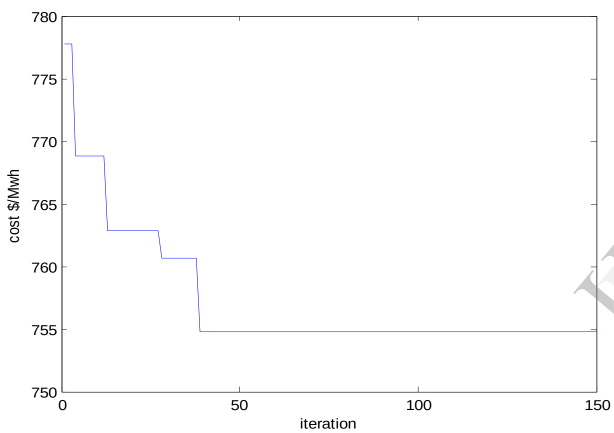

Figure 2. Cost Reduction using DE without TCSC

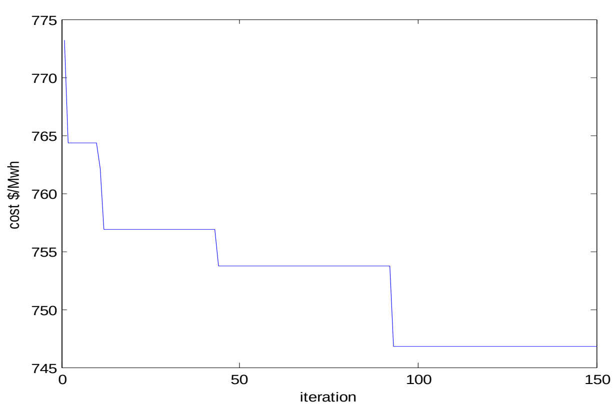

Figure 3 Cost Reduction using DE with TCSC

VII. CONCLUSIONS

. In this study, differential evolution is successfully implemented to minimize the generator fuel cost in optimal power flow control with TCSC keeping the equality and inequality constraints in limits. Differential evolution achieves better solution on modified IEEE 14-bus system with TCSC fixed at the given locations. The results has been compared with conventional load flow method and OPF using DE without TCSC and it is concluded that the generator fuel cost reduces significantly and losses are also less when we use TCSC with DE as compared to other two.

REFERENCES

[1] Hingorani NG. Power electronics in electrical utilities: Role of power electronics in future power systems. Proc IEEE 1988;76 (4):pp.481–482. April 1988.

[2] Chung, T. S.; Li, Y.Z., "A hybrid GA approach for OPF with consideration of FACTS devices," *IEEE Power Engineering Review*, vol.20, no.8, pp.54-57, Aug 2000

[3] Cai, L.J.; Erlich, I.; Stamtsis, G., "Optimal choice and allocation of FACTS devices in deregulated electricity market using genetic algorithms," *IEEE PES Power Systems Conference and Exposition, 2004*, vol.1, pp.201-207, 10-13 Oct. 2004

[4] Anastasios G. Bakirtzis, Pandel N. Biskas, Christoforos E. Zoumas, Vasilios Petridis, "*Optimal Power Flow by Enhanced Genetic Algorithm", IEEE Transactions On Power Systems*, Vol. 17, no. 2, pp 229-236, May 2002.

[5] M. Noroozian, G. Anderson, "*Power Flow Control by Use of Controllable Series Components*", IEEE Transactions on Power Delivery, VO1.8, No.3, July 1993, pp. 1420- 1428.

[6] A.A. Abou EI Elaa, M.A. Abidob, S.R. Speaa, " Optimal power flow using differential evolution algorithm" International Journal of Electric Power Systems Research 80, 878-885,2010

[7] Storn R, Price KV. Differential evolution – a simple and efficient heuristic for global optimization over continuous spaces. J Global Optim 1997;11 (4):341–59

[8] Price KV, Storn R, Lampinen J. Differential evolution: a practical approach to global optimization. Berlin: Springer-Verlag; 2005

[9] Taranto GN, Pinto LMVG, Pereira MVF. Representation of FACTS devices in power system economic dispatch. IEEE Trans Power Syst 1992;7 (2):572–6.

[10] Gotham DJ, Heydt GT. Power flow control and power flow studies for systems with FACTS devices. IEEE Trans Power Syst 1998;13 (1):60–5.

[11] Ge SY, Chung TS. Optimal active power flow incorporating power flow control needs in flexible AC transmission systems. IEEE Trans Power Syst 1999;14 (2):738–44.

[12] Ambriz-Perez H, Acha E, Fuerte-Esquivel CR. Advanced SVC model for Newton–Raphson Load Flow and Newton optimal power flow studies. IEEE Trans Power Syst 2000;15 (1):129–36.

[13] Chung TS, Li YZ. A hybrid GA approach for OPF with consideration of FACTS devices. IEEE Power Eng Rev 2001;21 (2):47–50

[14] Ongsakul W, Bhasaputra P. Optimal power flow with FACTS devices by hybrid TS/SA approach. Electr Power Energ Syst 2002;24:851–7.

[15] M. Basu, "Optimal power flow with FACTS devices using differential evolution", *International Journal of Electrical Power & Energy Systems*, Volume 30, Issue 2, , Pages 150-156, ISSN 0142-0615, February 2008

[16] Ongsakul W., Jirapong, P. "Optimal allocation of FACTS devices to enhance total transfer capability using evolutionary programming" *IEEE International Symposium on Circuits and Systems, 2005. ISCAS 2005*, Vol. 5, pp.4175-4178, 23-26, May 2005.