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Differential Evolution Algorithm for Security Constrained Optimal Power Flow

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Abstract - This paper presents a differential evolution algorithm approach to solve Security Constrained Optimal Power Flow (SCOPF) problem in power system including FACTS device. In this process, under a line outage the generation cost is to be minimised and to keep the power flow in their security limits, in addition to that the losses is to be minimised after installing the FACTS device. A versatile FACTS device Unified Power Flow Controller (UPFC) is considered as a combination of SVC and TCSC .The operating limit of the FACTS device is defined not only to minimize the total generation cost but also to reduce transmission loss. The proposed method was tested using standard IEEE-30 bus system with 6 generating units to show the effectiveness of the proposed algorithm for solving the SCOPF problem.

Index Terms- Differential Evolution, generation cost, transmission loss, Security Constrained Optimal Power flow, UPFC, SVC, TCSC.

I. INTRODUCTION

In any power system, the unexpected outages of lines occur due to faults or some other disturbances. These events, referred to as contingencies, may cause significant overloading of transmission lines or transformers, which in turn may lead to a viability crisis of the power system. The principle task of power system control is to maintain a secure system state, i.e., to prevent the power system moving from secure state into emergency state over the widest range of operating conditions. Optimal Power Flow (OPF) is major tool used to improve the security of the system. The main purpose of an OPF is to determine the optimal operating state of power system and the corresponding settings of the control variables for economic operation, while at the same time satisfying equality and inequality constraints. The power balance equations are the equality constraints and inequality constraints are the limits control variables and the operating limits of power system dependent variables. The most widely considered objective function amongst a number of different objectives that an OPF problem may be formulated is the fuel cost minimization. The power electronics-based FACTS devices can also be employed for corrective action due to its high speed of response. Unified Power Flow Controller (UPFC) is one such device which offers smooth and flexible control of both real and reactive power, with much faster response compared to the traditional control devices.

UPFC can be used effectively in maintaining system security in case of a contingency by eliminating or alleviating overloads along the selected network branches.

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The optimal base case control variables and the post contingency UPFC settings are obtained as the solutions to SCOPF problem of minimizing over loaded lines for single line outages. The various formulation aim at either minimizing the total fuel cost or minimizing some defined objective function i.e., minimizing/alleviating the line overloads with system security constraints [1,2]. A number of mathematical programming based techniques have been proposed to solve the OPF problem that can be classified in to linear, nonlinear or mixed integer linear problem [1,3]. In its most general formulation, the OPF is a nonlinear, non-convex and a static optimization problem. Many mathematical programming techniques such as linear programming [6], nonlinear programming, quadratic programming, gradient method [2-4], Newton method [5] and interior point methods have been applied to solve this problem. But the gradient and Newton methods suffer from the difficulty in handling inequality constraints. The interior point method has major drawbacks such as improper step size selection may cause the sub-linear problem to have a solution that is infeasible in original nonlinear domain. In addition to that an awful initialization and termination in interior point methods to solve nonlinear and quadratic objective functions.

In recent years, many heuristics algorithms such as genetic algorithm, simulated annealing, particle swarm optimization, chaos optimization algorithm, tabu search and differential evolution algorithm have been proposed for solving this problem, without any restrictions on the shape of the cost curves.

This paper presents a DE algorithm to solve the SCOPF. The proposed algorithm solves the SCOPF problem subject to the power balance equality constraints, limits on control variables namely active power generation, controllable voltage magnitude pertaining to the base case, UPFC for contingency case studies.

II. PROBLEM FORMULATION

The OPF problem is considered as a general minimization problem with constraints, and can be written in the following form:

$$\text{Min } f(x,u) \qquad (1)$$

$$\text{Subject to: } g(x,u) = 0 \qquad (2)$$

$$h(x,u) \leq 0 \qquad (3)$$

$$x_{min} \leq x \leq x_{max}$$

$$u_{min} \leq u \leq u_{max}$$

Where f(x,u) is the objective function, g(x,u) and h(x,u) are respectively the set of equality and inequality constraints. The vector of state and control variables are denoted by x and u respectively.

The objective function f is total generation cost as expressed follows:

$$\text{Min } f = \sum_{i=1}^{NG}(a_i + b_i P_{gi} + c_i P_{gi}^2) \qquad (4)$$

Where NG is the number of generating units, P_{gi} is the active power generation at unit i and a_i, b_i and C_i are the cost coefficients of the i^{th} generator.

A. Equality Constraints

The equality constraints g(x) are the real and reactive power balance equations, expressed as follows:

$$P_{gi} - P_{di} = V_i \sum_{j=1}^{N} V_j \left(g_{ij}\cos\delta_{ij} + b_{ij}\sin\delta_{ij}\right) \qquad (5)$$

and

$$Q_{gi} - Q_{di} = V_i \sum_{j=1}^{N} V_j \left(g_{ij}\sin\delta_{ij} - b_{ij}\cos\delta_{ij}\right) \qquad (6)$$

Where N is the number of buses, P_{gi}, Q_{gi} are the active and the reactive power generation at bus i; P_{di}, Q_{di} are the real and the reactive power demand at bus i , j , the voltage magnitude at bus i , j , respectively; δ_{ij} is the phase angle difference between buses i and j respectively, g_{ij} and b_{ij} are the real and imaginary part of the admittance (Y_{ij}) and N is the total number of buses.

B. Inequality Constraints

The inequality constraints h(x,u) reflect the security limits, which include the following constraints as mentioned below:

Generator Constraints

Upper and lower limits on the active power generations:

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad i = 1,2,K,NPV \qquad (7)$$

Upper and lower limits on the reactive power generations:

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \quad i = 1,2,K,NPV \qquad (8)$$

Upper and lower limits on the generator bus voltage magnitude:

$$V_{gi}^{min} \le V_{gi} \le V_{gi}^{max} \quad i = 1,2,K,NPV \qquad (9)$$

Security constraints

These include the constraints on voltage at loading buses (PQ buses) on transmission line loading, tap ratio(t) of transformer and FACTS controllers limit.

$$V_{Li}^{min} \le V_{Li} \le V_{Li}^{max} \quad i = 1,2,K,NPQ \qquad (10)$$

$$t_i^{min} \le t_i \le t_i^{max} \quad i = 1,2,..,NT \qquad (11)$$

$$X^{min} \le X_{FACTS} \le X^{max} \qquad (12)$$

III. MODELLING OF FACTS DEVICES

UPFC model is illustrated in Fig.1. It consists of two voltage-source converters, which is connected back to back through a DC capacitor. In this paper, the UPFC is modelled by the simultaneous presence of several FACTS devices in the same power transmission line [9]. A TCSC in the line and SVC at a bus in an adjacent branch incorporated as an UPFC in this paper.

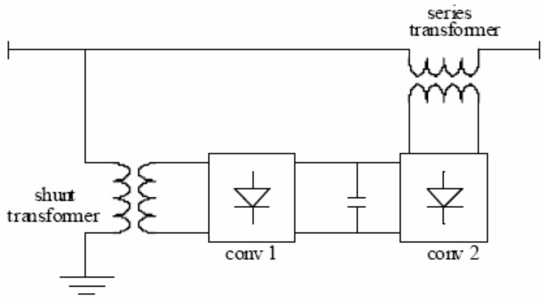

Fig. 1 UPFC model

The mathematical models of TCSC, is shown in Fig. 2. TCSC can be operated as the inductive or capacitive compensation by decreasing or increasing the reactance of the transmission line branch. Its value is function of the reactance of the line X_L where the TCSC is located [8].

$$Z_{ij} = Z_L + jX_{TCSC} \quad , \qquad X_{TCSC} = r_{TCSC} \cdot X_L$$

where Z_L is the impedance of the transmission line, X_{TCSC} is the reactance of the line where TCSC is located and r_{TCSC} is the coefficient which represents the compensation degree of TCSC.

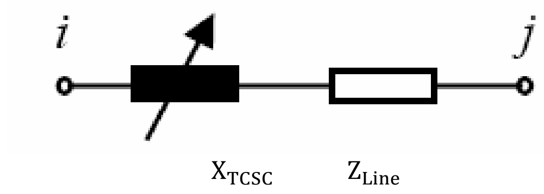

Fig. 2 Block diagram of the considered TCSC devices.

The SVC can be operated as both inductive and capacitive compensation which can control bus voltage by absorbing or injecting reactive power [7]. The SVC is modelled as a shunt variable susceptance added at both ends of the line. Hence, it is modelled as ideal reactive power injections to perform the steady-state condition at bus *i*, as shown in Fig. 3 [8].

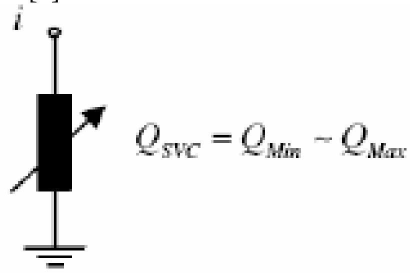

Fig. 3 Block diagram of the considered SVC devices The injected power at bus *i* is

$$\Delta Q_{is} = Q_{svc}$$

Where Q_{SVC} is the reactive power injected by the SVC placed bus in MVAR.

The chosen parameters for TCSC and SVC equipments are shown in Table I.

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TABLE I
Parameters of the Utilized FACTS Devices

	PARAMETER	MINIMUM	MAXIMUM
TCSC	X_{TCSC}	-0.5 XL	0.5 XL
SVC	Q_{SVC}	-200 MVAr	200 MVAr

IV. DE OPTIMIZATION PROCESS

A. Initialization

It begins with a randomly initiated population of *NP* number of *D*-dimensional real-valued parameter vectors. Each vector, also known as genome/chromosome, forms a candidate solution to the multi-dimensional optimization problem. We shall denote subsequent generations in DE by $G = 0,1.....,G_{max}$. The initial population (at $G = 0$) should cover the entire search space as much as possible by uniformly randomizing individuals within the search space constrained by the prescribed minimum and maximum bounds:

$$\vec{x}_{min} = \{x_{1,min}, x_{2,min}, \dots, x_{D,min}\}$$
$$\vec{x}_{max} = \{x_{1,max}, x_{2,max}, \dots, x_{D,max}\}$$

Hence, we may initialize the *j*-th component of the *i*-th vector as:

$$x_{j,i,0} = x_{j,min} + rand_{i,j}[0,1].(x_{j,max} - x_{j,min}) \quad (13)$$

Where rand is a uniformly distributed random number lying between 0 and 1 (actually $0 \leq rand_{i,j}\ [0,1] < 1$) and is instantiated independently for each component of the *i*-th vector.

B. Mutation

After initialization, DE creates a donor vector $\vec{v}_{i,G}$ corresponding to each population member or target vector $\vec{x}_{i,G}$ in the current generation through mutation. It is the method of creating this donor vector, which differentiates between the various DE schemes.

$$\vec{v}_{i,G} = \vec{x}_{r^i_{1,G}} + F.(\vec{x}_{r^i_{2,G}} - \vec{x}_{r^i_{3,G}}) \quad (14)$$

The indices r^i_1, r^i_2, r^i_3 are mutually exclusive integers randomly chosen from the range [1, *NP*], and all are different from the index *i*. These indices are randomly generated once for each donor vector. The scaling factor *F* is a positive control parameter for scaling the difference vectors and it lies usually in the range (0.4, 1)

C. Crossover

To improve the potential diversity of the population, a crossover operation comes into play after generating the donor vector in the mutation process. The donor vector exchanges its components with the target vector $\vec{x}_{i,G}$ in this process to form the trial vector $\vec{u}_{i,G}$. In this the widely used binomial crossover is performed on each of the *D* variables whenever a randomly generated number between 0 and 1 is less than or equal to a positive constant CR, called crossover rate. CR usually lies in the range (0.8to1). In this case, the number of parameters inherited from the donor has a (nearly) binomial distribution.

$$u_{j,i,G} = \begin{cases} v_{j,i,G} \text{ if } rand(0,1) \leq CR \text{ or } j = j_{rand} \\ x_{j,i,G} \text{ otherwise} \end{cases} \quad (15)$$

Where, $rand_{i,j}$ [0,1] is a uniformly distributed random number, which is called a new for each j[th] component of the i[th] parameter vector. j_{rand} Є [1,2,...,.*D*] is a randomly chosen index, which ensures that gets $\vec{u}_{i,G}$ at least one component from $\vec{v}_{i,G}$.

D. Selection

The selection operator chooses the vectors that are going to compose the population for the next generation. This operator compares the fitness of the trial vector and fitness of the corresponding target vector, and selects the one that performs better as mentioned in Eq. (16).

$$\vec{x}_{i,G+1} = \begin{cases} \vec{u}_{i,G} \text{ if } f(\vec{u}_{i,G}) \geq f(\vec{x}_{i,G}) \\ \vec{x}_{i,G} \text{ if } f(\vec{u}_{i,G}) < f(\vec{x}_{i,G}) \end{cases} \quad (16)$$

The selection process is repeated for each pair of target/ trail vector until the population for the next generation is complete.

V. DIFFERENTIAL EVOLUTION ALGORITHM IMPLEMENTATION

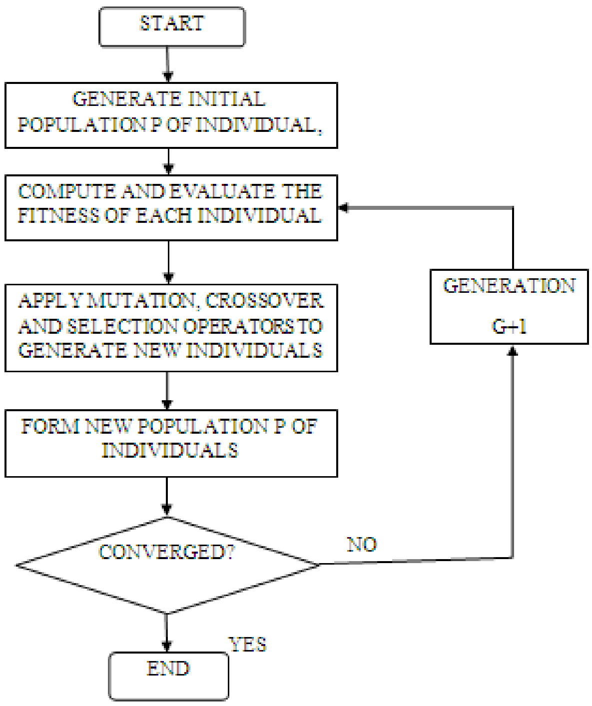

Fig. 4 DE algorithm

VI. RESULTS AND DISCUSSION

The proposed approach has been tested by using IEEE-30 bus system as shown in Fig. 5 which consists of 6 generators, 4 transformers, 41 lines, and two shunt reactors. In DE solution for OPF, the total control variables are 16: six unit active power outputs, six generator bus voltage magnitudes, and four transformers tap settings. All generator active power, and generator bus voltages and transformer tap setting are considered as continuous for simplicity. The generators cost coefficients of the IEEE 30-bus test system are given in the Table II.

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The limit of variables for the IEEE-30 bus system is given in Table III. The convergence characteristics for both base case and contingency condition are shown in Fig. 6.

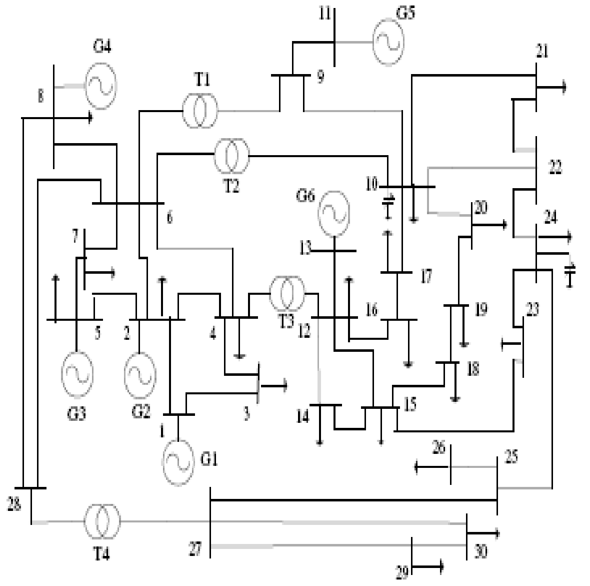

Fig. 5 IEEE-30 bus system

TABLE II

Generator Cost Coefficients of IEEE 30-Bus System

Bus No	Real Power Output Limit (MW)		Cost Coefficients		
	Min	Max	a_i	b_i	c_i
1	50	200	0	2.00	0.00375
2	20	80	0	1.75	0.01750
5	15	50	0	1.00	0.06250
8	10	35	0	3.25	0.00834
11	10	30	0	3.00	0.02500
13	12	40	0	3.00	0.02500

TABLE III

Limits of Variables for IEEE 30-Bus System

NO	DESCRIPTION	UNITS	LOWER LIMITS	UPPER LIMITS
1.	Voltage PQ bus	Pu	0.95	1.05
2.	Voltage PV bus	Pu	0.9	1.1
3.	Transformer taps	Pu	0.9	1.1

Table IV

Output Obtained From Test System

	WITHOUT LINE OUTAGE		WITH LINE OUTAGE(2-6)	
	Without UPFC	With UPFC	Without UPFC	With UPFC
P1	175.7754	169.3360	174.8205	169.3699
P2	49.1716	51.3479	48.4295	47.8898
P5	21.7542	21.8613	20.8091	21.9043
P8	21.9092	24.0115	25.3819	27.8841
P11	12.2328	13.3244	12.6150	13.9499
P13	12.1140	12.7371	12.1794	12.4545
V1	1.0500	1.0492	1.0499	1.0497
V2	1.0396	1.0355	1.0364	1.0381
V5	1.0174	0.9993	1.0034	1.0089
V8	1.0225	1.0098	1.0495	1.0127
V11	1.0017	1.0332	0.9918	1.0148
V13	1.0495	0.9974	1.0117	0.9920
T_{6-9}	1.0024	1.0015	1.0364	1.0012
T_{6-10}	0.9528	1.0599	1.0435	0.9907
T_{4-12}	1.0162	1.0838	0.9975	1.0542
T_{28-27}	0.9512	0.9966	0.9618	0.9744
Gen Cost $/hr	802.7683	802.6462	807.8546	807.2106
Loss	9.5572	8.8080	10.8358	10.0524
UPFC Line Location		12-3		12-16

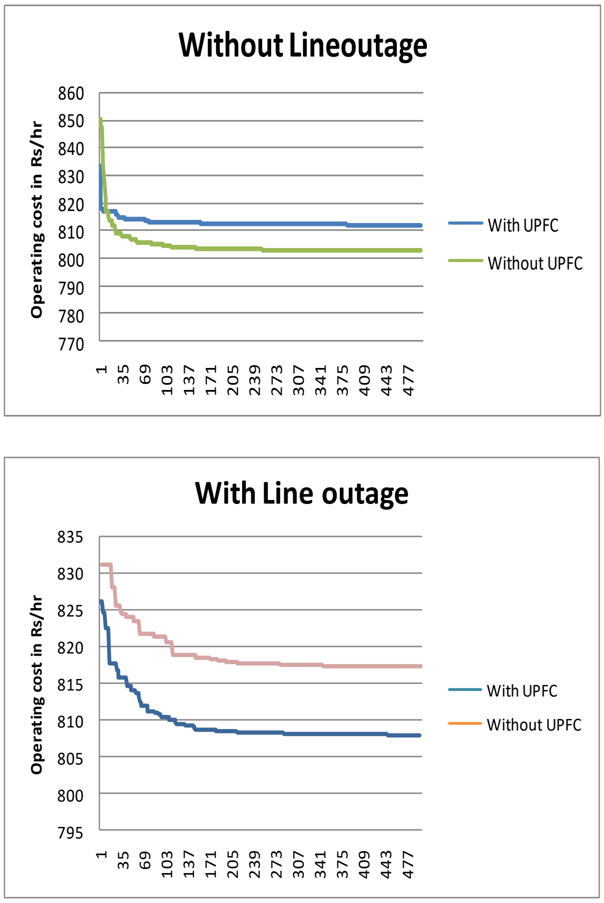

Fig. 6 Convergence characteristics

VII. CONCLUSION

This paper presents an effective method for solving SCOPF problem. The objective functions taken is the minimization of the total fuel cost under normal operating condition and minimize/eliminate the line overloads under contingency case.

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IEEE-30bus test system is used to evaluate the performance of the proposed approach. The main advantage of DE over other heuristics methods are modeling flexibility, sure and fast convergence and less computational time. The DE approach is useful for obtaining high-quality solution in a very less time compared to other methods.

REFERENCES

[1] Yunqiang lu, and AliAbur, "Static security enhancement via optimal utilization of thyristor controlled series capacitors", *IEEE Transactions on power Systems,* Vol,17 , pp. 324-329, 2002.

[2] O.Alsac,and B. Scott, "Optimal load flow with steady state security", *IEEE Transaction. PAS -1973*, pp. 745-751.

[3] A.Monticelli , M .V.F Pereira ,and S. Granville "Security constrained optimal power flow with post contingency corrective rescheduling" , *IEEE Transactions on Power Systems* :PWRS-2, No. 1, pp.175-182.,1987.

[4] K.Y Lee ,Y.M Park , and J.L Oritz, "Fuel –cost optimization for both real and reactive power dispatches" , *IEE Proc*; 131C,(3), pp.85-93.

[5] M.K. Mangoli, and K.Y. Lee, "Optimal real and reactive power control using linear programming" , *Electr.Power Syst*.Res, Vol.26, pp.1-10,1993.

[6] G.M. Lima, et al, "Phase shifter placement in large –scale systems via mixed integer programming" , *IEEE Trans*., PWRS-18,(3),pp.1029-1034,2003

[7] M. Saravanan, S.M.R. Slochanal, P. Venkatesh, and P.S. Abraham, "Application of PSO Technique for Optimal Location of FACTS Devices Considering System Loadability and Cost of Installation", *Power Engineering Conference*, Vol. 21, 2005, pp.716 -721.

[8] L.J. Cai, I. Erlich, "Optimal Choice and Allocation of FACTS Devices using Genetic Algorithms", *Proceedings on Twelfth Intelligent Systems Application to Power Systems Conference*, 2003, pp. 1–6.

[9] S. Gerbex, R. Cherkaoui and A. J. Germond, "Optimal Location of FACTS Devices to Enhance Power System Security", *Proceeding on IEEE Bologna PowerTech Conference*, Vol. 3, 2003, pp.1-7.

[10] Rainer Storn, Kenneth Price, "differential evolution – A simple and efficient adaptive scheme for global optimization over continuous spaces" TR-95-012, March 1995.

[11] Dervis Karaboga, Selcuk Okdem, "A Simple And Global Optimization Algorithm For Engineering Problems: Differential Evolution Algorithm", Turk J Elec. Engin., Vol. 12, No. 1, 2004, pp. 53-60.

[12] Raul E. Perez-Guerrero, Jose R. Cedeno- Maldonado, "Differential Evolution Based Economic Environmental Power Dispatch" Pp.191-197.

[13] R.Balamurugan and S.Subramanian ,"Self Adaptive Differential Evolution Based Power Economic Dispatch Of Generators With Valve Point Effects And Multiple Fuel Options", International Journal Of Computer Science And Engineering ,Vol. 1, No. 1, 2007, ISSN 1307-3699, pp. 10-17.

[14] Raul E. Perez-Guerrero and Jose R. Cedeno-Maldonado, "Economic Power Dispatch With Non-Smooth Cost Functions Using Differential Evolution", pp. 183-190.

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