Indian Streams Research Journal
ISSN 2230-7850
Volume-3, Issue-8, Sept-2013 Available online at www.aygrt.isrj.net

A Multi Objective Differential Evolution approach for optimal Reactive Power and Voltage Control

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ABSTRACT: Reactive power and voltage control is very essential for the proper operation and control of power system. This paper presents an efficient Differential Evolution approach to solve multi objective and multi constrained reactive power and voltage control problem. The objective functions are minimization of real power losses, minimization of voltage deviation and minimization of voltage stability index for the most vulnerable bus. In this approach the generator voltages, the transformer tap changers and the switchable VAR sources are taken as the control variables to get the optimal solution. The effectiveness of the proposed system has been tested in standard IEEE 30 bus test system it satisfies all the equality and inequality constraints and successful results have been obtained.

KEYWORDS: Differential evolution, Reactive Power and Voltage Control , Voltage Stability Index, Volt Ampere Reactive.

INTRODUCTION:

Reactive power and voltage control plays a vital role in power system in order to provide quality service. Proper control of voltage and reactive power is necessary to regulate the system voltage as well as reduce the real power loss and also maintaining the system stability. The purpose of reactive power and voltage control in power system is to identify the control variables which minimize the given objective functions. This goal is achieved by the proper setting of control variables such as magnitude of generator voltages, transformer tap settings and switchable VAR sources [1].

To solve the reactive power control problem several conventional techniques have been reported in [2-3]. Most of the conventional techniques converged in local optimal solution due to non-differential, non-linearity, non-continuous and non-convex nature of reactive power control problem [4-5]. Several mathematical models are also implemented [6]. Adaptive Hopfield Neural Network was implemented in [7]. The Genetic Algorithm approach to multi objective optimization problem reported in [8]. Most of the approach single objective function minimization of real power losses or minimization of voltage deviation or voltage stability improvement was selected. The resulting state may lack the required reserves to provide reactive power during the stressed conditions and outages. To avoid this multi objective optimization approaches are recently developed. But most of them adopted any of these two objective functions. Improved Genetic Algorithm approach for voltage stability enhancement [9] in this real power loss and voltage stability index are considered.

In Genetic Algorithm approach it has Hamming cliff problems [10] which may cause difficulties in the case of coding continuous and discrete variables. It is very difficult to use a fixed length binary coding to represent all permissible values. To overcome these difficulties the Differential Evolution Algorithm is implemented in this approach. Recently Differential Evolution algorithm has been implemented to solve reactive power optimization problem in [11]. DE has a realizing approach for optimization problems and successfully applied in many artificial and real optimization problems [12]. Differential Evolution algorithm is very robust and it can able to produce the same results over many trials. It is a user friendly algorithm and simple in coding. The convergence of this algorithm is very fast compared to Genetic Algorithm

In this paper the reactive power control problem is formulated as multi objective optimization problem. The objective of this proposed approach is minimization of real power losses, minimization of voltage deviation and minimization of voltage stability index all together. The effectiveness of the proposed approach is verified in standard IEEE 30 bus test system.

PROBLEM FORMULATION

A. Objective Functions

The basic objective of reactive power and voltage control is to identify the optimal values of reactive power control variables which minimize the objective function. In this approach the following objectives are considered.

a)Minimization of real power losses

The objective is to minimize the total real power losses in the system. This can be calculated as follows

$$F_1 = P_{Loss} = \sum_{i=1}^{nl} Loss_i \qquad (1)$$

$$P_{Loss} = \sum_{k=1}^{nl} g_k [V_i^2 + V_j^2 - 2V_iV_j \cos(\delta_i - \delta_j)] \qquad (2)$$

Where

$Loss_i$	:	power loss in branch i
nl	:	the number of branches
g_k	:	the conductance of the k^{th} line
V_i&V_j	:	the voltage magnitude at the end buses i & j
δ_i & δ_j	:	the voltage phase angle at the end buses i & j

b)Minimization of voltage deviation

Bus voltage is one of the important security and service quality indices. To improve the voltage profile the load bus voltage deviation should be minimized. This can be calculated as follows

$$F_2 = \sum_{i=1}^{NL} |V_i - 1.0| \qquad (3)$$

Where

NL	:	the number of load buses
V_i	:	the voltage magnitude of bus i

c)Minimization of voltage stability index:

To improve the voltage stability of the system the voltage stability index shoud be minimized. The voltage stability indices for all the load buses are calculated. The bus which is having the highest VSI is the most vulnerable bus. The objective function VSI can be calculated as.

$$VSIj = \left| 1 - \sum_{i=1}^{ng} F_{ji} \frac{V_i}{V_j} \right| i = ng + 1, \ldots.., n \quad (4)$$

The values of F_{ji} are obtained from Y bus matrix. Where

V_i&V_j	:	the voltage magnitude at the end buses i & j
n	:	the number of buses
ng	:	the number of generator buses

B. Problem Constraints

a)Equality Constraints

The equality constraints are the real and reactive power balance equations at all the bus bars. The equality constraints can be formulated as

$$P_{gi} - P_{di} = \sum_{j=1}^{n} |V_i| \, |V_j| |Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \quad (5)$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{n} |V_i| \, |V_j| |Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \quad (6)$$

Where

n	:	the number of buses
Y_{ij}	:	the mutual admittance between node i and j
δ_i&δ_j	:	the bus voltage angle of bus i and bus j respectively
θ_{ij}	:	the admittance angle of line between buses i and j
P_{gi}&Q_{gi}	:	the real and reactive power generation at bus i
P_{di}&Q_{di}	:	the real and reactive power demand at bus i

b) Inequality Constraints

The inequality constraints can be formulated as follows

Generator constraints

$$P_s \min \le P_s \le P_s \max \quad (7)$$

Where

$P_s$min and $P_s$max are the minimum and maximum real power of slack bus.

$$Q_{gi} \min \le Q_{gi} \le Q_{gi} \max \quad (8)$$

Where

Q_{gi} min and Q_{gi} max are the minimum and maximum value of reactive power generation.

$$V_{gi} \min \le V_{gi} \le V_{gi} \max \quad (9)$$

Where

V_{gi} min and V_{gi} max are the minimum and maximum value of generator voltages.

Transformer constraints

$$T_i \min \le T_i \le T_i \max \quad (10)$$

Where

T_i min and T_i max are the minimum and maximum range of ratio of tap changing transformer.

Switchable VAR constraints

$$Qc_i \min \leq Qc_i \leq Qc_i \max \qquad (11)$$

Where

Q_{ci} min and Q_{ci} max are the minimum and maximum allowable output of reactive power compensation equipment.

DIFFERENTIAL EVOLUTION ALGORITHM

A.Overview

Differential Evolution Algorithm is a new floating point encoded evolutionary algorithm developed by Storn and Price in 1996 for global optimization. It is a population based approach having crossover, mutation and selection. In this algorithm it is having a special differential operator used to create anew off spring from parent chromosomes instead of classical crossover. The convergence speed of DE is far better than that of Genetic Algorithm .The main advantage of DE is It can able to give the same results consistently for many trials. Due to this best performance DE has been successfully applied in many artificial and real time optimization problems [13]. The operators used in this technique are as follows.

Initialization

For initialization define the lower and upper boundary limits for each parameter. Initialize the independent variables randomly within their feasible numerical range between 0 and 1. If a variable is discrete or integral even then it should be initialized as real value.

Mutation

Mutation is the process of introducing new parameters into the population. The mutation operation of DE applies the vector differentials between the existing population members for determining both the degree and direction of perturbation applied to the individual subject of the mutation operation. The mutation process at each generation begins by randomly selecting three individuals in the population.

Crossover

Once the mutation process completed, the crossover process is activated. The perturbed individual vector and the current population member are subjected to crossover operation that finally generates the population of candidates or trial vectors. The trial vector is the combination of mutant vector and target vector.

Selection

After the mutation and crossover operations, the trial vector and target vector will approach to fitness functions to determine the one to be reserved for the next generation. Compare the fitness of the trial vector and the fitness of the corresponding target vector, and select the one which is having minimum value.

B. General procedure of Differential Evolution algorithm

Step 1 : Initialize vectors in a population.
Step 2 : Evaluate the fitness function after Newton Raphson power flow for each vector.
Step 3 : Choose a target vector in the population.
Step 4 : Calculate the trial vector for the selected target vector using mutation and crossover.
Step 5 : Compare the fitness of the target vector and the trial vector.
Step 6 : Select the best fitness vector among them.
Step 7 : Repeat step3 to step5 till the stopping criteria. The stopping criterion is number of iterations.

PROPOSED DE BASED APPROACH IMPLEMENTATION

The proposed multi objective DE based approach for optimal reactive power control has been developed and implemented using mat lab. In this approach the objective function minimization of real power losses, minimization of voltage deviation and minimization of voltage stability index can be achieved by the optimal settings of control variables by Differential Evolution Algorithm.

The first step in this approach is to generate an initial population for all the control variables. Then the Newton Raphson power flow is executed for this population. From the results of power flow solutions obtain the dependent and independent variables and verifies all the constraints within the limit. The generator voltages varies within the range of 0.95 to 1.1 p.u. the transformer tap settings varies within the range of 0.9 to 1.1 p.u and the switchable var sources are varies within the range from 0 to 5 with a step size of 1 p.u. If it is not within the limit then it will be eliminated from the population. Evaluate the fitness function for each individual in the population.

Perform the mutation and crossover process and generate the new off springs. Select the minimum value of vector among them .Repeat the process till the stopping criterion reached. The stopping criterion is the number of iterations, Here 100 iterations are considered.

The key parameters selected for the multi objective optimization of reactive power control based on Differential Evolution Algorithm is as follows.

Number of decision variables = 14
Number of populations = 30
Number of generations = 100
Scaling factor = 0.9
Cross over rate = 0.4

RESULTS AND DISCUSSION

The proposed multi objective DE based algorithm has been tested on standard IEEE 30-bus test system. The system having 41 transmission lines, 4 tap changing transformers, 6 generators and 5 static VAR compensators. The line data bus data and initial setting of control variables of IEEE 30 bus test system is taken from [14]. In this reactive power control optimization problem the optimal solution of the proposed algorithm can be demonstrated under the stressed condition of 125 % load in IEEE 30 bus test system. Under the stressed condition the load buses 30, 29, 26, 24 and 25 are identified as the most vulnerable buses based on VSI calculated from load flow studies by Newton Raphson method. The bus which is having maximum value of VSI is the most vulnerable bus. The most critical load bus is 30 and the value of voltage stability index is 0.1978. Select the most critical five buses, the buses are load bus 30, 29, 26, 24 and 25. Inject the reactive power in these particular buses by VAR sources. Apply the proposed algorithm and obtain the optimal settings of control variables to get the best solution. After the implementation of the proposed algorithm the VSI of load bus 30 is reduced to 0.1713, the real power loss is reduced to 10.422 and the voltage deviation is reduced to 0.2281.The effectiveness of the proposed multi objective algorithm is verified by comparing the test results with the base case and GA based approach with the objective function minimization of VSI and minimization of real power losses in [15]. Table I shows the control variable limits and optimal solution of IEEE 30 bus test system.

TABLE-I CONTROL VARIABLE LIMITS AND OPTIMAL SOLUTION OF IEEE30 BUS TEST SYSTEM

Sl. No .	Control variable	Min limit	Max limit	Initial Setting	Optimal setting using GA	Optimal setting using DE
1	Vg1	.95	1..05	1.0500	1.0500	1.050
2	Vg2	.95	1.05	1.0400	1.0256	1.028
3	Vg3	.95	1.05	1.0100	1.0063	1.008
4	Vg4	.95	1.05	1.0100	0.9895	1.018
5	Vg5	.95	1.05	1.0500	1.0584	1.030
6	Vg6	.95	1.05	1.0500	1.0806	1.030
7	T1	.9	1.1	0.9780	1.0500	0.971
8	T2	.9	1.1	0.969	0.9000	0.935
9	T3	.9	1.1	0.9320	0.9250	0.900
10	T4	.9	1.1	0.9680	0.9500	0.954

11	Q30	0	5	0	0	4
12	Q29	0	5	0	0	5
13	Q26	0	5	0	0	1
14	Q25	0	5	0	0	1
15	Q30	0	5	0	0	4
P Loss (MW)				**10.760**	**10.55**	**10.422**
VSI				**0.1978**	**0.1807**	**0.1713**
Voltage Deviation (p.u)				**-**	**-**	**0.2281**

Convergence Characteristics

The convergence characteristics of the objective function minimization of real power loss for 100 generations is shown in Fig.1

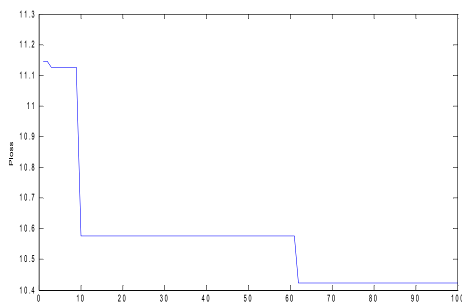

Fig. 1 Power loss variations for DE on IEEE 30-bus system

The convergence characteristics of the objective function minimization of voltage deviation for 100 generations are shown in Fig.2.

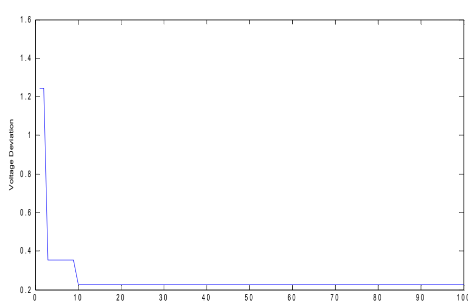

Fig. 2 Voltage deviation variations for DE on IEEE 30-bus system

The convergence characteristics of the objective function minimization of voltage stability index for the most vulnerable bus is shown in Fig.3.The bus 30 is considered as the most vulnerable bus. After the implementation of optimization the voltage stability index of this bus is reduced to 0.1713. By this Multi objective optimization approach the real power loss is minimized, the voltage deviation is minimized and the voltage stability index also minimized. By this the stability of the system is improved.

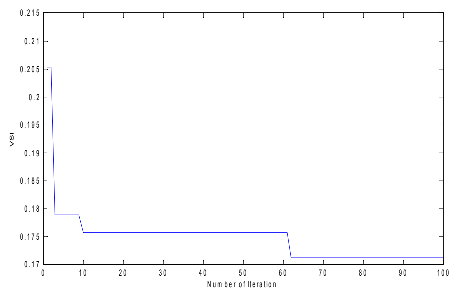

Fig. 3 VSI variations for DE on IEEE 30-bus system

Conclusion

In this paper the multi objective differential Evolution Algorithm based global optimization technique has been developed and successfully applied to solve reactive power control problems. This problem has been formulated with the different objective function minimization of real power losses, the voltage deviation and the VSI for most vulnerable bus. It is found that Differential Evolution Algorithm can effectively utilize the reactive power control variables and satisfies all the equality and inequality constraints. The effectiveness of the proposed approach has been examined on standard IEEE 30 bus test system and compared with the base case and other heuristic algorithm. The comparison shows the proposed approach results are superior and effective.

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