Optimal Reactive Power Dispatch for Voltage Stability Enhancement Using Real Coded Genetic Algorithm

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Abstract—**This paper presents an algorithm for solving the multi-objective reactive power dispatch problem in a power system. Modal analysis of the system is used for static voltage stability assessment. Loss minimization and maximization of voltage stability margin are taken as the objectives. Generator terminal voltages, reactive power generation of the capacitor banks and tap changing transformer setting are taken as the optimization variables. An improved genetic algorithm which permits the control variables to be represented in their natural form is proposed to solve this combinatorial optimization problem. For effective genetic operation, crossover and mutation operators which can directly operate on floating point number and integers are used. The proposed method has been tested on IEEE 30 bus system and has resulted in loss which is less than the value reported earlier and is well suited for solving the mixed integer optimization problem.**

Index Terms—**Modal analysis, optimal reactive power dispatch, loss minimization, genetic algorithm.**

I. Introduction

Optimal reactive power dispatch problem is one of the difficult optimization problems in power systems. The sources of the reactive power are the generators, synchronous condensers, capacitors, static compensators and tap changing transformers. The problem that has to be solved in a reactive power optimization is to determine the required reactive generation at various locations so as to optimize the objective function. Here the reactive power dispatch problem involves best utilization of the existing generator bus voltage magnitudes, transformer tap setting and the output of reactive power sources so as to minimize the loss and to enhance the voltage stability of the system. It involves a non linear optimization problem. Various mathematical techniques have been adopted to solve this optimal reactive power dispatch problem. These include the gradient method [1-2], Newton method [3] and linear programming [4-7].The gradient and Newton methods suffer from the difficulty in handling inequality constraints. To apply linear programming, the input- output function is to be expressed as a set of linear functions which may lead to loss of accuracy. Recently global optimization techniques such as genetic algorithms have been proposed to solve the reactive power flow problem [8, 9]. A genetic algorithm is a stochastic search technique based on the mechanics of natural selection. In this paper, genetic algorithm is used to solve the voltage constrained reactive power dispatch problem. The proposed algorithm identifies the optimal values of generation bus voltage magnitudes, transformer tap setting and the output of the reactive power sources so as to minimize the transmission loss and to improve the voltage stability. The effectiveness of the proposed approach is demonstrated through IEEE-30 bus system. The test results show the proposed algorithm gives better results with less computational burden and is fairly consistent in reaching the near optimal solution [10].

In recent years, the problem of voltage stability and voltage collapse has become a major concern in power system planning and operation. To enhance the voltage stability, voltage magnitudes alone will not be a reliable indicator of how far an operating point is from the collapse point [11]. The reactive power support and voltage problems are intrinsically related. Hence, this paper formulates the reactive power dispatch as a multi-objective optimization problem with loss minimization and maximization of static voltage stability margin (SVSM) as the objectives. Voltage stability evaluation using modal analysis [12] is used as the indicator of voltage stability.

II. Voltage Stabilty Evaluation

A. Modal analysis for voltage stability evaluation

Modal analysis is one of the methods for voltage stability enhancement in power systems. In this method, voltage stability analysis is done by computing eigen values and right and left eigen vectors of a jacobian matrix. It identifies the critical areas of voltage stability and provides information about the best actions to be taken for the improvement of system stability enhancements.

The linearized steady state system power flow equations are given by.

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}J_{p\theta}J_{PV}\\ J_{Q\theta}J_{QV}\end{bmatrix}\begin{bmatrix}\Delta\theta\\ \Delta V\end{bmatrix} \tag{1}$$

Where,

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ΔP = incremental change in bus real power.

ΔQ = incremental change in bus reactive power injection.

$\Delta\theta$ = incremental change in bus voltage angle.

ΔV = Incremental change in bus voltage magnitude

$J_{p\theta}, J_{PV}, J_{Q\theta}, J_{QV}$ are the sub-matrixes of the jacobian matrix

System voltage stability is affected by both P and Q. However at each operating point we keep P constant and evaluate voltage stability by considering incremental relationship between Q and V.

To reduce (1), let $\Delta P = 0$, then.

$$\Delta Q = [J_{QV} - J_{Q\theta} J_{P\theta}^{-1} J_{PV}]\Delta V = J_R \Delta V \quad (2)$$

and

$$\Delta V == J_R^{-1} \Delta Q \quad (3)$$ where,

$$J_R = (J_{QV} - J_{Q\theta} J_{P\theta} - 1 J_{PV}) \quad (4)$$

J_R is called the reduced Jacobian matrix of the system.

B. Modes of Voltage instability:

Voltage Stability characteristics of the system can be identified by computing the eigen values and eigen vectors.

Let $$\mathrm{J_R} = \xi \wedge \eta \quad (5)$$

where,

ξ = right eigenvector matrix of J_R

η = left eigenvector matrix of J_R

$\wedge$ = diagonal eigenvalue matrix of J_R

and

$$\mathrm{J_R}^{-1} = \xi \wedge^{-1} \eta \quad (6)$$

From (3) and (6), we have

$$\Delta V = \xi \wedge^{-1} \eta \Delta Q \quad (7)$$

Or

$$\Delta V = \sum_i \frac{\xi_i \eta_i}{\lambda_i} \Delta Q \quad (8)$$

where ξ_i is the i[th] column right eigenvector and η_i the i[th] row left eigenvector of J_R.

λ_i is the i[th] eigen value of J_R.

The i[th] modal reactive power variation is,

$$\Delta \mathrm{Q_{mi}} = \mathrm{K_i}\, \xi_\mathrm{i} \quad (9)$$

where,

$$K_1^{\,2} \sum_j \xi_{ji}^{\,2} - 1 \quad (10)$$

With ξ_{ji} the j[th] element of ξ_i

The corresponding i[th] modal voltage variation is

$$\Delta V_{mi} = \frac{1}{\lambda_1} \Delta Q_{mi} \quad (11)$$

It is seen that, when the reactive power variation is along the direction of ξ_i the corresponding voltage variation is also along the same direction and magnitude is amplified by a factor which is equal to the magnitude of the inverse of the i[lh]. eigenvalue. In this sense, the magnitude of-each eigenvalue λ_i determines the weakness of the corresponding modal voltage. The smaller the magnitude of λ_i, the weaker will be the corresponding modal voltage. If | λ_i | =0 the i[th] modal voltage will collapse because any change in that modal reactive power will cause infinite modal voltage variation.

In (8), let $\Delta Q = e_k$ where e_k has all its elements zero except the k[th] one being 1. Then,

$$\Delta V = \sum_i \frac{\eta_{1k} \xi_1}{\lambda_1} \quad (12)$$

where η_{1k} the k[th] element of η_i.

V - Q sensitivity at bus k,

$$\frac{\partial V_k}{\partial Q_k} = \sum_i \frac{\xi_{ki} \eta_{ik}}{\lambda_1} = \sum_i \frac{P_{ki}}{\lambda_1} \quad (13)$$

A system is voltage stable if the eigenvalues of the Jacobian are all positive.

Thus the results for voltage stability enhancement using modal analysis for the reduced jacobian matrix is when

eigen values λ_i > 0, the system is under stable condition

eigen values $\lambda_i < 0$, the system is unstable

eigen values $\lambda_i = 0$, the system is critical and collapse state occurs

III. Problem Formulation

Nomenclature:

N_B number of buses in the system

N_g number of generating units in the system

t_k tap setting of transformer branch k

P_{sl} real power generation at slack bus

V_i voltage magnitude at bus i

P_i, Q_i real and reactive powers injected at bus i

P_{gi}, Q_{gi} real and reactive power generations at bus i

G_{ij}, B_{ij} mutual conductance and susceptance between bus i and j

G_{ii}, B_{ii} self conductance and susceptance of bus i

(9)

θ_{ij} voltage angle difference between bus i and j

The optimal reactive power dispatch problem is formulated as an optimization problem in which a specific objective function is minimized while satisfying a number of equality and inequality constraints. The objectives of the reactive power dispatch problem considered here is to minimize the system real power loss and maximize the static voltage stability margins (SVSM). This objective is achieved by proper adjustment of reactive power variables like generator voltage magnitude (V_{gi}) , reactive power

generation of capacitor bank (Q_{ci}), and transformer tap setting (t_k).Power flow equations are the equality constraints of the problems, while the inequality constraints include the limits on real and reactive power generation, bus voltage magnitudes, transformer tap positions and line flows.
This objective function is subjected to the following constraints:

A. Real power losses:

To minimize the real power loss in the system, this can be expressed as

$$Minimize \quad P_{Loss} = \sum_{\substack{k \in Nl \\ k=(i,j)}} g_k (V_i^2 + V_j^2 - 2V_i V_j Cos\ \theta_{ij}) \tag{14}$$

B. Maximize SVSM:

This is the most widely accepted index for proximity of voltage collapse. It is defined as the largest load change that the power system may sustain at a bus or collective of buses from a well defined operating point. (Base case) .Using the modal analysis the minimal eigen value of the non-singular power flow jacobian matrix has been used to find the maximum static voltage stability margin in this proposed approach.

C. Equality Constraints

These constraints represent the typical load flow equation such as

$$P_i - V_i \sum_{j=1}^{N_B} V_j (G_{ij} Cos\theta_{ij} + B_{ij} Sin\theta_{ij}) = 0, i \in N_B - 1 \tag{15}$$

$$Q_i - V_i \sum_{j=1}^{N_B} V_j (G_{ij} Sin\theta_{ij} - B_{ij} Cos\theta_{ij}) = 0, i \in N_{PQ} \tag{16}$$

D. Inequality Constraints

These constraints represent the system operating constraints. Generator bus voltages (V_{gi}), reactive power generated by the capacitor (Q_{ci}), transformer tap setting (t_k), are control variables and they are self restricted. Load bus voltages (V_{load}) reactive power generation of generator (Q_{gi}) and line flow limit (S_l) are state variables, whose limits are satisfied by adding a penalty terms in the objective function. These constraints are formulated as

(i) Voltage limits

$$V_i^{\min} \le V_i \le V_i^{\max} \ ; i \in N_B \tag{17}$$

(ii) Generator reactive power capability limit

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} ; i \in N_g \tag{18}$$

(iii) Capacitor reactive power generation limit

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max} \ ; i \in N_c \tag{19}$$

(iv) Transformer tap setting limit

$$t_k^{\min} \le t_k \le t_k^{\max} \ ; k \in N_T \tag{20}$$

(v) Transmission line flow limit

$$S_l \le S_l^{\max} \ ; l \in N_l \tag{21}$$

The equality constraints are satisfied by running the power flow program. The active power generation (P_{gi}), generator terminal bus voltages (V_{gi}) and transformer tap settings (t_k) are the control variables and they are self restricted by the optimization algorithm. The active power generation at slack bus (P_{sl}), load bus voltage (V_{load}) and reactive power generation (Q_{gi}) are the state variables and are restricted by adding a quadratic penalty term to the objective function.

IV. Improved Genetic Algorithm

Genetic algorithms [13] are search algorithms based on a specific class of evolutionary algorithms. It is capable of solving various kinds of constrained / unconstrained optimization problems in which the objective function is discontinuous, non differentiable, stochastic or highly nonlinear. Each chromosome represents one solution of the load flow. The quality of this solution is defined by the fitness function *f* (Comparable with the object function of classic optimization methods). The GA search as from a population of points in the solution space and not from a single point, and thus improves the chances of finding a global optimum. Thus GAs has proven to be a useful approach to address a wide a variety of optimization problems. It performs well over a specific class of functions: continuous, smooth, multi-modal real –variable functions. Also GA performs well if it has a good chance of finding the global minimum. GAs is also able to find alternative good minima while reaching the global minimum too. GA use probabilistic rules to select new generations, by using three basic operators: selection, reproduction and mutation. The approach followed is time constrained and thus stopping criterion is a fixed number of generations. Figure 1 shows the flow chart of the GA-based algorithm for solving this optimization problem.

The GA uses three main operating schemes such as selection, crossover and mutation.

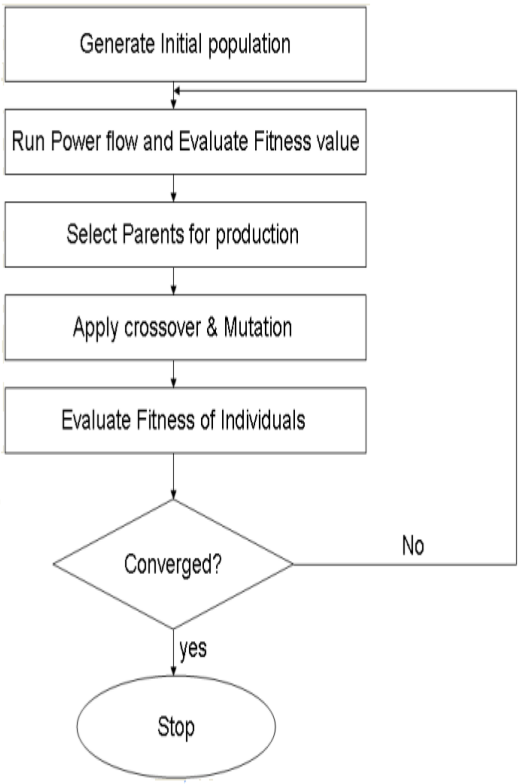

Fig: 1 Flow chart of GA approach:

A. Selection Scheme:

Selection is a method stochastically picks individuals from the population according to their fitness; the higher the fitness, the more chance an individual has to be selected for the next generation. There are a number of methods proposed in the literature for the selection operation. Tournament selection is used in this work. In this scheme we generate three groups of parents. The parents within any of the groups are different from each other, although an individual may occur in more than one group. The number of parents within a group depends on the crossover operator used. Here two members of the parent population are picked at random and the fittest among them was selected as a parent. This procedure is repeated until the required number of parents has been selected.

B. Crossover Scheme:

The crossover operator is mainly responsible for bringing diversity in the population. Crossovers for real parameter GAs have the interesting feature [14] of having tunable parameters that can be used to modify their exploration power. In this proposed approach each individual in the population consists of two types of variables: real and integer. Hence a two-part crossover which takes advantage of the special structure of the problem representation was developed. First, the two parents are applied on the floating point and integer parts. The blend crossover operator (BLX-α) is employed for real variables, and single point crossover is applied to the integer part.

BLX (Blend crossover operator) [15] is used which randomly selects a value for each offspring gene, using a uniform distribution within the range

$$\left[x_i^{(1)} - \alpha(x_i^{(2)} - x_i^{(1)}), x_i^{(2)} + \alpha(x_i^{(2)} - x_i^{(1)})\right]$$

Where $x_i^{(1)}$ and $x_i^{(2)}$ are the parental genes, and α is the tunable parameter, we use α the more explorative the search.

C. Mutation Scheme:

The mutation operator is used to inject new genetic material into the population. Mutation randomly changes the new offspring. In this work, the 'Uniform Mutation' operator is applied to the mixed variables with some modifications. First a variable is selected from an individual randomly. If the selected variable is a real number, it is set to a uniform random number between the variable's lower and upper limits. On the other hand, if the selected variable is an integer, the randomly generated floating point number is truncated to the nearest integer. After mutation, the new generation is complete and the procedure begins again with the fitness evaluation of the population.

V. GA Implementation to the Optimal Reactive Power Dispatch Problem

When applying GAs to solve a particular optimization problem, three main issues are taken into consideration namely:

(i) Representation of the decision variables

(ii) Treatment of constraints

(iii) Formation of the fitness function

These issues are explained in the subsequent section.

A. Representation of the decision variables

While solving optimization problems using GA, each individual in the population represents a candidate solution. In the reactive power dispatch problem, the elements of the solution consists of the control variables namely; Generator bus voltage (V_{gi}), reactive power generated by the capacitor (Q_{Ci}), and transformer tap settings (tk). These variables are represented in their natural form that is generator bus voltage magnitude and reactive power generation of capacitor are represented as floating point numbers whereas, the transformer tap setting , being a discrete quantity with tapping ranges of ± 10% and a tapping step of 0.025 p.u is represented from the alphabet (0, 1, ….8). With this representation, a typical chromosome for the optimal reactive power dispatch problem looks like as:

$$\underbrace{0.981}_{V_{g1}}\ \underbrace{0.970}_{V_{g2}}\ \underbrace{1}_{V_{gn}}\ \underbrace{4}_{Q_{c1}}\ \underbrace{3}_{Q_{c2}}\ \underbrace{4}_{Q_{cn}}\ \underbrace{-2}_{t_1}\ \underbrace{+1}_{t_2}\ \underbrace{+3}_{t_k}$$

The use of floating point numbers and integers to represent the solution alleviates the difficulties associated with the binary-coded GA for real variables. Also with direct representation of the solutions variables the computer space required to store the population is reduced.

B. Treatment of constraints

The function of each individual in the population is evaluated according to its 'fitness' which is defined as the non-negative figure of merit to be maximized. It is associated mainly with the objective function. In the RPD problem here the objective is to minimize the active power loss and maximize eigen values of the jacobian matrix of the singular value decomposition while satisfying the equality and inequality constraints. Gas are essentially unconstrained search procedures with the given representation space

C. Formation of the fitness function

In the optimal reactive power dispatch problem, the objective is to minimize the total real power loss while satisfying the constraints (14) to (21). For each individual, the equality constraints are satisfied by running Newton-Raphson algorithm and the constraints on the state variables are taken into consideration by adding penalty function to the objective function. With the inclusion of the penalty factors, the new objective function then becomes,

$$MinF = P_{loss} + wEig_{max} + \sum_{i=1}^{N_{PQ}} VP_i + \sum_{i-1}^{N_g} QP_{gi} + \sum_{l=1}^{N_l} LP_l \tag{22}$$

Where

$$VP_i = \begin{cases} K_v (V_i - V_i^{max})^2 & if \ V_i > V_i^{max} \\ K_v (V_i - V_i^{min})^2 & if \ V_i < V_i^{min} \\ 0 & otherwise \end{cases} \tag{23}$$

$$QP_{gi} = \begin{cases} K_q \ (Q_i - Q_i^{max})^2 & if \ Q_i > Q_i^{max} \\ Kq \ (Q_i - Q_i^{min})^2 & if \ Q_i < Q_i^{min} \\ 0 & otherwise \end{cases} \tag{24}$$

$$LP_l = \begin{cases} K_l (S_l - S_l^{max})^2 & if \ S_l > S_l^{max} \\ 0 & otherwise \end{cases} \tag{25}$$

In the above expressions w, K_v, K_q, K_l are the penalty factors for the eigen value, load bus voltage limit violation, generator reactive power limit violation and line flow limit violation respectively.

Generally, GA searches for a solution with maximum fitness function value. Hence, the minimization objective function given in (22) is transformed into a fitness function (f) to be maximized as,

$$f = K / F \tag{26}$$

where K is a large constant. This is used to amplify (1/F), the value of which is usually small, so that the fitness value of the chromosomes will be in a wider range.

VI. Simulation Results

In order to demonstrate the effectiveness and robustness of the proposed technique, minimization of real power loss under two conditions, without and with static voltage stability margin (SVSM) were considered. The validity of the proposed Genetic Algorithm technique is demonstrated on IEEE-30 bus system. The IEEE-30 bus system has 6 generator buses, 24 load buses and 41 transmission lines of which four branches are (6-9), (6-10) , (4-12) and (28-27) - are with the tap setting transformers. The real power settings are taken from [1]. The lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses and 1.05 p.u. for all the PQ buses and the reference bus. The GA –based optimal reactive power dispatch algorithm was implemented using the MATLAB programmed and was executed on a Pentium computer. The results of the simulations are presented in below Tables I, II, III &IV. The IEEE-30 bus single line diagram is given below:

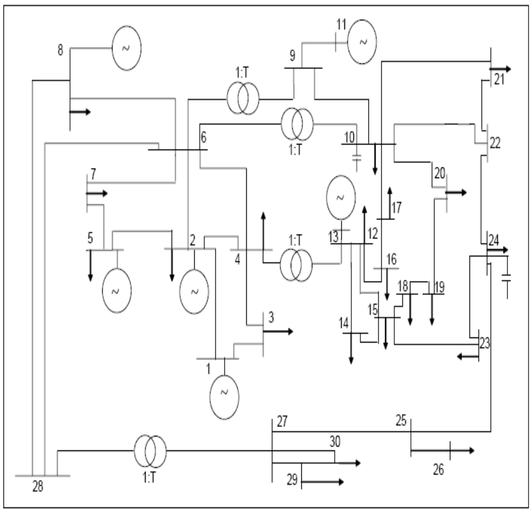

Fig 2. IEEE 30 bus system

Case1 : RPD with loss minimization objective

Here the GA-based algorithm was applied to identify the optimal control variables of the system under base-load condition, with loss minimization and without considering the voltage stability of the system. .It was run with different control parameter settings and the minimization solution was obtained with the following parameter setting:

Population size: 50
Crossover rate: 0.9
Mutation rate: 0.01
Maximum generations: 120

The optimal values of the control variables along with the minimum loss obtained are given in Table 1.Corresponding to this control variable setting, it was found that there are no limit violations in any of the state variables. The minimum loss obtained by the proposed method is less than the values presented in the other papers. It is tabulated in the TableV.This shows the powerfulness of the proposed work.

TABLE 1 RESULTS OF GA-RPD OPTIMAL CONTROL VARIABLES

Control variables	Variable setting
V_1	1.0498
V_2	1.0450
V_5	1.0258

V_8	1.0296
V_{11}	1.0064
V_{13}	1.0265
T_{11}	1.1000
T_{12}	0.97771
T_{15}	1.0669
T_{36}	0.9187
Q_{C10}	4
Q_{C12}	1
Q_{C15}	0
Q_{C17}	4
Q_{C20}	4
Q_{C21}	4
Q_{C23}	4
Q_{C24}	3
Q_{C29}	3
Real Power Loss	4.5015
SVSM	0.2462

To illustrate the convergence of the algorithm, the relationship between the best fitness value of the results and the average fitness are plotted against the generation number in Figure 2.From the figure it can be seen that the proposed method converges towards the optimal solution very quickly.

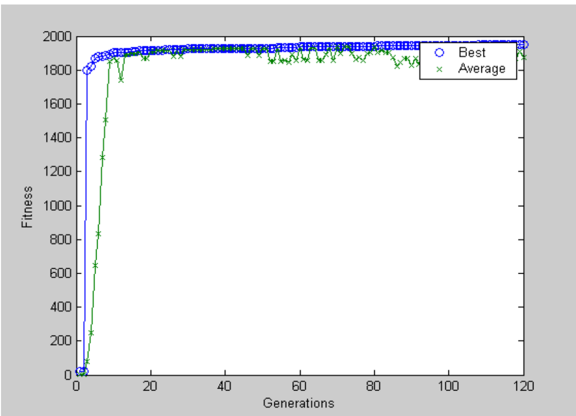

Fig: 3 Simulation Diagram:

Case 2: Multi-objective RPD with loss minimization:

RPD including voltage stability constraint problem was handled in this case as a multi-objective optimization problem where both power loss and maximum voltage stability margin of the system were optimized simultaneously. Table II indicates the optimal values of these control variables. Also it is found that there are no limit violations of the state variables. It indicates the VSM has increased to 0.2462 from 0.2471, an improvement in the system voltage stability.

To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained in case 1 and case 2. The eigen values corresponding to the four critical contingencies are given in Table III. From this result it is observed that the eigen values has increased appreciably for all contingencies in the second case. This improvement in voltage stability was achieved because of the additional objective included in the RPD problem in the base case condition. This shows that the proposed algorithm has helped to improve the voltage security of the system.

TABLE II. RESULTS OF GA-VSCRPD OPTIMAL CONTROL VARIABLES:

Control variable	Variable setting
V_1	1.0496
V_2	1.0399
V_5	1.0187
V_8	1.0217
V_{11}	1.0496
V_{13}	1.0498
T_{11}	0.9275
T_{12}	0.9275
T_{15}	0.9275
T_{36}	0.9225
Q_{C10}	3
Q_{C12}	0
Q_{C15}	2
Q_{C17}	5
Q_{C20}	4
Q_{C21}	5
Q_{C23}	3
Q_{C24}	3
Q_{C29}	5
Real Power Loss	5.0129
SVSM	0.2471

TABLE III VOLTAGE STABILITY UNDER CONTINGENCY STATE

Sl no	Contingency	RPD setting	VSCRPD setting
1	28-27	0.1303	0.1311
2	4-12	0.1638	0.1672
3	1-3	0.1704	0.1712
4	2-4	0.2045	0.2056

TABLE IV LIMIT VIOLATION CHECKING OF STATE VARIABLES

State variables	Limits		RPD	VSCRPD
	Lower	Upper		
Q_1	-20	150	1.2437	-1.2169
Q_2	-20	60	8.8952	9.7771
Q_5	-15	48.734	24.8880	24.2360
Q_8	-10	62.45	37.7320	39.7078
Q_{11}	-15	40	2.8311	4.9102

Q_{13}	-15	45	7.3079	5.2339
V_3	0.95	1.05	1.0264	1.0276
V_4	0.95	1.05	1.0205	1.0219
V_6	0.95	1.05	1.0169	1.0191
V_7	0.95	1.05	1.0094	1.0176
V_9	0.95	1.05	1.0483	1.0378
V_{10}	0.95	1.05	1.0425	1.0473
V_{12}	0.95	1.05	1.0300	1.0388
V_{14}	0.95	1.05	1.0486	1.0427
V_{15}	0.95	1.05	1.0467	1.0428
V_{16}	0.95	1.05	1.0413	1.0415
V_{17}	0.95	1.05	1.0296	1.0444
V_{18}	0.95	1.05	1.0294	1.0456
V_{19}	0.95	1.05	1.0281	1.0334
V_{20}	0.95	1.05	1.0126	1.0224
V_{21}	0.95	1.05	1.0335	1.0143
V_{22}	0.95	1.05	1.0342	1.0384
V_{23}	0.95	1.05	1.0456	1.0354
V_{24}	0.95	1.05	1.0479	1.0321
V_{25}	0.95	1.05	1.0131	1.0182
V_{26}	0.95	1.05	1.0464	1.0454
V_{27}	0.95	1.05	1.0446	1.0447
V_{28}	0.95	1.05	1.0143	1.0172
V_{29}	0.95	1.05	1.0419	1.0353
V_{30}	0.95	1.05	1.0408	1.0223

TABLE V: COMPARISON OF REAL POWER LOSS

Method	Minimum loss
Evolutionary programming[16]	
Genetic algorithm[17]	5.0159
Real coded GA with L_{index} as SVSM[10]	4.665
Proposed method	4.568
	4.5015

VII. CONCLUSION

This paper presents a real coded genetic-algorithm approach for reactive power dispatch including line flow and voltage stability constraint. The proposed method formulates reactive power dispatch problem as a mixed integer non-linear optimization problem and determines control strategy with continuous and discrete control variables such as generator bus voltage, reactive power generation of capacitor banks and on load tap changing transformer tap position. To handle the mixed variables a flexible representation scheme was proposed. For effectively processing the mixed string, a modified form of crossover and mutation were introduced. Thus the problem of discretization of the decision variables in the binary-coded GA has been alleviated by employing real numbers. The performance of the proposed algorithm demonstrated through its voltage stability assessment by modal analysis is effective at various instants following system contingencies. Also this method has a good performance for voltage stability enhancement of large, complex power system networks. The effectiveness of the proposed method is demonstrated on IEEE 30-bus system with promising results. From the simulation work, it is concluded that the real coded genetic algorithm is good to conventional and other optimization methods.

REFERENCES

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

[2] Lee K Y ,Paru Y M , Oritz J L –A united approach to optimal real and reactive power dispatch , IEEE Transactions on power Apparatus and systems 1985: PAS-104 : 1147-1153

[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] Deeb N ,Shahidehpur S.M ,Linear reactive power optimization in a large power network using the decomposition approach. IEEE Transactions on power system 1990: 5(2) : 428-435

[5] E. Hobson ,'Network consrained reactive power control using linear programming, ' IEEE Transactions on power systems PAS -99 (4) ,pp 868=877, 1980

[6] 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.

[7] 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.

[8] S.R.Paranjothi ,and K.Anburaja, "Optimal power flow using refined genetic algorithm", Electr.Power Compon.Syst , Vol. 30, 1055-1063,2002.

[9] D. Devaraj, and B. Yeganarayana, "Genetic algorithm based optimal power flow for security enhancement", IEE proc-Generation.Transmission and. Distribution; 152, 6 November 2005.

[10] D.Devaraj ,' Improved genetic algorithm for multi – objective reactive power dispatch problem' European Transactions on electrical power 2007 ; 17: 569-581

[11] C.A. Canizares , A.C.Z.de Souza and V.H. Quintana , " Comparison of performance indices for detection of proximity to voltage collapse ,'' vol. 11. no.3 , pp.1441-1450, Aug 1996

[12] B.Gao ,G.K Morison P.Kundur ,'voltage stability evaluation using modal analysis ' Transactions on Power Systems ,Vol 7, No .4 ,November 1992.

[13] D Goldberg, "Genetic algorithms in search, optimization and machine learning", Addison-Wesley,1989.

[14] -Deb,K.(201):Multi-objective optimization using evolutionary algorithms 1st ed.(John Wiley &Sons,Ltd.).

[15] - Eshelman.L.J and Schaffer;J.D.(193): Real coded genetic algorithms and interval schemata. In: foundations of Genetic Algorithms 2, Ed.L.Darrell Whitely (Morgan Kaugmann),PP 187-202

[16] Wu Q H, Ma J T. Power system optimal reactive power dispatch using evolutionary programming. IEEE Transactions on power systems 1995; 10(3): 1243-1248

[17] S.Durairaj, D.Devaraj, P.S.Kannan ,' Genetic algorithm applications to optimal reactive power dispatch with voltage stability enhancement' , IE(I) Journal-EL Vol 87,September 2006.

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