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Genetic Algorithm Optimization of Generator Reactive Power

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Abstract

Reactive power optimization in the power system tends to maintain good voltage profile by improving the voltage quality other than decreasing the power loss. This paper presents an improved Genetic algorithm (GA) approach for voltage stability enhancement. The proposed technique is based on the minimization of the maximum of L-indices of load buses. Generator voltages, switchable VAR sources and transformer tap changers are used as control variables. A case study is made on all the optimization variables mentioned and the effect on generators reactive power output is analyzed. The comparison of two optimization techniques is explained in detail. The results obtained for the IEEE-24 bus power system had indicated that the GA not only improves the voltage stability but also reduces the effect on generators for the Reactive Power.

Keywords: Reactive Power Optimization; Voltage Stability; Genetic Algorithm; Natural Selection.

1. Introduction

The unmatched generation and transmission capacity expansion, voltage instability is troubling the power engineers to optimize power system operation, while maintaining system security and quality of supply to customers. Under many disturbed conditions the operation of the power systems has to be restricted to design limits. It is turning complex to the power engineers to ensure the quality and reliability of supply to the customers by maintaining load bus voltages in their permissible limits. Despite of all, overloading in existing power transmission systems, voltage collapse and voltage stability are concerned as the major problems, to power system planning and operation engineers, which has to be enhanced. Voltage profile can be improved with reallocation of reactive power generations, by adjusting the controller parameters of transformer taps, generator exciters and Switchable VAR Compensator (SVC) settings to its best optimal values. Several have

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emerged earlier to solve this type of complex problems, like Linear programming (LP)[1] , Non-Linear Programming (NLP) [3]and Interior point method[4]. Though these techniques were applied for solving the reactive power dispatch problem, still some backdrops are associated with them. Linear Programming techniques with iterative schemes are proved to be the most promising tools for solving these types of problems earlier, with better results and good evaluation time. But this kind of approach is only limited to local minimum[5], where Genetic Algorithm technique (GA)[2] is being used as a recent trend which is a global minimum based optimization technique yielding to much more better results. The main advantages of GA[6]: It can find near optimal solution regardless the initial parameter values, Its convergence is fast It uses few number of control parameters. The system parameters V_e , V_s and $\sum L^2$ are calculated, along with the effect on the generators reactive power output. This paper presents an effective algorithm with GA approach with selected mutation rate and population size to find the optimized control settings for the given controllers. The optimized controller settings are considered and the power system parameters are again analyzed with new settings to minimize the sum of the squares of the L indices (V stability) and also to reduce the required reactive power through the generators in parallel. The algorithm is successfully applied to IEEE-24 bus system and is compared with the existing LP optimization values and presented for illustration purpose.

2.Analysis of Voltage Stability

A slow variation in the system operations, due to increase in loads results in the gradual decrease in the voltage magnitude. Careful monitoring and control action has to be taken from the operator when the operating point approaches the voltage stability limit. Recent literature presents many voltage stability and voltage collapse prediction methods. Among them, L index method is adopted in this paper for the calculation of Voltage stability which is described as follows.

2.1. *L-index method*

Consider a system where,

n=total number of busses, g=generator busses , s= SVC busses , t =number of OLTC transformers.A load flow result is obtained for a given system operating condition, which is otherwise available from the output of an on-line state estimator. Using the load flow results, the L-index [6] is computed as

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \tag{1}$$

where j=g+1... n and all the terms within the sigma on the RHS of (1) are complex quantities. The values F_{ji} are obtained from the Y bus matrix as follows

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \tag{2}$$

Where I_G, I_L and V_G , V_L represent currents and voltages at the generator nodes and load nodes. Rearranging (2) we get

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \tag{3}$$

where F_{LG}=-$[Y_{LL}]^{-1}[Y_{LG}]$ are the required values. The L-indices for a given load condition are computed for all load busses.

For stability, the bound on the index L_j must not be violated (maximum limit=1) for any of the nodes j. Hence, the global indicator L describing the stability of the complete subsystem is given by L= max of L_j for all j. An L-index value away from 1 and close to zero indicates an improved system security. For a given network, as the load/generation increases, the voltage magnitude and angles change, and for near maximum power transfer condition, the voltage stability index L_j values for load buses tends to 1, indicating that the system is near to voltage collapse. The stability margin is obtained as the distance of L from a unit value i.e. (1-L).

3.Modeling of Reactive Power Optimization Problem.

3.1. Objective function

The algorithm proposed is the single-objective optimization and the objective function is to minimize the sum of squares of the voltage stability L-indices of all the load buses. The objective function is shown as follows:

$$F(x) = V_L = \sum_{j=g+1}^{n}(L_j^2) \quad (4)$$

3.2 Equation constraints

Equation constraints of reactive power optimization are the power flow equations. Each node in the system has active and reactive power functions [2], which are given by

$$P_i = V_i \sum_{j=1}^{N} V_j\left(G_{ij}cos\delta_{ij} + B_{ij}sin\delta_{ij}\right) \quad (5)$$

$$Q_i = V_i \sum_{j=1}^{N} V_j(G_{ij}sin\delta_{ij} + B_{ij}cos\delta_{ij}) \quad (6)$$

In the above equations, V_i and V_j are the voltages at bus i and j; G_{ij} and B_{ij} are the conductance and susceptance of the line connecting bus i and j; δ_{ij} is the phase angle difference of voltage from bus i to j.

3.3 Inequality constraints

In reactive power optimization, generator bus voltage, transformer taps and reactive power compensation capacity are selected as control variables. So, the control variable constraints are given by:

$V_{Gimin} \le V_{Gi} \le V_{Gimax}$; $T_{imin} \le T_i \le T_{imax}$; $Q_{imin} \le Q_i \le Q_{imax}$;

V_{Gi}	=	Generator output Voltage,	T_i	=	Transformer tap position
Q_i	=	SVC setting positions,	V_{Gimin}	=	Minimum output Voltage of Generator
V_{Gimax}	=	Maximum output Voltage of Generator	T_{imin}	=	Minimum tap position of Transformer
T_{imax}	=	Maximum tap position of Transformer	Q_{imin}	=	Minimum output of SVC's
Q_{imax}	=	Maximum output of SVC's			

As the voltage of load and value of generator reactive power can be obtained after the power flow calculation, they are treated as state variables generally. The state variable constraints are given by:

$V_{imin} \le V_i \le V_{imax}$; $Q_{Gimin} \le Q_{Gi} \le Q_{Gimax}$;

V_i	=	Bus Voltage	Q_{Gi}	=	Reactive power generation
V_{imin}	=	Lower limit of load voltage	V_{imax}	=	Upper limit of load voltage
Q_{Gimin}	=	Lower limit of generator output of reactive power	Q_{Gimax}	=	Upper limits of generator output of reactive power

4 . Procedure for problem solving.

4.1. Computation of Power System operation

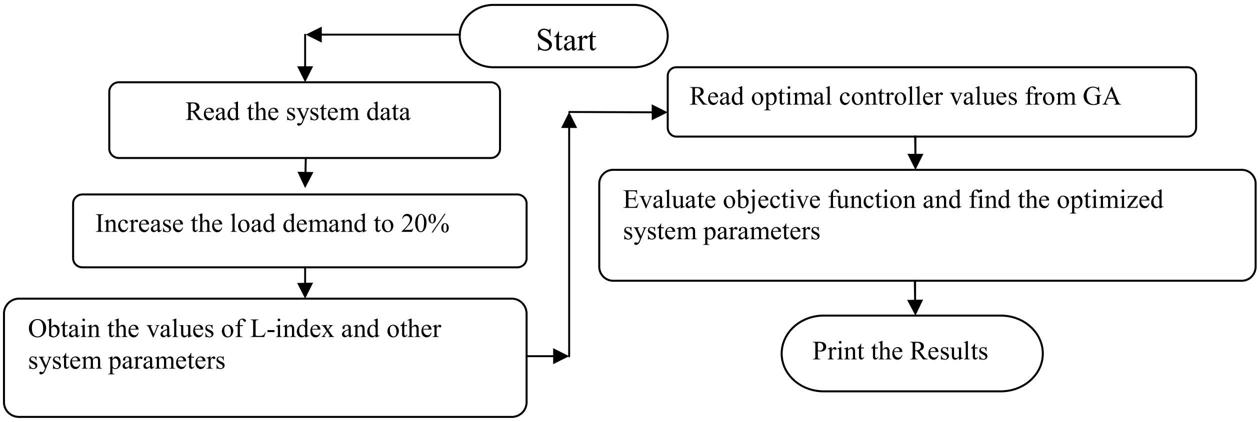

Figure 1: Flow chart for power system operation.

Figure 1 explains the step by step computational procedure for evaluation of objective function and calculation of system parameters like V_e, $\sum L^2$, P_{loss} , Q output at Generators.

4.2. Computation of GA optimization

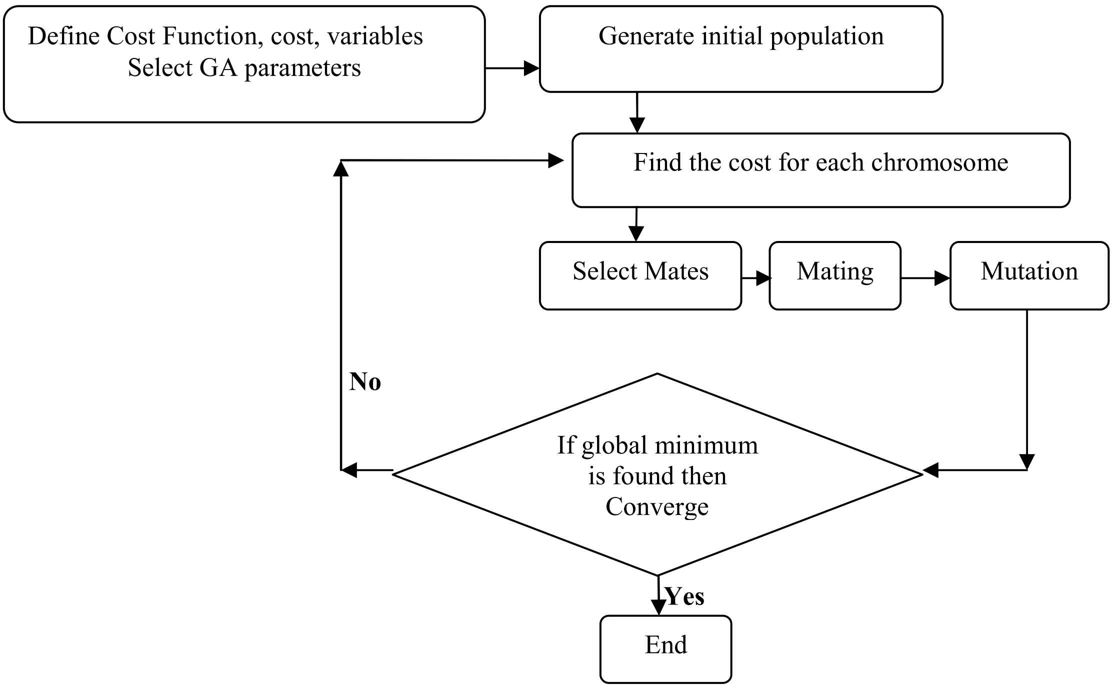

Figure 2: Flow chart for Genetic Algorithm Optimization.

Figure 2 explains the procedure of Genetic Algorithm optimization [7] to find the optimized cost and best setting value with respect to the cost function. The GA Optimized controller values obtained here are replaced with initial system controller setting

5. Case Study

5.1. System data

The proposed approach has been tested on the IEEE-24 Bus system. Details are as follows:

No. of. Generators	4
No. of. Transformers	11
No. of SVC buses	4
No. of. Transmission lines	16
P-generation in MW	2850
P-Load in MW	2620
Q-Load in MVAR	980

5.2. Results

5.2.1. *The initial system parameters*

Table 1: The initial system parameters

	V_e	$\sum L^2$	P_{loss}(MW)
Initial values	1.148	3.14359	73.63

5.2.2. *The Optimized controller Settings*

Table 2: Controller settings initial and optimized

Control Variables	Initial settings	GA optimized		Control Variables	Initial settings	GA optimized
V1	1	0.9881		T1(16-5)	0	0.93714
V2	1	0.9881		T2(19-6)	0	0.92866
V3	1	0.9881		T3(20-7)	0	0.9726
V4	1	0.9881		T4(14-8)	0	0.9392
Q5	0	9.5201		T5(23-9)	0	1.0262
Q6	0	13.0186		T6(18-10)	0	0.9272
Q7	0	18.514		T7(22-13)	0	0.9787
Q8	0	8.06				

5.2.3. *The system parameters after replacing initial control settings with optimized values.*

Table 3: Optimized System parameters

	V_e	$\sum L^2$	P_{loss}(M)
GA Optimized system parameters	0.152	2.3989	64.07

5.2.4. *Comparison of GA optimized values with Linear Programming technique*

Table 4: Initial and optimal system parameters

	$\sum L^2$	V_e	P_{loss}
Initial	3.14359	1.148	73.62
LP	2.5088	0.232	66.02
GA	2.3989	0.152	64.07

From the table 4 it can be observed clearly that the sum of squares of the voltage stability L-indices (i.e., $V_{stability}$ objective) is minimized much better even when compared to the conventional Linear Programming Technique, and it is also observed that Power loss is much reduced.

5.2.5. *Analysis of Effect on the generator reactive power.*

Table 5: Reactive power output of each generator at different conditions.

	Initial	**LP method**	**GA method**
Q at G1	5.5455	5.3455	4.5643
Q at G2	1.03	0.7607	0.47
Q at G3	1.7985	1.5985	1.0021
Q at G4	3.0926	2.8926	2.2151

From the obtained values of the Q output at different generators it is clearly observed that the burden on generators for supply of reactive power is being reduced. This can be helpful when there is much more requirement of reactive power during any sudden violations of voltages. Hence satisfactory results are obtained from the applied $V_{stability}$.

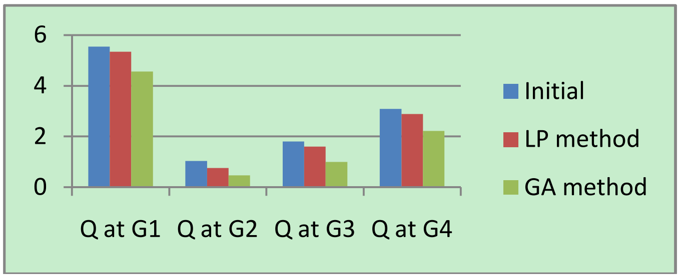

Figure 3: Change of Reactive power outputs of various generators

Figure 3 clearly explains the variations of effect of reactive power output of generators. When Linear Programming technique is considered, the Reactive Power(Q) output at generators is slightly reduced whereas reduction is much better when the Genetic Algorithm Technique is considered.

Conclusion

An approach for Reactive power Optimization is proposed in this paper with voltage stability objective using Genetic Algorithm technique and after comparing it with the existing LP technique betterment is seen. The $\sum L^2$ values obtained after optimization indicates improvement in Voltage stability. This objective of $V_{stability}$ is also helpful for finding the Reactive Power(Q) output at generators. The Q output requirement at generators is much reduced by GA optimization. Totally GA technique is proved to be far better optimization technique than any other techniques.

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