Reactive Power Scheduling by Optimization of Various Objective Functions Using Genetic Algorithm

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ABSTRACT:

The Unmatched Generation and Transmission capabilities of present Power System is causing a huge scarcity of Reactive Power, routing to Power Quality problems. Despite of all, overloading in all existing Power Transmission Systems, Voltage Collapse, Voltage Stability and Power loss are concerned as major problems in the System. At such conditions, it is necessary to supply the required Reactive Power or to optimize the requirement of Reactive Power. This is done by adjusting the controllers: Generator Exciters, On Load Tap Changers (OLTC's), Switchable VAR Compensators (SVC's), to its best optimized settings. Optimization of Generator output tends to increase the supply capabilities of Generators at different voltage disturbances. Similarly, Optimization of OLTC's, SVC's reduces the requirement of Reactive Power supply at Transmission and Distribution stages respectively. The Genetic Algorithm (GA) is proposed to optimize the effect of requirement of Reactive Power supply at three different stages in the Power systems. The proposed technique is tested with IEEE-24 bus system and a case study is done on all optimization variables (Control parameters) using three different objective functions. The obtained GA optimized values of the system are compared with conventional Linear Programming (LP) optimized values. The voltage stability and effect on Generator Reactive power output are analysed. The comparison clearly says that GA approach performs better Optimization than LP technique.

KEYWORDS: On Load Tap Changers (OLTC's), Switchable VAR Compensators (SVC's), Genetic Algorithm (GA).

I.INTRODUCTION

According to the different characteristics and types of the problems as well as their complexity, power systems operation is divided into the following aspects: Power flow analysis, Sensitivity analysis, Classical economic dispatch, Security-constrained economic dispatch, Multi-area systems economic dispatch, Unit commitment, Optimal power flow, Steady-state security regions, Reactive power optimization, Optimal load shedding, Optimal reconfiguration of electric distribution networks and Uncertainty analysis in power system.

From the view of optimization, the various techniques including traditional and modern Optimization methods, which have been developed to solve these power system operation problems, are classified into three groups:

Conventional optimization methods including: Unconstrained optimization approaches, Nonlinear Programming (NLP), Linear Programming (LP), Quadratic Programming (QP), Generalized reduced gradient method, Newton method, Network flow programming (NFP), Mixed-integer Programming (MIP), Interior Point (IP) methods

Intelligence search methods such as Neural network (NN), Evolutionary algorithms (EAs), Tabu search (TS), Particle swarm optimization (PSO). Non quantity approaches to address uncertainties in Objectives and Constraints Probabilistic optimization, Fuzzy set applications, Analytic hierarchical process (AHP).The Genetic algorithm method is considered as prominent technique to solve the Reactive Power Optimization problem in power system.

II. REACTIVE POWER OPTIMIZATION

The voltage profile of Power system is determined by Reactive Power balance in the system.

$$\sum_{i=1}^{NG} Q_{Gi} + \sum_{j=1}^{NC} Q_{Cj} = \sum_{k=1}^{ND} Q_{Dk} + Q_L$$

Where

Q_{Gi} = Reactive power generation of generator i

Q_{Cj} = Reactive power generation of the VAR compensation device j such asCapacitors, SVC's, etc.

Q_{dk} = Reactive power load at load bus k

Q_L = System Reactive power loss. It includes the Reactive power loss of Transformer and Transmission lines.

Reactive Power Economic Dispatch

$$Q_{Gimin} \leq Q_{Gi} \leq Q_{Gimax}$$

If the reactive power source has violation, set the reactive power output of this source to its corresponding limit. Then this source will not be considered in the rest of reactive power dispatch.

A. Linear Programming Method of VAR Optimization Reactive power optimization is a nonlinear optimization problem. If we consider network security constraints and bus voltage constraints, VAR optimization becomes a complex optimization problem. The linearization of the VAR optimization model is frequently adopted in conventional methods. This method gives optimal reactive power allocation in the system for improvement of voltage stability.

B. Genetic Algorithm Method of VAR Optimization the Genetic Algorithm (GA) is an optimization and search technique based on the principles of genetics and natural selection. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the "fitness" (i.e., minimizes the cost function). Components of Genetic Algorithm: The Variables & Fitness (cost) functions.

As our goal is to solve the Optimization problem, where we search an optimal (minimum) solution in terms of variables (N_{var}) of the problems, therefore we begin the process of fitting it to a GA by defining a chromosome as an array of variables to be optimized. Each chromosome has the fitness (cost) found by evaluating fitness function.

i.e., Fitness function f = f(chromosome)

Variable encoding and Bounding: Since the GA is a search technique, it must be limited to exploring a reasonable region of variable space. Sometimes this is done by imposing a constraint (Bounds) on the problem. If one does not know the initial search region, there must be enough diversity in the initial population to explore a reasonably sized variable space before focusing on the most promising regions.Initial Population: To begin the GA, we define an initial population of N_{pop} chromosomes. A matrix represents the population with each row in the matrix being a 1xNvar array (chromosome) of continuous values. Given an initial population of N_{pop} chromosomes, the full matrix of

N_{pop} xN_{var} random values is generated by

$$pop = rand(N_{pop}, N_{var})$$

All variables are normalized to have values between 0 and 1, the range of a uniform random number generator. The values of a variable are "un-normalized" in the cost function. If the range of values is between P_{lo} and P_{hi}, then the un-normalized values are given by

$$P = (P_{hi} - P_{lo})P_{norm} + P_{lo}$$

Where

P_{hi} = Highest number in variable range
P_{lo} = Lowest number in variable range
P_{norm} = Normalized value of variable

Natural Selection:

Now is the time to decide which chromosomes in the initial population are fit enough to survive and possibly reproduce offspring in the next generation. The N_{pop} costs and associated chromosomes are ranked from lowest cost to highest cost. The rest die off. This process of natural selection must occur at each iteration of the algorithm to allow the population of chromosomes to evolve over the generations to the most fit members as defined by the cost function. Not all of the survivors are deemed fit enough to mate. Of the N_{pop} chromosomes in a given generation, only the top N_{keep} are kept for mating and the rest are discarded to make room for the new offspring.

Pairing and Mating: The (N_{keep}) most-fit chromosomes form the mating pool. Two mothers and fathers pair in some random fashion. Each pair produces two offspring that contain traits from each parent. In addition the parents survive to be part of the next generation. The more similar the two parents, the more likely are the offspring to carry the traits of the parents. During Mating one or more points are chosen in the chromosome to mark as the cross over points. Cross over points are randomly selected, and then the variables in between are exchanged. The extreme case is selecting N_{var} points and randomly choosing which of the two parents will contribute its variable at each position. Thus one goes down the line of the chromosomes and, at each variable, randomly chooses whether or not to swap information between the two parents. Mutations: Here, as in the last chapter, we can sometimes find our method working too well. If care is not taken, the GA can converge too quickly into one region of the cost surface. If this area is in the region of the global minimum, that is good. However, some functions, such as the one we are modeling, have many local minima. If we do nothing to solve this tendency to converge quickly, we could end up in a local rather than a global minimum. To avoid this problem of overly fast convergence, we force the routine to explore other areas of the cost surface by randomly introducing changes, or mutations, in some of the variables. Hence we choose a mutation rate. Multiplying the mutation rate by total number of variables that can be mutated in the population gives number of mutations.

$$N_{mut} = mutrate \times N_{keep} \times N_{var}$$

Next Generations; Convergence: The above process is done for new generations until the global minimum is found. In order to break the continuity the generations are limited to random bigger value like 100. And when once the global minimum is found hence it converges and displays the global minimum value to the fitness function.

III. MODELLING OF POWER OPTIMIZATION PROBLEM

Objective Functions: The algorithm proposed is the Multi-objective optimization and the objective functions are to minimize the sum of squares of the voltage stability L-indices of all the load buses, to minimize the sum of squares of voltage deviations and to minimize the real power loss. The objective functions are shown as follows:

Minimize the sum of squares of the voltage stability L-indices

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

Minimize the real power loss

$$F(x) = P_L = S_{ij} + S_{ji}$$

Minimize the sum of squares of voltage deviations

$$F(x) = V_e = \sum_{j=g+1}^{n}(V_j^{desired} - V_j^{actual})^2$$

Constraints: There are the equation (equality) constraints and inequality constraints in order to solve every optimization problem, which are modelled as follows. Equality Constraints Equation constraints of reactive power optimization are the power flow equations. Each node in the system has active and reactive power functions, which are given by:

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

In the above equations,

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

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 as follows.

Control variable constraints .The control variable constraints give the maximum and minimum limits of the controllers.

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

Where

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

Dependent variable constraints: 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:

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

Where

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 limit of generator output of Reactive power

Voltage Stability Analysis L index method is adopted for the calculation of Voltage stability which is described as follows.

L-index method Consider a system where,

n=total number of busses, g=generator busses, s= SVC busses,t =number of OLTC transformers.

The L-index obtained from load flow is computed as

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

Where

$j=g+1... n$ and all the terms within the sigma on the RHS of above equation are complex quantities.

The values of F_{ji} are obtained from the Y_{bus} matrix as follows

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

Where

I_G = Current at generator nodes
I_L = Current at Load nodes
V_G = Voltage at generator nodes
V_L = Voltage at Load nodes.

Rearranging above equation we get

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

Where $F_{LG} = - [Y_{LL}]^{-1}[Y_{LG}]$ are the required values. The L-indices for given load conditions are computed for all load buses.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=maximum of L_j for all j (load buses).L-index value away from 1 and close to zero indicates an improved system security. For a given network, as the load/generations increases, the voltage magnitude and angles change, and for near maximum power transfer condition, the voltage stability index L_j values for load buses tend to be close to 1, indicating that the system is close to voltage collapse. The stability margin is obtained as the distance of L from a unit i.e. (1-L).Reactive Power Output at Generators.From the load flow studies, we can calculate the Q at generators by:

$$Q= -|V_i|*|V_j|*(G_{ij} \text{ Sin } \delta_{ij} - B_{ij} \text{ Cos } \delta_{ij})$$

Where,

G = Conductance, B = Susceptance

In order to consider the sensitivities regarding the other control parameters like Transformer taps and SVC settings, we also compute the line flow studies and then calculate the Q at generators.According to line flows

Q = imaginary of (PQlinepq)

Where PQlinepq is the power flow from line p to line q.

IV. IEEE 24 BUS SYSTEM ANALYSIS FOR PROPOSED TECHNIQUE

System Data

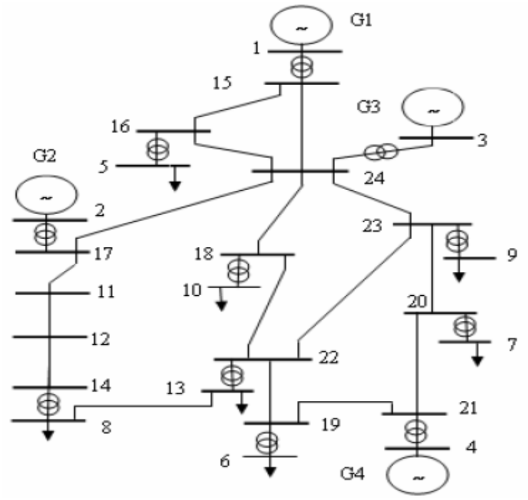

Figure 1 IEEE 24 bus EHV system

Table 1 gives the IEEE-24 bus EHV system data

Table 1: 24-Bus EHV System

Number of Generators	4
Number of Transformers	11
Number of Transmission lines	16
Number of Loads	8
Number of Shunt Compensators	4
Number of Reactors	17
P-load(peak, MW)	2620
Q-load(peak, MVAR)	980

Table 2 gives the IEEE-24 bus system generation

Table 2: Generation data

Bus	**P_{gen}(MW)**	**Q_{max}(MVAR)**	**Q_{min}(MVAR)**	**V_m(pu)**	**V_{gmax}**	**V_{gmin}**	**Step Size**
1	1820.0	950.0	-150.0	1.0	1.05	0.95	0.0125
2	160.0	320.0	-50.0	1.0	1.05	0.95	0.0125
3	350.0	400.0	-100.0	1.0	1.05	0.95	0.0125
4	520.0	400.0	-90.0	1.0	1.05	0.95	0.0125

Table 3 gives the system load data

Table 3: Load data

Bus	**P_d(MW)**	**Q_d(MVAR)**
5	430.0	170.0
6	280.0	90.0
7	320.0	110.0
8	180.0	70.0
9	120.0	40.0
10	60.0	20.0
13	450.0	180.0
15	780.0	300.0

Power Flow Analysis: The Newton Raphson method is adopted here to run the power flow analysis.After the Power flow is done for the above given IEEE-24 bus system the system parameters of Voltage error, Voltage stability index and Real power loss are calculated as follows:

Table 4 gives the System parameters calculated through Power flow studies:

Table 4: System parameters

The Voltage error(V_e)	1.148
The Voltage stability index ($\sum L^2$)	3.14359
The Real Power loss (P_{loss})	73.63 (MW)

Optimization of Controller Settings The three controllers taken in the system are

Generator Exciters (V_1, V_2, V_3, V_4)
SVC's (Q_5,Q_6,Q_7,Q_8)
OLTC Taps (T_1(16-5),T_2(19-6),T_3(20-7),T_4(14-8),T_5(23-9),T_6(18-10), T_7(22-13))

These controllers are set to some initial settings and then optimization is done using Genetic Algorithm technique. Since Three objective functions are taken in this problem, the Genetic Algorithm optimization in done with respect to each objective function individually. The Initial settings and the optimized settings (w.r.to each objective) are tabled further.

Table 5 gives the initial and optimized (w.r.t. each objective) settings of the controllers.

Table 5: Controller settings

Controller	**Initial Settings**	**Optimized settings**		
		w.r.t $V_{desired}$ Obj	**w.r.t $V_{stability}$ Obj**	**w.r.t P_{loss} Obj**
V_1	1	0.98632	0.9881	0.98588
V_2	1	0.98632	0.9881	0.99005
V_3	1	0.98632	0.9881	0.96676
V_4	1	0.98632	0.9881	0.96171
Q_5	0	11.867	9.5201	8.62508
Q_6	0	10.973	13.0186	11.0941
Q_7	0	20.041	18.514	10.377
Q_8	0	7.5645	8.06	11.0938
T_1(16-5)	0	1.0284	0.93714	0.99925
T_2(19-6)	0	0.92135	0.92866	1.011
T_3(20-7)	0	0.96792	0.9726	0.95542
T_4(14-8)	0	1.0051	0.9392	1.0306
T_5(23-9)	0	0.9769	1.0262	0.94541
T_6(18-10)	0	1.0116	0.9272	0.95373
T_7(22-13)	0	0.96087	0.9787	1.0063

Optimal Power Flow Analysis: The Optimal Power flow analysis for different objectives done is and results are obtained as follows. Objective $V_{Desired}$: After the Power flow is done using the new controller settings optimized with respect to $V_{desired}$ objective function, the system parameters of Voltage error, Voltage stability index and Real power loss are calculated as follows

Table 6 gives the System parameters calculated for $V_{desired}$ objective function.

Table 6: System parameters for $V_{desired}$ objective function

The Voltage error(V_e)	0.103
The Voltage stability index ($\sum L^2$)	2.363
The Real Power loss (P_{loss})	63.56(MW)

Objective $V_{Stability}$: After the Power flow is done using the new controller settings optimized with respect to $V_{stability}$ objective function, the system parameters of Voltage error, Voltage stability index and Real power loss are calculated as follows:

Table 7 gives the System parameters calculated for $V_{stability}$ objective function.

Table 7: System parameters for $V_{stability}$ objective function

The Voltage error(V_e)	0.152
The Voltage stability index ($\sum L^2$)	2.3984
The Real Power loss (P_{loss})	64.07(MW)

Objective P_{Loss}: After the Power flow is done using the new controller settings optimized with respect to P_{loss} objective function, the system parameters of Voltage error, Voltage stability index and Real power loss are calculated as follows:
Table 8 gives the GA Optimized System parameters calculated for P_{loss} objective function.

Table 8: GA Optimized System parameters for P_{loss} objective function

The Voltage error(V_e)	0.193
The Voltage stability index ($\sum L^2$)	2.5466
The Real Power loss (P_{loss})	66.13(MW)

Comparison Of Ga And Lp Techniques: The GA optimized system parameters are compared with the system parameters obtained from LP Optimization Technique .Objective $V_{Desired}$: The system parameters of Voltage error, Voltage stability index and Real power loss calculated after the Power flow is done using the new controller settings optimized by GA with respect to $V_{desired}$ objective, are compared with that of the system parameters optimized by LP optimization technique.
Table 9 gives the system parameters calculated for $V_{desired}$ objective function by GA and LP Optimization techniques.

Table 9: Comparison of GA and LP optimized System parameters for $V_{desired}$ objective function

System Parameters	By GA	By LP
The Voltage error(V_e)	0.103	0.125
The Voltage stability index ($\sum L^2$)	2.363	2.4902
The Real Power loss (P_{loss})	63.56(MW)	65.18(MW)

Objective $V_{Stability}$: The system parameters of Voltage error, Voltage stability index and Real power loss calculated after the Power flow is done using the new controller settings optimized by GA with respect to $V_{stability}$ objective, and are compared with that of the system parameters optimized by LP optimization technique.
Table 10 gives the System parameters calculated for $V_{stability}$ objective function by GA and LP Optimization techniques.

Table 10: Comparison of GA and LP optimized System parameters for $V_{stability}$ objective function

System Parameters	By GA	By LP
The Voltage error(V_e)	0.152	0.232
The Voltage stability index ($\sum L^2$)	2.3989	2.5088
The Real Power loss (P_{loss})	64.07(MW)	66.02(MW)

Objective P_{Loss}: The system parameters of Voltage error, Voltage stability index and Real power loss calculated after the Power flow is done using the new controller settings optimized by GA with respect to P_{Loss} objective, are compared with that of the system parameters optimized by LP optimization technique.
Table 11 gives the system parameters calculated for P_{loss} objective function by GA and LP Optimization techniques.

Table 11: Comparison of GA and LP optimized System parameters for P_{loss} objective function

System Parameters	By GA	By LP
The Voltage error(V_e)	0.083	1.505
The Voltage stability index ($\sum L^2$)	2.5466	2.7728
The Real Power loss (P_{loss})	66.13(MW)	68.61(MW)

Voltage Stability Analysis: The voltage stability is mathematically obtained as the minimization of sum of squares of L-indices of all load buses .i.e., Minimization of $\sum L^2$ value.
These values are already tabulated above for every objective function individually where the GA values are reduced compared to LP values. This explains the Voltage Stability is increased by GA optimization than by the LP optimization.

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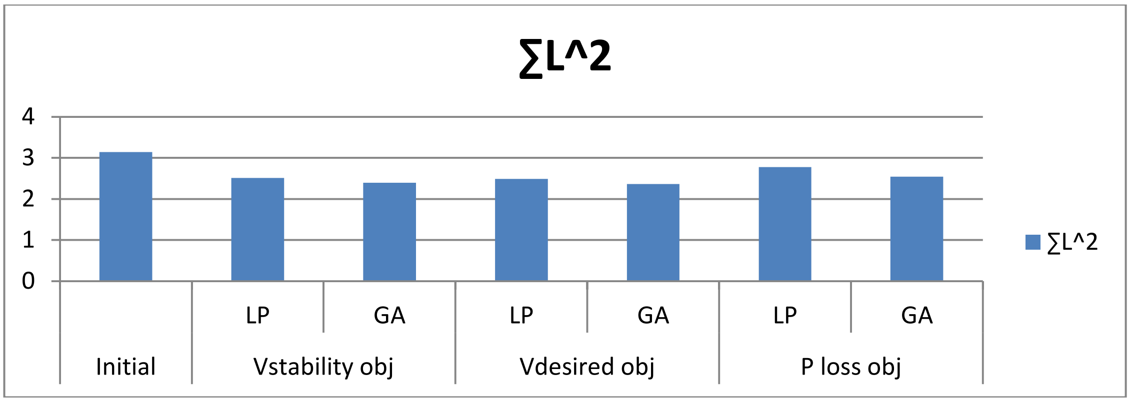

Figure 2 Voltage stability $\sum L^2$ values

Figure 2 gives the graphical variations in the voltage stability in the system by both GA and LP optimization methods for each objective Analysis of Effect on Generator Reactive Power Output.The computation of effect on generator reactive power output is mathematically modeled in Section 4.5. Let us graphically analyze the generator reactive power output after optimizing with respect to the assumed three objective functions.Objective $V_{desired}$.

Table 12 gives the Initial, Optimized (LP and GA) generator reactive power output for objective $V_{desired}$.

Table 12: Reactive power output at generators by different methods for $V_{desired}$ objective

$V_{desired}$ obj	Initial	LP method	GA method
Q at G1	5.5455	5.3497	4.3564
Q at G2	1.03	0.7899	0.549
Q at G3	1.7985	1.1603	1.0989
Q at G4	3.0926	2.9001	2.1794

From the obtained values of the Q output at different generators for objective function $V_{desired}$, it is observed that the burden on generators reactive power is reduced. This is helpful when there is more requirement of reactive power during sudden violations of voltages.

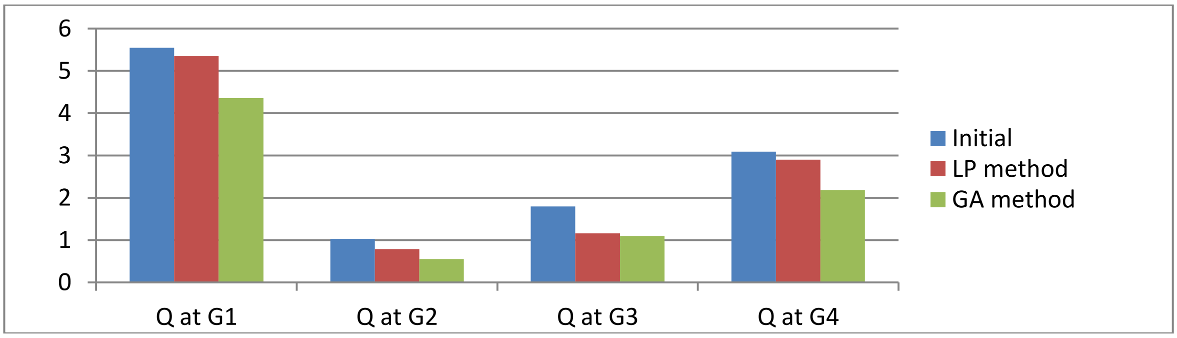

Figure 3: Analysis of Reactive power outputs of generators for $V_{desired}$ objective function.

Figure 3 clearly explains the variations of effect of reactive power output of generators with $V_{desired}$ objective function. 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.

Objective $V_{stability}$:

Table 13 gives the Initial, Optimized (LP and GA) generator reactive power output for objective $V_{stability}$.

Table 13: Reactive power output at generators by different methods for $V_{stability}$ objective

$V_{stability}$ obj	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 for objective function $V_{stability}$, it is observed that the burden on generators reactive power is reduced. This is helpful when there is more requirement of reactive power during sudden violations of voltages.

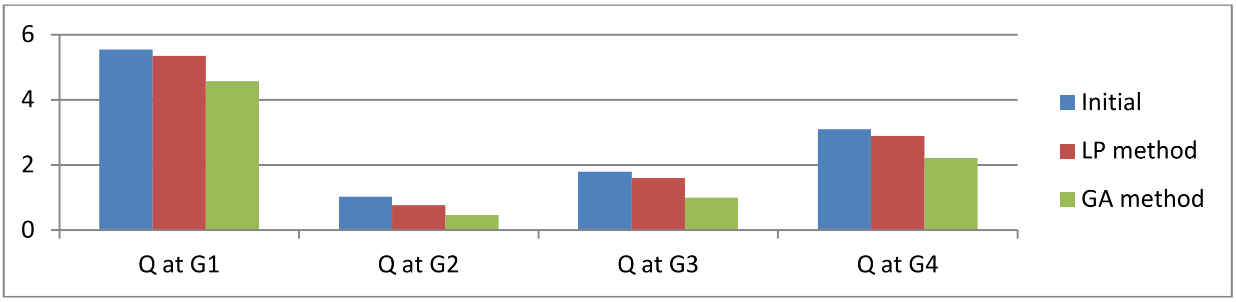

Figure 4: Analysis of Reactive power outputs of generators for $V_{stability}$ objective function.

Figure 4 clearly explains the variations of effect of reactive power output of generators with $V_{stability}$ objective function. 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.

Objective P_{loss}

Table 14 gives the Initial, Optimized (LP and GA) generator reactive power output for objective P_{loss}.

Table 14: Reactive power output at generators by different methods for P_{loss} objective

P_{loss} obj	Initial	LP method	GA method
Q at G1	5.5455	5.3645	3.8521
Q at G2	1.03	0.9510	0.791
Q at G3	1.7985	1.6791	1.2542
Q at G4	3.0926	2.9086	2.1335

From the obtained values of the Q output at different generators for objective function P_{loss}, it is observed that the burden on generators reactive power is reduced. This is helpful when there is more requirement of reactive power during sudden violations of voltages.

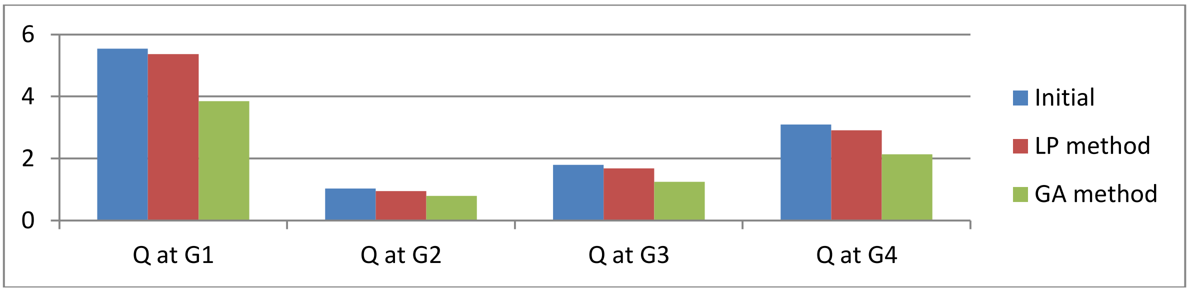

Figure 5: Analysis of Reactive power outputs of generators for P_{loss} objective function

Figure 5 clearly explains the variations of effect of reactive power output of generators with P_{loss} objective function. 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.

V.CONCLUSION

From the obtained results for the proposed technique The controller settings are optimized with the assumed three objective functions.The system parameters are obtained through load flow studies after using the optimal controller settings.The system parameters obtained are of much better values after the optimization is done.The comparison study clearly explains that GA optimization is yielding good results than the conventional LP optimization.The Voltage stability analysis says that the voltage stability margin is increased taking the system in more stable situation.The effect on generator reactive power output required is reduced which indicates the reduction in burden on generators to supply the reactive power.

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