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Optimal placement of static VAR compensator using genetic algorithm and particle swarm optimization techniques

A.Jagadeesh[1] and G. V. Nagesh Kumar[2]

[1]Department of Electrical and Electronics Engineering, Vignan's Institute of Information Technology, Visakhapatnam.

[2]Department of Electrical and Electronics Engineering, GITAM University, Visakhapatnam.

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ABSTRACT

The transfer reactive power from production source to consumption areas during steady-state operating conditions is a major problem of voltage stability. Hence voltage stability enhancement margin is interrelated with Reactive power loss (RPL). In practical, the power system network has 80-90% inductive loads. When the loads are increased, the line currents are increased, reflecting to the increase in Reactive power loss. This will leads to voltage instability that means the power system gets closer to the instability point. Reactive power can be dispatched effectively to maintain acceptable voltage levels. Maintaining viable voltage levels are very important to avoid voltage collapse. The optimal allocation of a VAR compensator is implemented using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). These two algorithms are implemented considering its less memory requirement and inherent simplicity. Simulation is carried out by using MATLAB Software for IEEE 14 bus system and the results are presented and analysed.

Introduction

For many years, voltage collapse problems in power systems have been of permanent concern for electric utilities and a subject of great importance due to the events of voltage instability and collapses that have occurred worldwide. Voltage collapse is due to voltage instability. Voltage stability problems normally occur in heavily stressed systems. While the disturbance leading to voltage collapse may be initiated by a variety of causes, the underlying problem is an inherent weakness in the power system. In addition to the strength of transmission network and power transfer levels, the principal factors contributing to voltage collapse are the generator reactive power/voltage control limits, load characteristics, characteristics of reactive compensation devices, and the action of voltage control devices such as transformer under load-tap changers (ULTCs).

Some of the causes for occurrence of voltage instability are

- Different in Transmission of Reactive Power under Heavy Loads.
- High Reactive Power Consumption at Heavy Loads.
- Occurrence of Contingencies.
- Voltage sources are too far from load centers.
- Due to unsuitable locations of FACTS controllers.
- Poor coordination between multiple FACTS controllers.
- Presence of Constant Power Loads.
- Reverse Operation of ON Load Tap-Changer (OLTC).

Optimization of GA and PSO Techniques

Optimization is the method of obtaining the best result under given circumstances. In engineering design activities (design, construction and maintenance), engineers have to take many technological and managerial decisions at several stages. The main and important goal of all such decisions is either to minimize the effort required or to maximize the desired benefit.

Genetic algorithm

Genetic Algorithms (GA) are based on stochastic global search method that mimics the metaphor of natural biological evolution. At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation.

Particle swarm optimization

The PSO as an optimization tool provides a population-based search procedure in which individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called Pbest), and according to the experience of a neighboring particle (This value is called Gbest), made use of the best position encountered by itself and its neighbor. It could be implemented and applied easily to solve various function optimization problems, or the problems that can be transformed to function optimization problems.

Location of Series Capacitors

In the power system when the load demands are increased, the load current also increased. This will leads to more reactive power consumed by the transmission line (I^2X_L).Due to the consumption of reactive power, the generated reactive power is not sufficient to reach the loads. This shortage of reactive power will drops the voltages at load buses. Further the entire power system gets closer to the instability point. Hence to maintain proper voltage profile at all buses is our main criteria.

The various steps involved in solving the problem are given below:

Tele:
E-mail addresses: gundavarapu_kumar@yahoo.com

Step 1: Conduct the Newton-Raphson method for a given Bus system with the input constraints and find where the reactive power losses are maximum.
Step 2: Select two or three lines for placement of VAR compensator(among these lines find out the best line for compensation)
Step 3: Take first line and conduct the optimization technique. Find the new value of X_L using GA or PSO.
Step 4: Now replace the X_{old} value with X_{new} value in the transmission lines.
Step 5: Conduct Newton-Raphson method and take the results i.e
i) Voltage at various Buses ii) Reactive power losses
Step 6: Now take the next line and repeat the same procedure from step 3

Implementation In Genetic Algorithm And Particle Swarm Optimization

The Particle Swarm Optimization, Genetic algorithm and evolutionary programming is well known optimization algorithm for engineering application .In this paper PSO and Genetic algorithm have been implemented considering its less memory requirements and inherent simplicity, to obtain the optimal locations of the Var compensators

Implementation of PSO

Since its introduction, PSO has been successfully applied to optimize various continuous nonlinear functions. The objective in the case being discussed is to minimize the series reactive power loss in the system. To do so, the transmission lines, where the RPL is maximum, are to be located and hence, series compensation is to be applied in these lines to minimize the losses. objective function is given by

$$Q_{loss} = [V_i^2 + V_j^2 - 2V_iV_j \cos(\delta_i - \delta_j)]X_l \Big/ (X_l^2 + R_l^2) \quad (1)$$

X_L is the variable in this case. Usually, a practical upper limit, lesser than 1, is chosen for the degree of compensation. This is because for K_{se}=1, the effective line reactance would become zero, so the smallest disturbance of the relative rotor angles of the terminal synchronous machines would result in the flow of large currents Moreover, the circuit would become series resonant at the fundamental frequency, and it would be difficult to control transient voltages and currents during disturbances. The practical upper limit chosen in this case is 70% i.e. upper limit for X_L is chosen as [1-(70/100)]* X_L = 0.3 X_L. A lower limit for compensation is also chosen as 10% i.e. 0.9 X Hence, XL is varied from 0.3 X_L to 0.9 X_L. The Steps involved to optimize the objective function is as follows:
Step 1: Set initial population generation and population size
Step 2: Give the objective function as

$$F(X) = f(X) \quad (2)$$

Where

$$f(x) = \sum_{k=1}^{N_l} Q_{kloss} + \sum_{k=1}^{N_g} Q_{kgen} + \lambda_1 \sum_{k=1}^{N_{pq}} V_k - V_k^{Lim} + \lambda_2 \sum_{k=1}^{N_G} Q_k - Q_k^{Lim} \quad (3)$$

where
N_L=No. of lines,
N_G=No. of Generators
N_{PQ}=No. of PQ Buses
λ_1 and λ_2 =Penalty Factor coefficients
Step 3: The constraints are given as

$$V_{min} < V_k^{lim} < V_{max} \quad (4)$$

$$Q_{min} < Q_k^{lim} < Q_{max} \quad (5)$$

$$0 < \lambda_1, \lambda_2 < 20 \quad (6)$$

Step 4: Set iteration i=1
Step 5: Find the best value of X_L

$$V_{ij}^t = W * V_{ij}^t + C_1 * r_1 * (P_{bestij}^{t-1} - X_{ij}^{t-1}) + C_2 * r_2 * (G_{bestij}^{t-1} - X_{ij}^{t-1}) \quad (7)$$

For i=1,2….N_D,j=1,2………..N_{par}
$P_{best}(t+1) = P_{best}(t)$ if $P(t+1) > P_{best}(t)$
$P_{best}(t+1) = P_i(t+1)$ if $P(t+1) < P_{best}(t)$
$G_{best}(t+1) = G_{best}(t)$ if $P_{best}(t+1) > G_{best}(t)$
$G_{best}(t+1) = P_{best}(t+1)$ if $P_{best}(t+1) < G_{best}(t)$
$X_{ij}^t = X_{ij}^{t-1} + V_{ij}^t$
$X_{min} < X < X_{max}$
Step 6: Is constraints are satisfied then Newton-Raphson method else set i=i+1 , go to step 4
Step 7: The above process is repeated for selected lines and optimal location is obtained.

Implementation of Genetic Algorithm

Since its introduction, GA has been successfully applied to optimize various continuous nonlinear functions. The objective (as stated above) is to minimize the series reactive power loss in the system. To do so, reactive power loss in each and every line is calculated and the lines having maximum reactive power loss are selected and hence, series compensation is applied on these lines to minimize the losses. Steps involved to optimize the objective function is as follows
Step 1 The constraint limits for the reactance of the line is set between 10% and 70%.
Step 2 Random values of X are generated between limits

$$X_{new}(w,t,l) = X_{\min} + Y(t,l) * \{(X_{\max} - X_{\min}) / ((2 \wedge l) - l)\} \quad (8)$$

Step 3 The values are converted to decimal- 8 bit.
Step 4 The values of generated reactances are put into the objective function
Step 5 The fitness evaluation is done for the various reactance values
Step 6 The best fit is calculated
Step 7 Selection based on the roulette wheel concept is done, the values providing the best fit being given a higher percentage on the wheel area so that values providing a better fit have higher probability of producing an offspring.
Step 8 Crossover is performed on strings using midpoint crossover. Crossover provides incorporation of extra characteristics in the off springs produced.
Step 9 Mutation is done if consecutive iteration values are the same
Step 10 The new reactance's that satisfy the objective of minimization of reactive power loss and the corresponding losses are tabulated.

Results and Discussions

To verify the effectiveness of the proposed approach, simulation is performed on the IEEE -14 bus system. Series capacitors were employed in the system which changes the effective reactance of the line. The effect of this compensation on the system was analyzed with the various values of degree of compensation the optimal degree of Compensation is obtained at K=0.29 and the optimal location of the line is 2-5 for IEEE -14 bus and simulation was done using MATLAB and PSAT (Power System Analysis Toolbox). The results are given in Figures 1 to 5 and Table 1 to 2.

The maximum Q_{loss} lines are identified. The capacitors are placed for the lines 1-2, 2-3, 1-5.

Fig 1 depicts voltage stability margin for the compensated line before optimization. Figure 2 &3 shows the P-V curve after the implementation of optimization. Line 1-2 gives the better stability enhancement compared to the other two lines. Hence, the same three lines are considered for the GA and PSO optimization.

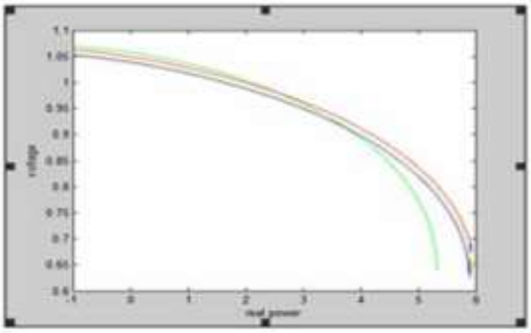

Figure 1. PV Curve before optimization with degree

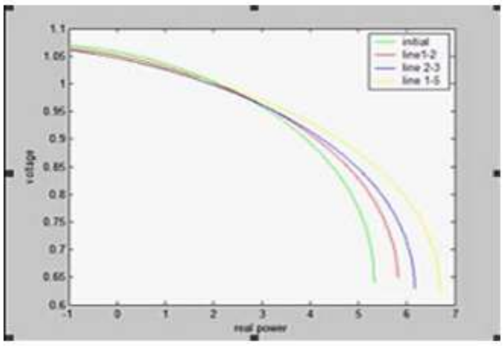

Figure 2. PV Curve after optimization (GA) with degree of compensation K=0.29

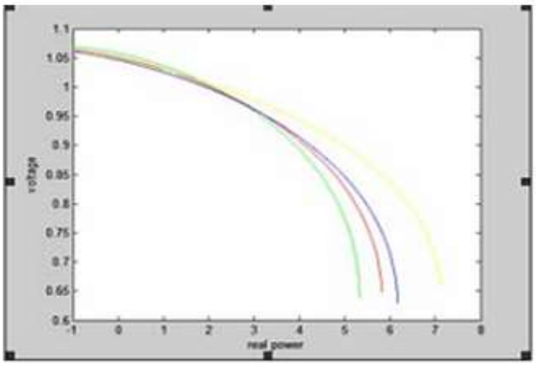

Figure 3. PV curve of the compensated line after optimization (PSO)

Table 1 gives the series reactive power loss for IEEE 14 Bus system (PSO &GA implementation) Table 2 gives the comparison of Q loss before and after optimization with the degree of compensation. This shows that PSO gives the better optimization with minimum Qloss and also good voltage stability margin enhancement. Figure 4 & 5 gives the λ (loading parameter) versus Voltage curve for bus number 14 using PSAT before and after optimization (PSO).

PSAT tool box uses Continuation power flow based voltage stability assessment. This also shows that PSO based optimization of Qloss gives a better `stability margin enhancement. It is observed that line 1-5 gives the enhanced stability margin with the maximum power demand of 6.8p.u using GA,7.1p.u.using PSO and 6.0p.u. before optimization

Thus optimal location of installing a var capacitor will be in line1-5 which is identified as the optimized value using one of the evolutionary computation algorithm say particle swarm optimization (PSO). A software program is developed in mat lab for the maximum number of series capacitors to be included in the system to have a better RPL compensation to enhance the voltage stability margin. The program calculates the stability indicators for each line and selects the best one line for the compensation based on the Qloss. Then the selected line is compensated for the degree of compensation (Ks) to meet the system reactive power requirement. The bus voltage are then calculated and updated with the predefined compensated line. The program continues to iterate till all the bus voltages of the load buses are shown above stability limit. When the selected lines are compensated by 70% the iteration ends. The optimal location of the series compensators are obtained with the above stability index. In Fig 1 for the compensated line 1-5 the stability margin of the real power is 6 p.u. before the optimal locations of capacitor for minimizing the RPL. With the optimization technique applied for the same line using PSO and Genetic algorithm the real power margin improved to 7.0 & 6.7 p.u. respectively as shown in Fig 2 &3. Hence PSO gives better optimization and the best location of the capacitor.

The stability margin enhancement is also analyzed with the PSAT toolbox. Fig 4 shows the load bus stability margin before and after optimization technique applied in the same line. It is evident from the table that PSO optimization technique gives a better compensation with the best locations of the series capacitor. optimization technique. The voltage stability margin enhancement is validated in Fig 4 &5 for bus 14 with and with out optimization using PSAT.

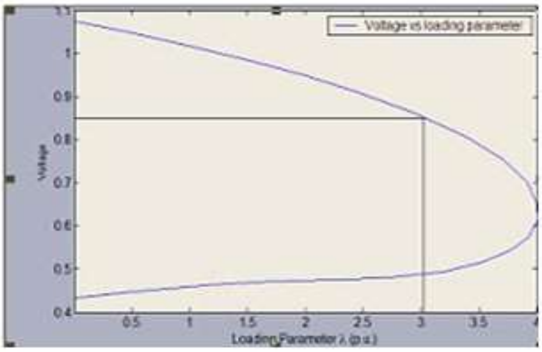

Figure 4. λ Vs V before optimization using PSAT (bus 14)

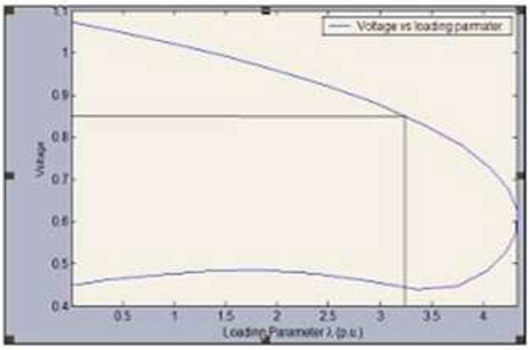

Figure 5. λ Vs V after optimization using PSAT (bus14)

Conclusion

In this paper the series reactive power loss minimization is achieved through the series compensation method. The exact location and the degree of compensation for the series capacitor to be installed in the transmission line were found out. The algorithm developed and the indicator dQloss/dKs shows the exact line for the employment of series capacitor. This reduces the effective reactance of the line and helps reduce the reactive power loss in turn providing high degree of stability to the system. Compensation in the form of series capacitors also increases the power transfer capability of the line. The results obtained are verified with the standard IEEE 14 bus systems. Paper also deals with the optimal location of the series capacitors to minimize the reactive power loss in order to enhance the stability by obtaining the appropriate value of compensation. The optimized value for the series capacitor is found with the degree of compensation. Using PSO and genetic algorithm the optimal location of the series capacitors is carried out. The graph shown in Fig 4 &5 clearly shows the voltage stability margin of bus 14 increases to better value with the appropriate location of the series capacitor using the optimization techniques.

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Table 1, Series Reactive Power Loss IEEE 14 Bus System (PSO & GA Implementation)

From bus	To bus	RPL(Without compensation)	RPL(GA)(With compensation)	RPL(PSO) (With compensation)
1	2	12.963	5.735	4.828
1	5	11.643	7.132	6.774
2	3	9.599	6.876	6.664
2	4	5.087	3.750	2.750
2	5	2.821	2.181	1.181
3	4	0.963	0.191	0.191
4	5	1.494	1.447	1.417
4	7	1.631	1.683	1.652
4	9	1.277	1.256	1.281
5	6	5.152	6.247	5.247
6	11	0.265	0.269	0.269
6	12	0.167	0.167	0.168
6	13	0.494	0.486	0.496
7	8	1.111	1.146	1.146
7	9	1.050	1.073	1.050
9	10	0.020	0.028	0.020
9	14	0.201	0.214	0.202
10	11	0.129	0.134	0.133
12	13	0.010	0.010	0.010
13	14	0.218	0.222	0.222

Table 2. IEEE-14 Bus Values Comparison

Line	% Compensation	RPL before Compensation	RPL after Genetic algorithm	RPL after PSO
1-2	49.36	12.963	5.735	4.828
1-5	48.97	11.643	7.132	6.774
2-3	63.21	9.599	6.876	6.664