Reactive Power Planning and Voltage Control using Particle Swarm Optimization

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Abstract: A new tool for planning reactive power compensation is presented. It is based on the capability chart of the power system, which describes the domain of allowable operation of the system in the plane of total active and reactive load demand. Power flow concepts are used to describe the ability of the power system to face the load; the optimization approach is adopted because load system is fundamentally nonlinear. Results for the IEEE-24 bus test system are presented.

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1. Introduction

The losses are naturally occurring in electrical system components such as transmission lines, power transformers, measurement systems, etc. due to their internal electrical resistance. It is not possible to achieve zero losses in a power system, but it is possible to keep them at minimum. The losses are becoming higher when the system is heavily loaded and transmission lines are transmitting high amount of power. The transmitted power for this case consists of active and reactive power. Necessity of reactive power supply together with active power is one of the disadvantages of the power generation, transmission and distribution with alternating current (AC). Reactive power can be leading or lagging. It is either generated or consumed in almost every component of the power system. In AC system Reactance can be either inductive or capacitive, which contribute to reactive power in the circuit. In general most of the loads are inductive and they should be supplied with lagging reactive power. We need to release the power flow in transmission lines for partially solving of problem of supply the reactive power locally where it is highly consumed in a system. In this way the loading of lines would decrease. It would decrease the losses also and with this action the problem of voltage drops could be solved also. By means of reactive power compensation transmission system losses can be reduced as shown in many papers in the literature [1-4]. It has also been widely known that the maximum power transfer of the transmission system can be increased by shunt reactive power compensation, typically by capacitors banks placed at the end of the transmission lines or a the load terminals [5]. Therefore, planning of reactive power supports would give benefits to the users of the transmission systems, in terms of loss reduction, among other technical benefits, such as improving steady-state and dynamic stability, improve system voltage profiles, etc. which are documented in [6]. The reactive power planning problem involves optimal allocation and sizing of reactive power sources at load centers to improve the system voltage profile and reduce losses. However, cost considerations generally limit the extent to which this can be applied.

This paper presents an optimal reactive power planning of power system using the Static Var Compensator (SVC). The proposed planning optimizes several objective functions at the same time within one general objective. The optimized objectives are minimization of average voltage deviation, minimization of total system loss and total system cost. particle swarm optimization (PSO) is used to solve the optimization problem. Simulation results emphasis on the validity of the proposed method.

2. Problem formulation

As referred before, in this paper three different parameters are considered as objective function. These parameters are: total investment cost, average voltage deviation and total system loss. Also the power system constrains such as generation reactive limits, voltage limits and etc, should be incorporated in planning. Therefore, the objective functions are as follows:

$$J_1 = \sum_{k\in\Omega_1} (c_{0k} + c_{1k} q_k) u_k \quad (1)$$

Where, c_0 and c_1 are fixed and variable costs of locally reactive sources. q is amount of locally reactive source in bus K and u_k is a binary vector that indicates whether or not to install reactive power sources at bus k.

$$J_2 = P_{loss} \quad (2)$$

$$J_3 = \sum_{i=1}^{n} (V_{ref} - V_i)^2 \quad (3)$$

Where, J_1 shows the investment cost due to locally reactive sources. J_2 shows the system losses and J_3 presents the voltage deviation. These objective functions should be converted to a unique unit. The coefficients ω convert the proposed functions to a unique unit. Eventually, reactive power planning formulation can be represented as follows:

$$\text{Min } \omega_1 J_1 + \omega_2 J_2 + \omega_3 J_3 \quad (4)$$

Subject to

$$P(V,\Theta,n) - P_G + P_D = 0 \quad (5)$$

$$Q(V,\Theta,n) - Q_G + Q_D - q = 0 \quad (6)$$

$$P_G^{min} \le P_G \le P_G^{max} \quad (7)$$

$$Q_G^{min} \le Q_G \le Q_G^{max} \quad (8)$$

$$V^{min} \le V \le V^{max} \quad (9)$$

$$(N+N0)S^{from} \le (N+N0)S^{max} \quad (10)$$

$$(N+N0)S^{to} \le (N+N0)S^{max} \quad (11)$$

$$q^{min} \le q \le q^{max} \quad (12)$$

Equations (5) and (6) introduce the conventional equations of AC power flow and (7) and (8) show the limits for real and reactive power for generators. Equation (9) presents the limits for voltage magnitude. Capacity limits of the line flows are presented by (10) and (11). Equation (12) presents the limit for locally reactive sources.

The proposed formulation in used to find the best place of SVCs. In this paper particle swarm optimization (PSO) is used to solve the optimization problem. In the next section a brief introduction about PSO is presented.

3. Particle swarm optimization

PSO was formulated by Edward and Kennedy in 1995. The thought process behind the algorithm was inspired by the social behavior of animals, such as bird flocking or fish schooling. PSO is similar to the continuous GA in that it begins with a random population matrix. Unlike the GA, PSO has no evolution operators such as crossover and mutation. The rows in the matrix are called particles (same as the GA chromosome). They contain the variable values and are not binary encoded. Each particle moves about the cost surface with a velocity. The particles update their velocities and positions based on the local and global best solutions as shown in (13) and (14) [8]:

$$V_{m,n}^{new} = w \times V_{m,n}^{old} + \Gamma_1 \times r_1 \times (P_{m,n}^{local\ best} - P_{m,n}^{old}) + \Gamma_2 \times r_2 \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \quad (13)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + \Gamma V_{m,n}^{new} \quad (14)$$

Where:

$V_{m,n}$ = particle velocity

$P_{m,n}$ = particle variables

W= inertia weight

r_1, r_2 = independent uniform random numbers

$\Gamma_1 = \Gamma_2$ = learning factors

$P_{m,n}^{local\ best}$ = best local solution

$P_{m,n}^{global\ best}$ = best global solution

The PSO algorithm updates the velocity vector for each particle then adds that velocity to the particle position or values. Velocity updates are influenced by both the best global solution associated with the lowest cost ever found by a particle and the best local solution associated with the lowest cost in the present population. If the best local solution has a cost less than the cost of the current global solution, then the best local solution replaces the best global solution. The particle velocity is reminiscent of local minimizes that use derivative information, because velocity is the derivative of position. The advantages of PSO are that it is easy to implement and there are few parameters to adjust. The PSO is able to tackle tough cost functions with many local minima [8].

4. Illustrative system

Figure 1 shows a typical electric power system. IEEE-24 bus test system is considered as illustrative system. The system data are presented appendix [7]. The fixed and variable costs of locally reactive sources are as c_0 = 100$ and c1 = 0.3$/kvar, respectively. To implement PSO, initial population size, cross over rate and mutation rate are chosen as 24, 0.5 and 0.1 respectively. Also 110% and 90% of the nominal value are used for the maximum and minimum voltage magnitude limits.

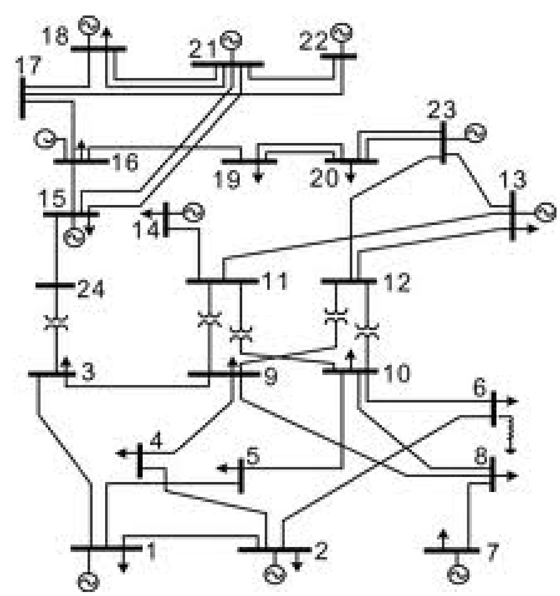

Figure 1. IEEE 24 bus test system

5. Results and discussions

In this section the SVC placement based on the particle swarm optimization is presented. The SVC places are accuracy calculated using PSO and the results are listed in Table 1. The locally reactive sources are places near to load buses and it is due to compensation of reactive demands. In this way, the current in transmission lines are reduced and the total loss is reduced. Also, because of locally supply of reactive demands, the congestion of lines is reduced.

Table 1. Optimal SVC places

Bus	Locally Reactive Source (MVAR)
3	300.0
4	43.60
9	97.11
12	200.8
24	149.2

6. Conclusion

The particle swarm optimization (PSO) approach has been developed for solving the Reactive Power Planning (RPP) problem in large-scale power systems. The application studies on the IEEE 24 bus system show that PSO gives suitable results and always leads to the global optimum points of the multi-objective RPP problem. By the PSO approach, more savings on the energy and installment costs are achieved and the violations of the voltage and reactive power limits are eliminated.

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