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Using Tabu Search for Reactive Power Planning in Power Systems

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Abstract

This paper addresses an optimal Reactive Power Planning (RPP) of power system. The Static Var Compensator (SVC) is introduced into power system in order to reactive power support and voltage control. The locations and the outputs of SVCs are determined using our proposed optimal reactive power planning model. The proposed method optimizes several objective functions at the same time within one general objective. The optimized objectives are minimization of total investment in reactive power support, average voltage deviation and minimization of total system loss. These objective functions are one of the most important objectives for every transmission and distribution systems. Tabu search (TS) is used to solve the optimization problem. The validity of the proposed method is tested on a typical power system.

Key Words: Reactive Power Planning; Static Var Compensator; Multi Objective Optimization; Tabu search

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. Tabu search (TS) is used to solve the optimization problem. Simulation results emphasis on the validity of the proposed method.

Rest of the paper is structured as follows: In section 2, problem is formulated and required equations are introduced. In section 3, a brief description about TS is given. In section 4 a modified Graver system is considered as test system. In section 5, results and discussions are presented. And finally, the paper is concluded in section 6.

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:

$$J_1 = \sum_{i\in N_B} (c_0 + c_1 q_i) u_i \tag{1}$$

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

$$J_2 = P_{loss} \tag{2}$$

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

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:

$$\text{Min } \omega_1 J_1 + \omega_2 J_2 + \omega_3 J_3 \tag{4}$$

Subject to

$$P_i(V,\Theta,n) - P_G + P_D = 0 \tag{5}$$

$$Q_i(V,\Theta,n) - Q_G + Q_D - q_i = 0 \tag{6}$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \tag{7}$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \tag{8}$$

$$V_i^{min} \le V_i \le V_i^{max} \tag{9}$$

$$S^{from} \le S^{max} \tag{10}$$

$$S^{to} \le S^{max} \tag{11}$$

$$q_i^{min} \le q_i \le q_i^{max} \tag{12}$$

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 elements of vectors $P_i(V,\Theta,n)$ and $Q_i(V,\Theta,n)$ in (5), (6) are calculated as follows [7]:

$$V_i \sum_{j\in N_B} V_j [G_{ij}(n)\cos\theta_{ij} + B_{ij}(n)\sin\theta_{ij}] \tag{13}$$

$$V_i \sum_{j\in N_B} V_j [G_{ij}(n)\sin\theta_{ij} + B_{ij}(n)\cos\theta_{ij}] \tag{14}$$

The elements of bus admittance matrix (G and B) are calculated as follows [7]:

$$G = \begin{cases} G_{ij}(n) = -(g_{ij}) \\ G_{ii}(n) = \sum_{j\in\Omega_1} (g_{ij}) \end{cases} \tag{15}$$

$$B = \begin{cases} B_{ij}(n) = -(b_{ij}) \\ B_{ii}(n) = b_i^{sh} + \sum_{j\in\Omega_1} [(b_{ij} + b_{ij}^{sh})] \end{cases} \tag{16}$$

Where, g_{ij} and b_{ij} show conductance and susceptance of the transmission line or transformer ij. b_{ij}^{sh} shows shunt susceptance of the transmission line or transformer ij (if ij is a transformer $b_{ij}^{sh} = 0$ $b_{ij}^{sh} = 0$) and b_i^{sh} shows shunt susceptance at bus i. Ω_1 indicates Set of all load buses.

Elements (ij) of vectors S^{from} and S^{to} of (10) and (11) are given by the following relationship:

$$S_{ij}^{from} = \sqrt{(P_{ij}^{from})^2 + (Q_{ij}^{from})^2} \tag{17}$$

$$S_{ij}^{to} = \sqrt{(P_{ij}^{to})^2 + (Q_{ij}^{to})^2} \tag{18}$$

Where:

$$P_{ij}^{from} = V_i^2 g_{ij} - V_i V_j (g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}) \tag{19}$$

$$Q_{ij}^{from} = -V_i^2 (b_{ij}^{sh} + b_{ij}) - V_i V_j (g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}) \tag{20}$$

$$P_{ij}^{to} = V_j^2 g_{ij} - V_i V_j (g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}) \tag{21}$$

$$Q_{ij}^{to} = -V_j^2 (b_{ij}^{sh} + b_{ij}) - V_i V_j (g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}) \tag{22}$$

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

Tabu Search

Tabu search (TS) was first presented in its present form by Glover [8]; Many computational experiments have shown that TS has now become an established optimization technique which can compete with almost all known techniques and which - by its flexibility - can beat many classical procedures.

Up to now, there is no formal explanation of this good behavior. Recently, theoretical aspects of TS have been investigated [9].

The success with TS implies often that a serious effort of modeling be done from the beginning. In TS, iterative procedure plays an important role: for most optimization problems no procedure is known in general to get directly an “optimal” solution.

The general step of an iterative procedure consists in constructing from a current solution x_i a next solution x_j and in checking whether one should stop there or perform another step.

In other hand, a neighborhood $N(x_i)$ is defined for each feasible solution x_i, and the next solution x_j is searched among the solutions in $N(x_j)$.

In this part we summarize the discrete TS algorithm in four steps. Assume that X is a total search space and x is a solution point sample and f (x) is cost function:
1- Choose x $\in \in$ X to start the process.
2- Create a candidate list of non-Tabu moves in neighborhood. (x_i, i=1,2,...,N)
3-Find x_{winner} $\in\in$ N(x) such that $f(x_{winner}) < f(x_i)$, $i \neq$ winner .
4- Check the stopping criterion. If satisfied, exit the algorithm. If not, winner x = x_{winner}, update Tabu List and then go to step 2.

In order to exit from algorithm, there are several criterions that are considered in our research.
1- by determining a predetermined threshold: If the value of cost function was less, algorithm would be terminated.
2- Determination of specific number of iterations.
3- If the value of the cost was remained invariable or negligible change for several iterations, algorithm would be terminated.
A didactic presentation of TS and a series of applications have been collected in [10].

Illustrative System

Figure 1 shows a typical electric power system. Modified Graver system is considered as illustrative system. The system data are presented in appendix [7]. The fixed and variable costs of locally reactive sources are as c_0 = 100$ and c1 = 0.3$/kvar, respectively. To implement TS, 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.

RESULTS AND DISCUSSIONS

In this section the result of the SVC placement based on the Tabu search is presented. The SVC places are accuracy calculated using TS 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. The flows in transmission lines are listed in Table 2. It is clearly seen that the maximum admissible flows are not violated. The power flow results are also presented in Table 3. The voltages are in allowable limits.

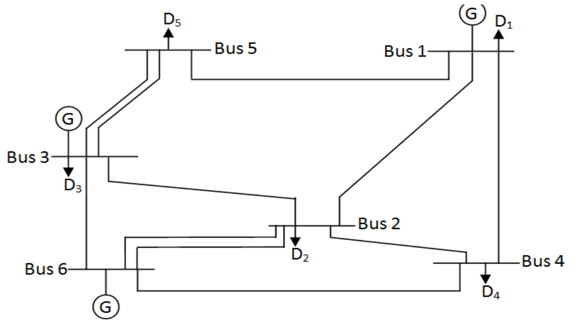

Fig. 1. Schematic of modified Graver system

Table 1. Optimal SVC places

Bus	**Locally Reactive Source (MVAR)**
4	34.75
5	6.781

Table 2. Flows in transmission lines

From bus	To bus	S_ij (p.u.)	S_ji (p.u.)	S_ij max (p.u.)
Bus1	Bus4	0.28346	0.27333	1.0
Bus1	Bus2	0.18000	0.17341	1.2
Bus5	Bus1	0.38822	0.40553	1.2
Bus2	Bus4	0.24616	0.24638	1.2
Bus3	Bus2	1.06490	0.99677	1.2
Bus3	Bus6	0.17673	0.18168	1.2
Bus5	Bus3	1.03000	1.10740	1.2
Bus5	Bus3	1.03000	1.10740	1.2
Bus2	Bus6	0.76119	0.83600	1.2
Bus2	Bus6	0.76119	0.83600	1.2
Bus4	Bus6	1.08360	1.18900	1.2

Table 3. Power flow results

Bus	(P_G-P_L) [MW]	(Q_G-Q_L)[MVAR]	V [p.u.]
Bus1	80	32	0.9923
Bus2	-240	-48	0.9560
Bus3	298.657	93	1.0212
Bus4	-160	-2.56	0.9569
Bus5	-240	-41.5	0.95
Bus6	277.149	120	1.05

CONCLUSION

The Tabu search (TS) approach has been developed for solving the Reactive Power Planning (RPP) problem in large-scale power systems. The application studies on the modified Graver system show that TS gives suitable results and always leads to the global optimum points of the multi-objective RPP problem. By the TS 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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Appendix

Table 4 shows the Modified Graver system data.

Table 4. Modified Graver system data

Bus Data								
Bus	Type	P_D [MW]	Q_D[MVar]	P_G^{max} [MW]	P_G^{min} [MW]	Q_G^{max} [MW]	Q_G^{min} [MW]	
1	VΘ	80	16		0	48	-10	
2	PQ	240	48	-	-	-	-	
3	PV	40	8	360	0	101	-10	
4	PQ	160	32	-	-	-	-	
5	PQ	240	48	-	-	-	-	
6	PV	0	0	600	0	183	-10	
Branch Data								
Bus From	Bus To	r_{ij}[p.u.]	x_{ij}[p.u.]	b_{ij}^{sh} [p.u.]	s_{ij}^{max} [MVA]	c_{ij}[US$]	n_{ij}^{0}	n_{ij}^{max}
1	2	0.040	0.400	0.00	120	40	1	5
1	3	0.038	0.380	0.00	120	38	0	5
1	4	0.060	0.600	0.00	100	60	1	5
1	5	0.020	0.200	0.00	120	20	1	5
1	6	0.068	0.680	0.00	90	68	0	5
2	3	0.020	0.200	0.00	120	20	1	5
2	4	0.040	0.400	0.00	120	40	1	5
2	5	0.031	0.310	0.00	120	31	0	5
2	6	0.030	0.300	0.00	120	30	0	5
3	4	0.059	0.590	0.00	120	59	0	5
3	5	0.020	0.200	0.00	120	20	1	5
3	6	0.048	0.480	0.00	120	48	0	5
4	5	0.063	0.630	0.00	95	63	0	5
4	6	0.030	0.300	0.00	120	30	0	5
5	6	0.061	0.610	0.00	98	61	0	5

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