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Reactive Power Expansion Planning under a Deregulated Market Power System

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Abstract: In deregulated electric power systems, one of the most important topics is to augment the total system social welfare. Many different methods have been carried out for this problem. One of the most viable methods to increasing system social welfare is to supply the reactive demands as locally. In this way, the reactive demands are supplied via locally reactive sources and the capacity of transmission lines is not used to transfer reactive power of demands. Thus, the congestion of lines is not reached and the system social welfare which is related to the congestion of lines is increased. In this scope, this study addresses an optimal Reactive Power Planning (RPP) in a deregulated power system. The proposed method optimizes two objective functions at the same time within one general objective. The optimized objectives are minimization of total investment in reactive power support and maximizing of total system social welfare. Genetic Algorithm (GA) is used to solve the optimization problem. The validity of the proposed method is verified on a typical power system.

Keywords: Genetic algorithm, local marginal prices, reactive power planning, social welfare

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 (Mamandur and Chenoweth, 1981; Iyer *et al*., 1984; Conejo *et al*., 2001; Abdel-Moamen and Padhy, 2003). 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 (Wollenberg, 2002). 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 by Miller (1982). 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.

As referred in last sections, RPP is performed in order to power system utilization in a better way. The proposed RPP can also be performed to improve power system social welfare. In this scope, this paper presents an optimal reactive power planning of power system using the Static Var Compensator (SVC) in a deregulated electricity market. The proposed planning optimizes two objective functions at the same time within one general objective. The optimized objectives are minimization of total system cost and maximizing of social welfare. GA is used to solve the optimization problem. Simulation results emphasis on the validity of the proposed method.

PROBLEM FORMULATION

As referred before, in this paper two different parameters are considered as objective function. These parameters are: total investment cost and social welfare.

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Also the power system constrains such as generation reactive limits, voltage limits and etc, should be incorporated in the planning. Therefore, the objective functions are as follows:

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

$$J_2 = \min \left(\sum \Pi_{Di} \times P_{Di} - \sum \Pi_{Gi} \times P_{Gi}\right) \tag{2}$$

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. Π_D and Π_G are demand and supply bids, respectively.

P_D and P_G are demand and supply powers respectively. J_1 shows the investment cost due to locally reactive sources. J_2 shows the system social welfare. Eventually, reactive power planning formulation can be represented as follows:

$$\text{Min } \omega_1 J_1 + \omega_2 J_2 \tag{3}$$

Subject to:

$$P(V,\Theta,n) - P_G + P_D = 0 \tag{4}$$

$$Q(V,\Theta,n) - Q_G + Q_D - q = 0 \tag{5}$$

$$P^{min}{}_G \leq P_G \leq P^{min}{}_G \tag{6}$$

$$Q^{min}{}_G \leq Q_G \leq Q^{min}{}_G \tag{7}$$

$$V^{min} \leq V \leq V^{max} \tag{8}$$

$$(N+N0)S^{from} \leq (N+N0)S^{max} \tag{9}$$

$$(N+N0)S^{to} \leq (N+N0)S^{max} \tag{10}$$

$$q^{min} \leq q \leq q^{max} \tag{11}$$

where, the coefficients ω is a weighting factor. Equation (4) and (5) introduce the conventional equations of AC power flow and (6) and (7) show the limits for real and reactive power for generators. Equation (8) presents the limits for voltage magnitude. Capacity limits of the line flows are presented by (9) and (10). Equation (11) presents the limit for locally reactive sources.

The elements of vectors P(V,Θ,n) and Q(V, Θ, n) in (4), (5) are calculated as follows (Rider *et al*., 2007):

$$P_i(V,\Theta,n) = V_i \sum_{j = N_B} V_j \left[G_{ij}(n)\cos\theta_{ij} + B_{ij}(n)\sin\theta_{ij}\right] \tag{12}$$

$$P_i(V,\Theta,n) = V_i \sum_{j \in N_B} V_j \left[G_{ij}(n)\sin\theta_{ij} + B_{ij}(n)\cos\theta_{ij}\right] \tag{13}$$

The elements of bus admittance matrix (G and B) are calculated as follows (Rider *et al*., 2007):

$$G = \begin{cases} G_{ij}(n) = -\left(n_{ij} g_{ij} + n_{ij}^0 g_{ij}^0\right) \\ G_{ij}(n) = \sum_{j \in \Omega_1} \left(n_{ij} g_{ij} + n_{ij}^0 g_{ij}^0\right) \end{cases} \tag{14}$$

$$B = \begin{cases} B_{ij}(n) = -\left(n_{ij} b_{ij} + n_{ij}^0 g_{ij}^0\right) \\ B_{ii}(n) = b_i^{sh} \sum_{j \in \Omega_1} \left[n_{ij}\left(b_{ij} + b_{ij}^{sh}\right) + n_{ij}^0\left(b_{ij}^0 + b_{ij}^{sh}\right)^0\right] \end{cases} \tag{15}$$

Elements (ij) of vectors S^{from} and S^{to} of (9) and (10) are given by the following relationship:

$$S_{ij}^{form} = \sqrt{\left(P_{ij}^{form}\right)^2 + \left(Q_{ij}^{form}\right)^2} \tag{16}$$

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

where,

$$P_{ij}^{form} = V_i^2 g_{ij} - V_i V_j \left(g_{ij} \cos\theta_{ij} + b_{ij} \sin\theta_{ij}\right) \tag{18}$$

$$Q_{ij}^{form} = -V_i^2 \left(b_{ij}^{sh} + b_{ij}\right) - V_i V_j \left(g_{ij} \sin\theta_{ij} - b_{ij} \cos\theta_{ij}\right) \tag{19}$$

$$P_{ij}^{to} = -V_i^2 g_{ij} - V_i V_j \left(g_{ij} \cos\theta_{ij} - b_{ij} \sin\theta_{ij}\right) \tag{20}$$

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

The proposed formulation in used to find the best place of SVCs. In this study GA is used to solve this optimization problem. In the next section a brief introduction about GA is presented.

GENETIC ALGORITHMS

Genetic Algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetic (Randy and Sue, 2004). They

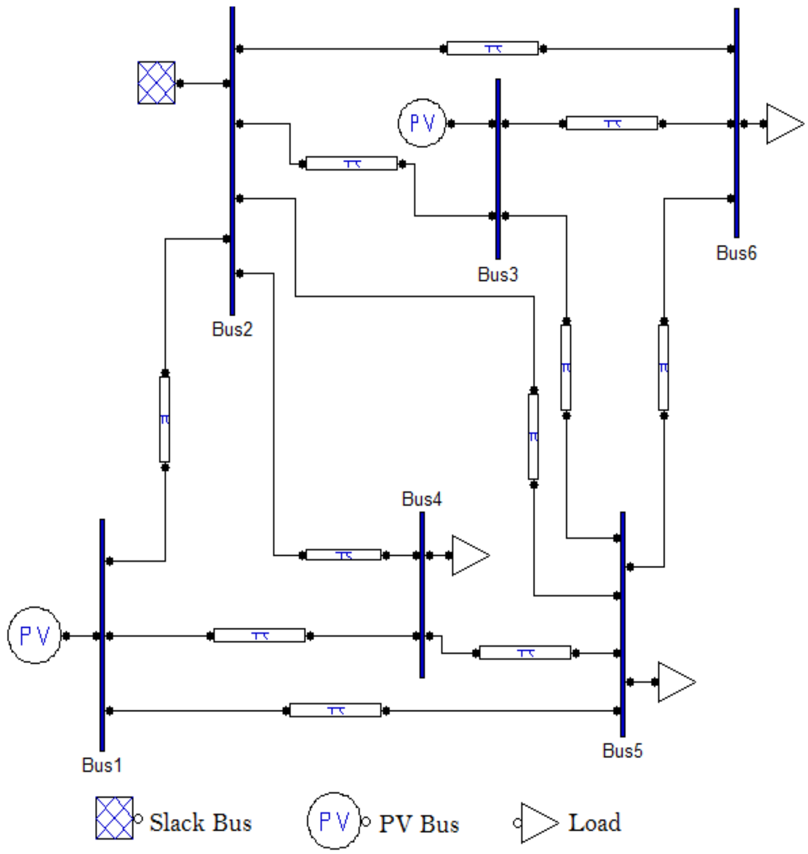

Fig. 1: IEEE 6-bus test system

operate on a population of current approximations-the individuals-initially drawn at random, from which improvement is sought. Individuals are encoded as strings (Chromosomes) constructed over some particular alphabet, e.g., the binary alphabet {0.1}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation Genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into three main categories: Reproduction, crossover and mutation (Randy and Sue, 2004).

Illustrative system: Figure 1 shows a typical electric power system. IEEE 6-bus power system is considered as illustrative system. The system data are presented in Appendix. The fixed and variable costs of locally reactive sources are as c_0 = 100$ and c1 = 0.3$/kvar, respectively. Also 110 and 90% of the nominal value are used for the maximum and minimum voltage magnitude limits.

RESULTS AND DISCUSSION

The proposed method is carried out on the test system given in section 4. The optimal places of reactive sources are accuracy obtained based on the proposed method by using GA. The results are listed in Table 1. The locally reactive sources are places near to load buses and it is due

Table 1: Locally reactive sources places

Bus	Locally reactive source (Mvar)
4	-20.144
5	53.4674
6	-61.2244

Table 2: Power flow results

Bus	(P_G-P_L) [MW]	(Q_G-Q_L) [MVAR]	V [p.u.]	LMP ($/Mwh)
Bus1	90	38.690	1.1	6.8165
Bus2	137.402	97.700	1.1	6.8635
Bus3	63.81	108.88	1.1	7
Bus4	-90	-80.140	1.027	7.1802
Bus5	-100	-66.530	1.016	7.3082
Bus6	-90	-121.22	1.009	7.2028
Total lost: 11.274 [MW]				
Social welfare: 21.6138 [$/h]				

Table 3: Flows in transmission lines

From bus	To bus	I_ij (p.u.)	I_ji (p.u.)	I_ij max (p.u.)
Bus2	Bus3	0.13001	0.11748	0.3082
Bus3	Bus6	0.93241	0.95066	1.3973
Bus4	Bus5	0.08943	0.07907	0.1796
Bus3	Bus5	0.30182	0.33648	0.6585
Bus5	Bus6	0.01103	0.05973	0.2000
Bus2	Bus4	0.71413	0.72730	1.3740
Bus1	Bus2	0.13098	0.11153	0.2591
Bus1	Bus4	0.44553	0.47078	0.9193
Bus1	Bus5	0.38621	0.41505	0.8478
Bus2	Bus6	0.49788	0.52973	0.9147
Bus2	Bus5	0.32611	0.34906	0.7114

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. This results in increasing social welfare of system. the Local Marginal Prices (LMP) are near to each other and the different between energy price in all areas is very low. The power flow results are presented in Table 2. The voltages are in allowable limits. Also the LMPs are clearly near to each other and the system social welfare is very high. The flows in transmission lines are listed in Table 3. It is clearly seen that the maximum admissible flows are not violated. The results show that the proposed planning obtains the optimal places of reactive sources without contravene the constraints.

CONCLUSION

In this study a reactive power planning in a deregulated power system has been successfully carried out. In the proposed planning, the locally reactive sources have been replaced with considering cost and also local marginal prices. This planning results in increasing social welfare of network. The proposed method has been carried out on IEEE 6-bus test system. The GA approach has been used to solve the problem. By the proposed approach, more savings on the energy and installment costs achieved and breaking of the constraints (i.e., voltage and reactive power limits) eliminated.

Appendix: Table 4 shows the IEEE 6-bus system data. Also the data for electricity market are presented in Table 5.

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Table 4: IEEE 6-bus system data for power flow analysis

Bus data

Bus	Type	P_D [MW]	Q_D[Mvar]	P^{max}_G[MW]	P^{min}_G[MW]	Q^{max}_G [MW]	Q^{min}_G[MW]
1	PV	0	0	900	0	150	-150
2	VΘ	0	0	1500	0	150	-150
3	PV	0	0	600	0	150	-10
4	PQ	90	60	0	0	0	0
5	PQ	100	70	0	0	0	0
6	PQ	90	60	0	0	0	0

Branch data

Bus from	Bus to	r_{ij}[p.u.]	x_{ij}[p.u.]	b^{sh}_{ij}[p.u.]	I^{max}_{ij} [p.u.]
2	3	50.05	0.25	0.06	0.3082
3	6	0.02	0.1	0.02	1.3973
4	5	0.2	0.4	0.08	0.1796
3	5	0.12	0.26	0.05	0.6585
5	6	0.1	0.3	0.06	0.2000
2	4	0.05	0.1	0.02	1.3740
1	2	0.1	0.2	0.04	0.2591
1	4	0.05	0.2	0.04	0.9193
1	5	0.08	0.3	0.06	0.8478
2	6	0.07	0.2	0.05	0.9147
2	5	0.1	0.3	0.04	0.7114

Table 5: IEEE 6-bus system data for market an

Bus	MW offer	Price ($/Mwh)
1	200	9.7
2	250	8.8
3	200	7
4	-	-
5	-	-
6	-	-

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