Capacitor Placement In Distribution Systems Using Genetic Algorithms and Tabu Search

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Abstract: This paper presents a new method for determining capacitor placement in distribution systems. The capacitor placement problem consist of finding places to install capacitor bank in an electrical distribution system aiming to reduce losses due to the compensation of the reactive component of power flow. The capacitor placement is hard to solve in sense of global optimization due to the high non linear and mixed integer problem. To solve the problem efficiently, this paper focuses on complex Genetic Algorithm (GA) and tabu search (TS) that is two of the efficient optimization methods. The proposed method has been tested on a real distribution system.

Keyword: capacitor placement, distribution systems, genetic algorithm, tabu search,optimization

1. Introduction

Capacitors are often installed in distribution system for reactive power compensation to carry out power and energy loss reduction, voltage regulation, system security improvement and system capacity release. Economic benefits of the capacitor depends mainly on where and how many capacities of the capacitor are installed and proper control schemes of the capacitors at different load levels in the distribution system [1].

The problem of capacitor placement in a distribution network consists of finding sizes, location and the number of capacitors that have to be placed on the network. This is one of the combinational optimization problems with the size of search space is being equal $(k+1)^n$, where n is the number of buses on distribution network and k is the number of possible capacitor sizes that can be placed on the network. This problem has traditionally been solved using mathematical non linear and mixed integer programming techniques. A capacitor placement techniques can be found in [2]. Among various approaches, the metaheuristics play a relevant role, since exact optimization methods are not suitable for tacking real world instances. Focusing only on metaheuristic methods, [3-6] propose different methods for capacitor placement problem.

This paper presents a new approach base on a complex Genetic Algorithm (GA) and Tabu search (TS) for solving the problem. Since, power flow is one of most important tools for solving the problem, this paper presents a very fast and simple power flow problem for solving the capacitor placement. The main contribution of this study is combination of GA-TS and a proper power flow base on the network-topology. To demonstrate the effectiveness of proposed algorithm, this method is applied to a real radial distribution feeder.

2. Problem Formulation

The objective function of the problem can be expressed as follows to minimize the capacitor investment cost and system energy loss:

$$Min_{q^0,q^i} \sum_{i=1}^{I} C_i(q_i^0) + \sum_{j=1}^{L} k_{ej} T_j P_{loss}(x^j, q^j) \qquad (1)$$

subject to

$$P_{flow}(z^i, q^i) = 0 \quad \text{(power flow constraints)} \qquad (2)$$

$$V_i^{\min} \le V_i^i \le V_i^{\max} \quad \text{(voltage constraints)} \qquad (3)$$

q_i^i :discrete variables, for fixed typed capacitor:

$$q_i^l = q_i^i = q_i^0, l, j \in \{1,2,3,\ldots,L\} \qquad (4)$$

for switched type capacitor

$$0 \le q_i^j \le q_i^0, i \in \{1,2,3,\ldots,I\} \qquad (5)$$

where, q^0 is the sizing vector whose components are multiples of the standard size of one capacitor bank. q^i is the control scheme vector at load level *j* whose components are discrete variables. $C_i(q_i^0)$ represent the investment cost associated with the capacitor installed at location *i*. P_{loss} is the power loss at load level *j* with at time duration T_j and K_{ej} is different energy loss cost for each load level. $x_k = [P_k, Q_k, |V_k|^2], Z_k = [P_k, Q_k]$ represent state variable vectors of real and reactive powers P_k, Q_k as well as squared voltage magnitude $|V_k|^2$ at branch *k*,*L* and *I* denote numbers of load levels and candidate locations to install the capacitors.[4]

3. Genetic Algorithm

3.1 Overview

Genetic Algorithm are general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time [7-11].

Generally, GA comprises three different phases of search: phase 1: creating an initial population; phase 2: evaluating a fitness function; phase 3: producing a new population.

A genetic search starts with a randomly generated initial population within which each individual is evaluated by means of a fitness function. Individual in this and subsequent generations are duplicated or eliminated according to their fitness values. Further generations are created by applying GA operators. This eventually leads to a generation of high performing individuals [7].

3.2 The genetic algorithm operators

There are usually three operators in a typical genetic algorithm [7]: the first is the production operator (elitism) which makes one or more copies of any individual that posses a high fitness value; otherwise, the individual is eliminated from the solution pool; the second operator is the recombination (also known as the ' crossover') operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. Thus, the probability of a better performing offspring is greatly enhanced; the third operator is the 'mutation' operator. This operator acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings. Since frequent application of this operator would lead to a completely random search, a very low probability is usually assigned to its activation.

4. Tabu Search

4.1 Overview

Tabu search is characterized by an ability to escape local optimal by using a short-term memory of recent solutions. This is achieved by a strategy of forbidding certain moves. The purpose of classifying a certain move as forbidden (tabu) is basically to prevent cycling. Moreover, TS permits backtracking to previous solutions, which may ultimately lead, via a different direction to better solutions [12].

The main two components of TS algorithm are the tabu list (TL) restrictions and the aspiration level (AV) of the solution associated with the recorded moves.

4.2 Tabu List

TL is managed by recording moves (trial solutions) in the order in which they are made. Each time a new element is added to the 'bottom' of a list, the oldest element on the list is dropped from the 'top'.

Empirically, TL sizes which provide good results often grow with the size of the problem and stronger restrictions are generally coupled with smaller size. Best sizes of TL lie in an intermediate range between these extremes. In some applications a simple choice of TL size in a range centered seem to be quite effective [13].

4.3 Aspiration Criteria

Another key issue of TS arises when the move under consideration has been found to be tabu. Associated with each entry in the tabu list there is a certain value for the evaluation function AV. Roughly speaking, AV criteria are designed to override tabu status if a move is 'good enough' with the compatibility of the goal of preventing the solution process from cycling [12].

5. The proposed algorithm

5.1 GA Implementation

The solution of the problem is represented by a binary coding. As in the example, 4 sizes of capacitors (*5,10,15,25 kVar* at *380 Volts*) are used, 3 bits are considered for coding: one for presenting the capacitors bank on bus and 2 bits for size of capacitor.

The fitness of each chromosome is the sum of installation cost and costs of power losses. Selection of chromosome for applying various GA operators is based on their scaled fitness function accordance to the roulette wheel selection rule. The roulette wheel slots are sized according to the accumulated probabilities of reproducing each chromosome.

Crossover and mutation operators are carried with the prespecified probabilities.

5.2 TS Implementation

In this paper we introduce a proper approach for creating the TL for capacitor allocation problem. TL is created as a matrix of dimension $Z \times M$, where Z and M are the TL size and the total number of capacitor location candidates in the distribution network, respectively. Each vector in the matrix represents the TL for one capacitor allocation candidate.

Different forms of aspiration criteria are used in literature. The one we used in this paper is to override the tabu status has better objective function than the one obtained before for the same move.

6. Numerical Examples

In order to test the proposed algorithm, a real distribution network has been considered, Figure 1 and Table 1 shows the single line diagram and specifications of test network, respectively.

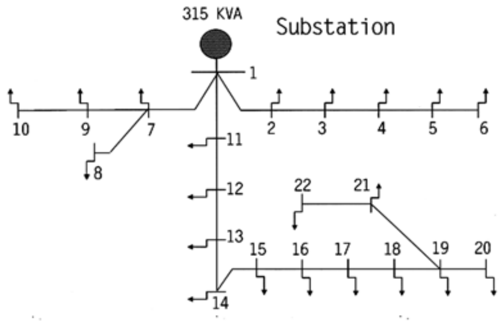

Figure1. single line diagram of test network

Power		Impedance of Section	Number of Customer		Bus Number
kW	*kVar*		Single	Three	
0	0	…	0	0	1
2.7	0.9	0.016+j0.039	1	0	2
2.7	0.9	0.015+j0.04	5	1	3
7.2	2.7	0.015+j0.038	5	1	4
16.2	6.3	0.017+j0.041	2	0	5
58.5	27	0.017+j0.041	3	0	6
7.2	2.7	0.015+j0.039	2	0	7
18.9	8.1	0.013+j0.037	4	0	8
7.2	2.7	0.014+j0.04	4	1	9
24.3	10.8	0.017+j0.042	1	0	10
0	0	0.015+j0.039	3	1	11
12.6	5.4	0.016+j0.041	1	4	12
18	7.2	0.016+j0.041	1	1	13
5.4	1.8	0.015+j0.038	1	0	14
8.1	3.6	0.015+j0.038	1	0	15
5.4	1.8	0.016+j0.041	1	1	16
10.8	4.5	0.013+j0.044	1	3	17
15.3	6.3	0.015+j0.039	10	7	18
2.7	0.9	0.012+j0.035	1	1	19
12.6	4.5	0.014+j0.039	2	3	20
20.7	9	0.015+j0.041	1	1	21
7.2	2.7	0.016+j0.041	9	0	22

Table1. Specification of test network

Total current and total power losses at network whitout capacitor and the ideal network (reactive power at the loads = 0) are 432.82 A, 12963 watt and 399.54 A, 11069 watt respectively .
After running the program, Table 2 shows the placement of capacitor at the buses, total current and total power losses in GA and GA-TS algorithms.

Bus Number	Capacitor (*kVar*)	Bus Number	Capacitor (*kVar*)
5	10	5	10
6	25	6	25
8	10	9	15
10	15	13	10
17	15	17	15
21	15	21	15
22	5	-	-
Total Current=408.6578 (A)		Total Current=400.6455 (A)	
Power Losses=11169 (watt)		Power Losses=11127(watt)	

Table 2. Capacitor placement results

7. Cost Analysis

For economic evaluating of the proposed algorithm, the following equation were considered for the economic gain:

$$\textit{Annual Gain} = 8750 \times kwh.cost \times \Delta P_{loss} \qquad (6)$$

Where:
Annual Gain: the annual economic gain with using the capacitors regard to losses reduction for one year.
8750: the conversion factor of power losses to energy losses.
Kwh.cost: the cost of energy.
ΔP_{loss}: power losses reduction regard to use of capacitors.

$$\textit{Annual Cost:}\ ((i.CapCost)/(1-(1/(1+i)^k)) \qquad (7)$$

Where:
Annual Cost: the total cost of capacitors and their accessories for one year.
k : Investment period
i : Interest rate.
According to above relations, the fitness function can be formulated as:

$$\textit{Fitness} = \textit{Annual Gain} - \textit{Annual Cost} \qquad (8)$$

In this study for the example network and with considering of the cost in *IRAN*, for the planning study *10* years long and interest rate *15%*, inflation rate *15%*, *kWh.cost = 120* Rials *(0.015 $)*, the reduction cost of investment cost of losses for *3* years was equal to cost of investments and the fitness will be *13790000* Rials (*1723 $*) for *10* years period.

8. Conclusion

In this paper, implementation of GA and GA-TS to the optimal placement of capacitor bank has been illustrated. The approach can be extended to other networks also. The results showed the GA-TS is a one proper optimization method for optimal placement of capacitors bank in distribution network. The economic study showed the investments costs will be compensated in a few 3 years by reduction costs of losses.

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