Sample construction and local search for the switch allocation problem

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Abstract

We study the problem of allocating switches in electrical distribution networks to improve their reliability. We presented a sample construction algorithm and a sample local search to this problem. We compare these approaches with random and semi-greedy constructions and with first and best improvement local searches (and combinations). We present and comment experimental results, showing that sample approaches are inexpensive and find good quality solutions.

1 Introduction

According to Teng and Liu (2003), most of the faults take place in the distribution network of electrical power systems. The most common method to improve the reliability is to add redundant connections with switches, to easily alter the network topology in case of failures. The costs of implementing automatic switches all over the network are impracticable due to high costs. Because of that, the places where switches should be installed, must be carefully chosen. This problem is called the switch allocation problem.

The remainder of the paper is organized as follows. In Section 2 we explain reconfiguration and allocation problems. In Section 3 we present the network reliability evaluation method. In Section 4 we describe the three construction algorithms (random, sample and semi-greedy) and the three local search variations (sample search, first and best improvement) In Section 5 we show some computational results. Concluding remarks are given in Section 6.

2 The Switch Reconfiguration and Allocation Problems

An example of electrical power distribution networks appears in Figure 1. Distribution networks are configured to work as noncyclic networks under normal operating conditions. They present distribution substations (black nodes), consumers (white nodes), and line feeders. Redundant switched tie-lines (dotted lines) exist to restore part of the energy supply in case of failures. Those tie-lines are disconnected in normal conditions.

2.1 The switch reconfiguration problem

After a power failure is detected, the network topology must be modified to isolate failures and to restore the energy supply by alternate line feeders. The network reconfiguration is the process of opening and closing some switches in the line feeders to change the topology. Considering a failure in feeder 17 of the example given in Figure 1. Without switches, the whole subtree under feeder 16 would be unattended. If we install automatic switches in feeders 16 and 19, we can isolate the failure by opening them. And closing an automatic switch in the line 35 can restore the service to some consumers. The switch reconfiguration problem consists in choosing which switches must be opened or closed to minimize the unattended area, and it is a complex non-linear combinatorial problem (Thakur and Jaswanti, 2006).

This problem has been studied extensively in the literature. Among the metaheuristics proposed to solve it are simulated annealing (Jeon et al., 2002; Santander et al., 2005), tabu search (Zhang et al., 2005; Zhang, Fu and Zhang, 2007), genetic algorithms (Delbem et al., 2005; Carreno et al., 2007), ant colony optimization (Su

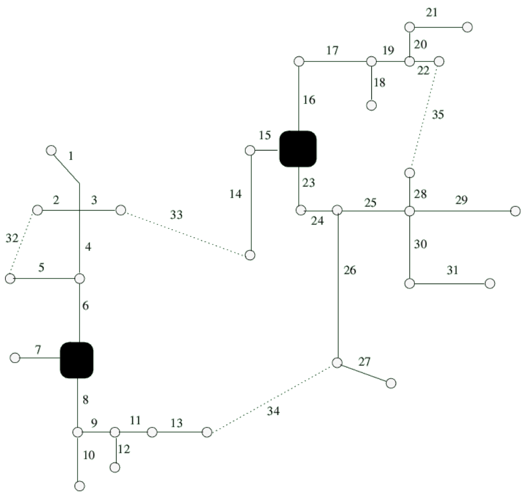

Figure 1. Distribution Network Example

et al., 2005; Khoa and Binh, 2006), particle swarm optimization (Zhang, Zhang and Gu, 2007; Wu et al., 2007), and plant growth simulation algorithm (Wang and Cheng, 2008; Wang et al., 2008).

The present paper considers this problem as a subproblem of the switch allocation problem.

2.2 The switch allocation problem

According to Billinton and Jonnavithula (1996), switches play a key role in the reliability of a power distribution system. The service restoration capability is directly related to the number and position of the switches in the network. The installation of automatic switches in the distribution system allows a better and faster reconfiguration, and hence increases reliability. Electrical power distribution networks are big, and installing automatic switches at every feeder is not possible due to high costs. Thus, the switch allocation problem consists in selecting locations to install switches in a distribution network, and it is very important in electrical systems planning. The objective function is to maximize the reliability, i.e. minimize the unattended area in the case of failures, and it is subject to the number of available switches for allocation and the electrical constraints.

Note that, differently to the reconfiguration problem, we must consider every possible fault to calculate the network reliability as we explain in the next section.

This problem has been studied by several authors with different approaches: simulated annealing approach (Billinton and Jonnavithula, 1996), divide-and-conquer approach (Carvalho et al., 2005), genetic algorithm (da Silva et al., 2004), tabu search (da Silva et al., 2008) three state particle swarm optimization (Moradi and Fotuhi-Firuzabad, 2008), Ant Colony Optimization (Falaghi et al., 2009).

3 Network Reliability Evaluation

We selected the expected energy non supplied or EENS (Falaghi et al., 2009) to evaluate the network reliability. The EENS units are $MWh/year$. The EENS for a given failure f is calculated as

$$EENS = \sum_{i \in L} r_i \cdot \lambda_i \cdot \sum_{j \in N_i} P_j$$

where L is the set of lines that can fail, r_i and λ_i are the respective average outage time and average failure rate of i, N_i is the set of consumer nodes affected by the failure i, and P_j is the power load of node j.

To calculate the network reliability, we must consider every possible failure, isolate it, maximize the restored area, and calculate the EENS. Finally we return the total EENS.

We use the algorithm proposed by Benavides et al. (2009) to calculate the unattended area. This algorithm expands iteratively the supplied area and checks the electrical constraints feasibility. The considered electrical constraints are feeder and substation capacities and acceptable voltage drop. The electrical simulation is computationally very expensive, but it is important to reflect a real approximation of the power recovered area.

4 Construction and local search algorithms

In this section we explain the construction and local search algorithms. The sample construction and the sample local search are proposed in this paper. The semi-greedy construction and the first improvement and best improvement local searches were proposed by Benavides et al. (2009).

4.1 Construction algorithms

We used three construction algorithms: random construction, sample construction and semi-greedy construction. Random construction selects n switches randomly and evaluates the resulting solution.

The sample construction (Algorithm 1) and the semi-greedy construction (Algorithm 2) build a feasible solution one element at a time. Both create a small list of candidates and select one element to be added to the current solution. The difference lies in the way they creates that small list.

Algorithm 1 Sample Constructive Algorithm

```
Input: $SwitchNumber$, $\beta$ sample percentage
$Solution \leftarrow \emptyset$
while $SwitchNumber$ is not attained do
    $CandidateList \leftarrow$ feasible switch locations
    $SampleCandidateList \leftarrow$ select randomly $\beta$ percent switch locations
    evaluate all elements in $SampleCandidateList$
    $s \leftarrow$ select the best from $SampleCandidateList$
    $Solution \leftarrow Solution \cup s$
end while
return $Solution$
```

Algorithm 2 Semi-greedy Constructive Algorithm

```
Input: $SwitchNumber$, $\alpha$ randomness
$Solution \leftarrow \emptyset$
while $SwitchNumber$ is not attained do
    $CandidateList \leftarrow$ feasible switch locations
    evaluate all elements in $CandidateList$
    $RestrictedCandidateList \leftarrow$ best $\alpha$ switch locations
    $s \leftarrow$ select randomly a switch from $RestrictedCandidateList$
    $Solution \leftarrow Solution \cup s$
end while
return $Solution$
```

The semi-greedy construction first evaluates every possible element. Then, a portion of α switches with the highest reliability are kept. and finally pics one element randomly from the restricted candidate list. A value of $\alpha = 0$ is equivalent to a greedy algorithm and selects always the best element, and $\alpha = 1$ is equivalent to a random construction.

The sample construction first selects randomly a portion of β switches. Then, evaluates this sample candidate list and pics the best one to join the solution.

4.2 Local search algorithms

We used three local search variations: sample local search and first and best improvement local search. Those algorithms receive as parameters the initial solution created by a constructive algorithm and a stop criterion. They search in a neighbourhood defined by the relocation of one switch.

Algorithm 3 depicts the first improvement local search. If it finds a better solution, it becomes the current solution. It stops when there are no better solutions in the neighbourhood. The best improvement searches through all the neighbourhood to select the best new solution, while the first improvement stops when it finds any better solution (line 10). Finally the best found solution is returned.

Algorithm 4 depicts the sample local search. It does not explore the whole neighbourhood, it selects a β portion of switches and a β portion of places to explore and find a better solution. This method is not exhaustive, so it does not guarantee to find the best local neighbour. In exchange, this method explores quickly the neighbourhood and improves quickly the solution in the beginning of the search as we show in the results section.

5 Experimental Results

For our tests we used a common instance, RBTS Bus 4, introduced by Billinton and Jonnavithula (1996). This instance has 38 consumer load points, 3 substations, 67 line feeders, 5 tie-lines, a voltage operation of

Algorithm 3 First Improvement Local Search Algorithm

```
Input: $StopCriteria, InitialSolution$
Evaluate $InitialSolution$
$BestSolution \leftarrow CurrentSolution \leftarrow InitialSolution$
while $StopCriteria$ is not satisfied do
  for all feeders $f_a$ without switch do
    for all feeders $f_b$ with switch do
      if can reallocate a switch from $f_b$ to $f_a$ then
        $NewSolution \leftarrow$ Move the switch in $CurrentSolution$
        Evaluate the $NewSolution$
        if $NewSolution > BestSolution$ then
          $BestSolution \leftarrow NewSolution$
          exit for
        end if
        Restore $CurrentSolution$
      end if
    end for
  end for
  $CurrentSolution \leftarrow BestSolution$
end while
return $BestSolution$
```

$11000V$, a current capacity of $500A$, and an outage time of 3 hours. Some of those values were completed by Falaghi et al. (2009).

We executed 8 tests, mixing the constructions and local search methods explained in Section 4. They are semi-greedy construction – sample local search (SGr-Spl), semi-greedy construction – first improvement local search (SGr-FI), random construction – first improvement local search (Rnd-FI), random construction – sample local search (Rnd-Spl), random construction – best improvement local search (Rnd-BI), sample construction – sample local search (Spl-Spl), sample construction – first improvement local search (Spl-FI) and sample construction – best improvement local search (Spl-BI). Every semi-greedy construction has $\alpha = 0.5$ and every sample has $\beta = 20\%$. Each test were executed 1000 times.

Results are presented in Figure 2 and Table 1. Instead of time, we present the number of solution appraises. There is a correlation of 300 appraises per seconds approx. Figure 2 presents the average EENS achieved trough the number of appraises. Table 1 presents the average EENS and number of executed appraises to obtain the initial solution, the average EENS and the average number of executed appraises in the final solution, the number of solutions that are equal and better than the greedy built solution.

As we can see, semi-greedy construction is very expensive compared with sample construction and has a poor improvement (10%) over random solution. Sample construction has a good initial solution with an small number of appraises. Random construction generates more diverse start solutions, and leads to better final solutions. Sample and semi-greedy constructions lead almost always to solutions worse or equal than the greedy solution. In general, first improvement has better results than sample local search but it is more expensive. Best improvement searches are the most expensive, Rnd-BI finds the greatest number of solutions under the greedy solution, but is the most expensive. Sample local searches does not guarantees to find the best in the neighbourhood, thus it stops before achieving local minima, in exchange it is inexpensive and finds good and more diverse final results. Spl-Spl and Rnd-Spl are the most inexpensive and Rnd-Spl finds slightly better results than Spl-Spl.

6 Concluding Remarks

In this paper we presented the switch allocation problem, with the switch reconfiguration problem as a subproblem. The objective is to improve network reliability by decreasing the unattended demand in case of feeder failures. We presented and compared the combination of three construction algorithms and three local searches variations. Experimental results show that sample construction and sample local search are very inexpensive and create good and diverse solutions. It show that semi-greedy construction is expensive and does not generate great improvements in start solutions. We think that a more directed local search combined with sample construction might give better results.

Algorithm 4 Sample Local Search Algorithm

```
Input: $StopCriteria$, $InitialSolution$, $\beta$ sample percentage
Evaluate $InitialSolution$
$BestSolution \leftarrow CurrentSolution \leftarrow InitialSolution$
while $StopCriteria$ is not satisfied do
    $SampleSwitches \leftarrow$ pick randomly $\beta$ feeders with switches
    $SamplePlaces \leftarrow$ pick randomly $\beta$ feeders without switches
    for all feeders $f_a \in SampleSwitches$ do
        for all feeders $f_b \in SamplePlaces$ do
            swap switch between $f_a$ and $f_b$
            Evaluate the $NewSolution$
            if $NewSolution > BestSolution$ then
                $BestSolution \leftarrow NewSolution$
            end if
            swap switch between $f_a$ and $f_b$
        end for
    end for
    $CurrentSolution \leftarrow BestSolution$
end while
return $BestSolution$
```

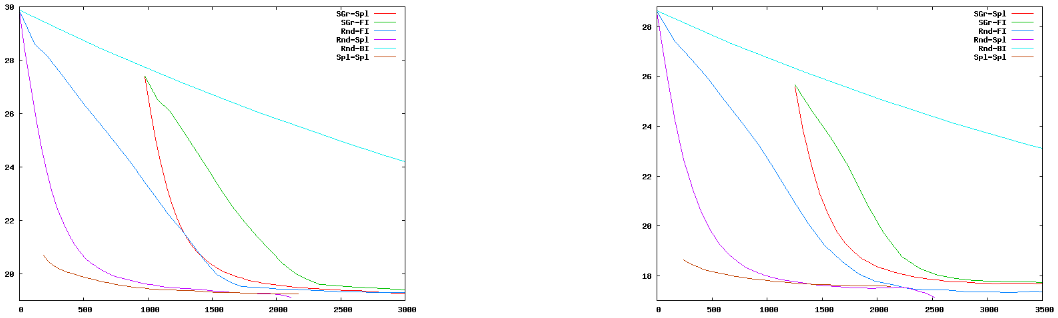

Figure 2. EENS vs Appraises (left: 15 switches, right:20 switches)

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Table 1. Initial and final results for 15 and 20 switches

20 Switches	Start solution		Final Solution			
Algorithms	Average EENS	Appraises	Average EENS	Average Appraises	= 17.560	< 17.560
SGr-Spl	25.577 ± 1.779	1250	18.349 ± 1.432	2419 ± 468	69	26
SGr-FI	25.662 ± 1.798	1250	17.560 ± 0.000	6793 ± 697	1000	0
Rnd-FI	28.608 ± 1.655	1	17.324 ± 0.292	5380 ± 529	592	408
Rnd-Spl	28.566 ± 1.632	1	17.931 ± 1.033	1374 ± 428	56	279
Rnd-BI	28.641 ± 1.687	1	17.290 ± 0.267	16490 ± 1832	456	544
Spl-Spl	18.633 ± 0.904	242	17.915 ± 0.595	990 ± 361	103	19
Spl-FI	18.629 ± 0.905	242	17.538 ± 0.110	3103 ± 732	961	39
Spl-BI	18.705 ± 0.948	242	17.542 ± 0.100	6907 ± 1383	967	33
15 Switches	Start solution		Final Solution			
Algorithms	Average EENS	Appraises	Average EENS	Average Appraises	= 19.245	< 19.245
SGr-Spl	27.375 ± 1.598	975	19.720 ± 0.892	2008 ± 345	77	2
SGr-FI	27.399 ± 1.569	975	19.293 ± 0.043	6003 ± 815	441	0
Rnd-FI	29.862 ± 1.493	1	19.251 ± 0.109	4829 ± 720	428	142
Rnd-Spl	29.822 ± 1.409	1	19.594 ± 0.703	1138 ± 334	68	71
Rnd-BI	29.865 ± 1.411	1	19.185 ± 0.147	11309 ± 1282	468	317
Spl-Spl	20.688 ± 1.230	189	19.670 ± 0.795	843 ± 284	73	2
Spl-FI	20.698 ± 1.232	189	19.282 ± 0.043	3602 ± 974	575	0
Spl-BI	20.641 ± 1.209	189	19.272 ± 0.047	5411 ± 1160	674	3

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