Middle-East Journal of Scientific Research 23 (3): 514-518, 2015
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2015.23.03.22102

Implementation of an Optimization Model for the Establishment of New Substations

[1]*S. Maheswari,* [2]*R. Santhoshkumar and* [3]*C. Vijayalakshmi*

[1]Deparment of Mathematics, Sathyabama University, Chennai, India
[2]Assitant Engineer TNEB, Chennai, India
[3]Deparment of Mathematics, VIT University Chennai Campus, India

Abstract: This paper mainly deals with the establishment of new substations for the electric utilities to meet the future demand. An Integer programming problem (IPP) model is designed and optimal solution is obtained by Lagrangian Relaxation (LR) technique. The objective of the IPP is to minimize the cost of the new substations and losses while operating the system. This model leads to schedule the new substations with respect to demand. Based on numerical calculations and graphical representations, the appropriate substation is selected by minimizing the feeder route cost.

Key words: Electrical distribution system · Integer programming · Lagrangian Relaxation · Primary feeders · Secondary feeders.

INTRODUCTION

In day to day life decision making for new substations is one of the emerging problems for the electricity board to meet the future electric load. S. Sivanagaraju *et al.* have defined the substation as an assembly of apparatus installed to perform switching voltage transformation, power factor correction, power and frequency converting operations.

John S. *et al.* [1], the power is utilized in the substation at high voltages from the transmission (or) sub transmission level, reduce its voltage and supply it to a number of primary voltage feeders for distribution in the area surrounding to it. In addition, it performs operational and emergency switching and protection duties at both the transmission and feeder level.John D. McDonald [2] has discussed four types of substations and S. Sivanagaraju *et al.* [3] have classified the substation based on service and design.

Optimal Substation: In order to meet out the demand, the power is being transferred from the nearest substation. Distribution delivery distance must be as short as possible, which reduces feeder cost, electric power loss costs and service interruption exposure is discussed in H. Cotton *et al.* [4]. A. S. B. Humayd *et al.* [5] have discussed Comprehensive multi-year distribution system planning using back-propagation approach.

S.N. Singh [6] has defined some rules for the new location. The new location design aims to achieve high degree of continuity, maximum reliability and flexibility, to meet these objectives with the maximum possible economy.

- Location of distribution substation depends on the several technical factors such as voltage levels, voltage regulation consideration, sub transmission cost, the cost of primary feeders, mains and distribution transformers.
- The most economical position of the substation is at the centre of gravity of loads to be supplied.
- The substation is located in the nearest place which is close to the load centre of the service area so that the sum of the load times, distance of the substation is minimised.
- The substation is located such that proper voltage regulation can be obtained without taking expensive measure.
- The selected substation location provides proper access for incoming sub transmission lines and outgoing primary feeders and also capable to handle the future expansion.
- The selected substation location should be in accordance with the electricity rule and land use regulation.

Corresponding Author: S. Maheswari, Deparment of Mathematics, Sathyabama University, Chennai, India.

- The selected substation minimize the number of consumers affected by any service discontinuity.

The next section is literature review. In section 3, Mathematical formulation is discussed. The Integer Programming model is presented in section 4. It is followed by the solution methodology in section 5. In section 6, based on numerical calculations and graphical representations the optimal number of new substations and minimum cost of the feeders can be obtained.

Literature Review: An useful introduction to the discrete network location models were provided in John current *et al.* Willis *et al.* [7,8] have discussed feeder layout, cable sizes and load distribution across the feeders and substations. One of the earliest references optimal planning approach toward the design of electrical networks is by Knight [9]. Based on a given set of geographical locations, a minimum cost network design was obtained using a network flow algorithm. The objective function accounted for circuit length and apparent power and the constraints included security and switchgear limitations. Similar approaches are also seen in the following references.

In [10] Wall *et al.* use a transshipment algorithm to determine decisions conditional on a choice of integer variables. A branch-and-bound algorithm selects the optimal solution from the candidate solutions generated by the transshipment code. Capital costs are included for potential substations.

El-Kady [11] modeled the planning of distribution substations and associated feeders over time. Marshall *et al.* [12] solved a distribution planning problem by a slight modification in the objective function. The costs in this particular methodology arose from cabling, switchgear and the incremental costs of building an extra circuit to a load node. This ensures that every load point has some security of supply; if one circuit goes down, another supplies it with power. The cost of losses was not included in this study. Provisions were made to ensure the security of the network. The solution methodology adopted is that of maximizing the Lagrangian dual using the NETOPT program.

Yahav and Oron [13] accounted for the nonlinear costs of losses and construction through the solution of a nonlinear program using the off-the-shelf solver. New feeder routes and substation locations are the optimal decisions of the mathematical program. Amongst the more restrictive assumptions made are the linear relationship between losses and distance as well as the ignoring of voltage constraints. S. M. Mazhari[14] et.al have discussed Dynamic sub-transmission substation expansion planning using learning automata.

Mathematical Formulation: The main objective is to minimize the cost for the establishment of new substation and losses when operating the feeders in the electrical system.

System Constraints: It includes elements of rated voltage, rated frequency, system configuration present and future, connected loads, lines generation, voltage tolerance (over and under), thermal limits, short circuit levels, frequency tolerance (over and under), stability limits, critical fault cleaning time, system expansion and inter connection.

Demand Constraints: It includes environmental consideration, space consideration, power quality, reliability, availability, network security, expandability and maintainability.

System Parameters:

I = The set of demand nodes indexed by i

K = The set of candidate new substations indexed by k

h_i = Demand at node i

FC_k = Fixed cost of a new substation at a site k

nl_{cap} = Capacity of a new substation at k

FR_k^{loss} = The cost per unit demand per unit distance which is associated with the losses when operating the feeders in the system

FR_{cap} = Capacity of the feeders

FR^{min} = Minimum number of feeders

FR^{max} = Maximum number of feeders

Decision Variables:

$$x_k = \begin{cases} 1 & \text{if we locate at the site k} \\ 0 & \text{otherwise} \end{cases}$$

d_{ik} = Distance between demand node i and candidate site k

$$y_{ik} = \begin{cases} 1 & \text{if demand node i assigned to a new location site k} \\ 0 & \text{otherwise} \end{cases}$$

Model Formulation: The feeder switching performs the following operations.

- Minimize the overloaded equipment
- Low voltage conditions
- Unbalanced loading among interconnected feeders.

$$y = \min \sum_{k\in K} Fc_k x_k + \sum_{i\in I} \sum_{k\in K} FR_k^{loss}(h_i/d_{ik} y_{ik})$$

Subject to the constraints,

$$\sum_{k\in K} y_{ik} = 1, \quad \forall\, i \in I \qquad \text{(a)}$$

$$y_{ik} - x_k \le 0, \quad \forall\, i \in I, k \in K \qquad \text{(b)}$$

$$\sum_{k\in K} (h_i y_{ik} - n\ell_{cap} x_k) \le 0, \quad \forall\, i \in I \qquad \text{(c)}$$

$$\sum_{k\in K} (h_i y_{ik} - FR_{cap} x_k) \le 0, \quad \forall\, i \in I \qquad \text{(d)}$$

$$(1 - y_{ik}) FR^{min} \le I \le (1 - y_{ik}) FR^{max} \qquad \text{(e)}$$

$$\sum_{k\in K} FR_k^{loss} y_{ik} = 1, \quad \forall\, i \in I \qquad \text{(f)}$$

$$x_k \in \{0, 1\}, \quad \forall\, k \in K \qquad \text{(g)}$$

$$y_{ik} \in \{0, 1\}, \quad \forall\, i \in I, k \in K \qquad \text{(h)}$$

Relax constraint (a),
Lagrangian Function

$$L(y,\lambda) = \min[\sum_{k\in K} Fc_k x_k + \sum_{i\in I} \sum_{k\in K} FR_k^{loss}(h_i/d_{ik} y_{ik}) - \lambda \sum_{k\in K} y_{ik} - 1]$$

(a) = Constraint states that each demand mode assigned to exactly one new sub station (unique way).
(b) = Constraint restricts that demand mode assignments only to open substations(new).
(c) and (d) = Demands to be assigned only to new locations in a random manner (open way).
(e) = Refers that the minimum and maximum number of the feeders of the demand.
(f) = Constraint gives the feeder cost (losses while operating system) of the each demand mode assigned to exactly one new sub station
(g) = Locating decision variable as binary.
(h) = Requires the demand at a node to be assigned to one new sub station only.

Algorithm:

Step 1 : Assign the inputs for FC_k, x_k, FR_k^{loss}, h_i, d_{ik}, y_{ik}.
Step 2 : Assign the inputs for nl_{cap}, FR_{cap}, FR^{min}, FR^{max}.
Step 3 : If ($y_{ik} = 1$) is true for K sustations and the set of demand nodes I then goto step 10
Step 4 : If (($y_{ik} - x_k$) $\le$ 0) then goto step 10.
Step 5 : Assign DL= ($h_i \times y_{ik} - nl_{cap} \times x_k$). If DL $\le$ 0 then goto step 10
Step 6 : Assign FC= ($h_i \times y_{ik} - FR_{cap} \times x_k$). If FC$\le$ 0 then goto step 10
Step 7 : If $(1 - y_{ik}) FR^{min} \le I \le (1 - y_{ik}) FR^{max}$ then goto step 10
Step 8 : If ((FR_k^{loss} × yik) = 1) then goto step 10
Step 9 : Assign binary values for substations as well as demands. If this is true goto step 10
Step 10 : If 3 to 9 are true, then minimize

$$y = ((FC_k \times x_k) + (FR_k^{loss}(h_i/d_{ik} y_{ik})))$$

for K locations and the set of demand nodes I.

Lagrangian Relaxation Method: Lagrangian Relaxation method is discussed in Maheswari *et al.* Lagrangian Relaxation is a general solution strategy for solving mathematical programs that allows in decomposing problems to exploit their structure. This approach to solution leads to bounds on the optimal objective function value. Lagrangian Relaxation replaces the original problem with an associated Lagrangian problem, the optimal solution of which provides a bound on the objective function of the problem. This is achieved by eliminating (relaxing one or more) constraints of the original model and adding these constraints associated with a Lagrangian multiplier in the objective function [15-20].

The main objective of this method is to relax the constraints that results in a Lagrangian problem. When the sub-problem gives the values of multipliers, it is easier to solve it optimally. The role of these multipliers is to derive the Lagrangian problem towards a solution that satisfies the relaxed constraints.

The Lagrangian Relaxation approach replaces the problem of identifying the optimal values of all the decision variables with one of finding optimal values for the Lagrangian multipliers. Most Lagrangian-based heuristics use a search heuristic to identify the optimal multipliers. A major benefit of Lagrangian-based heuristics is that they generate bounds (i.e. lower bounds for minimization problems and upper bounds for maximization problems) on the value of the optimal solution of the original problem. For any set of values to the Lagrangian multipliers, the solution lies in the Lagangian model which is less than or equal to the

Table 1: Optimization table

Substations x_k	Variable Cost FR_k^{loss}	Demand MVA h_i	No. of feeders assigned for the Demand y_{ik}	$FR_k^{loss}[h_i/d_{ik} \times y_{ik}]$	Total Cost (crore)
1	12,077	132	9	8,435	5.0008
2	13,083	32	9	2.125	5.0002
3	15,700	74	6	12,909	5.0013
4	9,235	148	12	4,219	5.0004
5	12,077	132	9	8,435	5.0008
6	17,444	32	7	4,691	5.0005
7	7,136	164	16	2,032	5.0001
8	9,235	148	12	4,219	5.0004
9	14,273	132	7	15,832	5.0016
10	10,467	132	10	6,280	5.0006
11	15,700	48	7	6,333	5.0006
12	15,700	32	8	3,140	5.0003

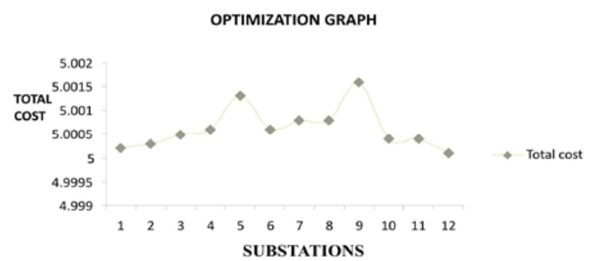

Fig. 1:

solution to the original model. Therefore, the Lagrangian solution is a lower bound on the solution to the original problem.

Numerical Calculations and Graphical Representations: Algorithm gives the schedule for new substations and this is implemented in MATLAB 7.0. computations were performed in ACER PC. The testing datasets are summarized in the following table.

Let Fixed Cost FC_k = 5 crore and

Distance di_k = (2, 1, 3, 4, 2, 5, 3, 2, 4, 1, 2, 3) km

Based on numerical calculations and graphical representations, the losses were minimized so that the appropriate new substation is obtained which satisfies the maximum power demand 164 MVS with the minimum cost 5.0001 crore [21-25].

CONCLUSION

In this paper, the Lagrangian Relaxation model is designed for new substation which is formulated as an Integer Programming Problem (IPP) and optimal solution is obtained by Lagrangian relaxation technique. An algorithmic approach is designed for the Lagrangian Relaxation method. The schedule for new substations is being achieved so that the feeder route cost is minimized and the appropriate substation is obtained.

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