I.J. Computer Network and Information Security, **2014, 7, 35-41**

DOI: 10.5815/ijcnis.2014.07.05

A New Optimization Model for Distribution Siting and Sizing in Unbalanced Three-phase Networks for Loss and Cost Minimization

Farzaneh Yazdani, Seyyed Mehdy Hosseini, Taghi Barforuoshi
Department of Electrical Engineering, Babol Noshirvani University of Technology, Babol, Iran
, mehdi.hosseini@nit.ac.ir , barforoshi@nit.ac.ir f.yazdani85@yahoo.com

Abstract—Since distribution substations connect transmission lines and distribution system, planning these substations is a very important step in scheduling process of power system and optimal placement of distribution transformers for reducing the involved loss is of concern. In this paper a new model is [proposed for solving optimal substation planning of distribution networks. In the objective function, we have included both capital and operation (loss) costs. The optimization problem is solved by genetic algorithm (GA). In order to evaluate the effects of load imbalance in low-voltage system, a group of balanced one-phase and three-phase and imbalanced three-phase in 4-wire system are used. As a case study, the optimization model is tested on the 33-bus system. Simulation results show that the total cost is reduced by balancing the load of different phases. Also, the results confirm a 48 % reduction in loss and an 11 % reduction in costs of the network planning. Moreover influence of energy cost change and load change on distribution network planning is evaluated by investigating on 33-bus system.

Index Term—Distribution substation, unbalanced three-phase loads, losses, genetic algorithm.

I. INTRODUCTION

Electrical distribution networks have very important role in transportation of electric energy from various energy supply sources to consumers. Many of these consumers comprising residential, commercial and small industrial loads are supplied through secondary distribution networks which are provided through reducing voltage by distributions transformers. Totally, as much as 40% of the energy is consumed at a residential level that results increase of power and energy loss due to the rise of system line currents. Nowadays, optimizing the design and operation of the entire chain of electrical supply is compulsory. Moreover, the efficient usage of energy is a necessity and the utilization patterns of electrical energy distribution companies are more stringent in terms of supply quality and profitability took advantage of the electrical business. This condition has generated a wide domain of study on electrical distribution networks.

Low voltage electrical networks deliver electricity to residential customers using distribution transformers connected to medium voltage feeder transformation substations. The site of this transformer depends on the size and position of the demands to be supplied. The size of the distribution transformer will depend on the extent of reducing substations which is vital for supplying a special sector. Eventually, the number of equipments to be installed will principally depend on the economic criteria joined to the investment and operational costs. These costs will depend on site, size and number of network distribution transformers [1].

Distribution substation planning is one of the most important steps in the power system planning. This is because it expresses the main join between transmission and distribution system. Substation planning involves site selection of substations, substation size and service areas definition. The site choice of the substation is not entirely based on electrical criteria. City plots and environmental limitations are commonly the main determining factors in this process. In the best condition, the city will provide a set of candidate sites for planner to choose from. Usually, the substation site selection procedure is considered as a screening process.

The substation size and the service zone are usually determined based on electrical criteria, such as: equipment capacities and feeders’ voltage drop constraints [2, 3].

Distribution transformers are one of the main elements of the power distribution system. These transformers are selected based on the need and density of the considered area. In order to optimally investment the capacity, maximum use of installed capacity is of concern. On the other hand, consumption is variable due to weather variation and seasonal differences. Growing development of buildings and populations growth cause the load density to increase so possibility of sudden forecasted over-load and have to be taken care of in the design process.

Load imbalance is one of the possible problems in distribution systems. Random and asynchronous behavior of one-phase consumers and non-uniform distribution of them between different phases are the causes of load and current imbalance in networks. This has improper consequences on the behavior of network and other elements and consumers such as increase in loss, electrifying neutral point of network, heating up the electric motors and transformers and saturation of magnetic cores. Load imbalance has an important role in an increase in copper loss of network.

In [5] a method is presented to solve the optimal planning problem of distribution substations where does not require candidate substation locations. The service area of the power distribution system is divided into a grid of small squares, each having a load point in its centre and can automatically select the optimal sizes, sites and service areas of substations in power distribution systems. In [6] a model is developed non-discrete functions for distribution substation sizing and sitting that account the different components for the substations cost function and various constraints including, voltage, power flow, radial flow, and capacities constraints. The problem was formulated as a Mixed Integer Nonlinear Programming (MINLP), which could rebound in local optimal solutions because of nonlinearity. In [7], a probabilistic methodology was presented for distribution substation location selection, where the hourly (or daily) load cycle was modeled as three different bivariate probability distributions: the Gaussian distribution, a bivariate version of Freund’s exponential distribution, and the Weibull probability distribution. For different hourly load scenarios, the load center locations are determined and weighted according to their load extent. These locations are then used to develop a probability distribution that is used in deciding the maximum probability around of the area where the substation should be located. In [8], the quasi-Newton procedure actuates in the search for optimal substation location co-ordinates, and the genetic algorithm procedure actuates in the design of optimal network topologies. In [1], objective function is defined based on cost of substation installation, transformer losses and feeders’ losses; and such as [5], [6], [7] and [8] don’t consider loss of neutral wire due to be single-phase system.

According to the above mentioned factors, in this paper a method is presented in which a network with least loss and cost and proper voltage is achieved via considering distribution system imbalance as well as balancing the load on different phases. Optimization algorithm is tested on the 33-bus test system and results are presented.

The paper is organized as follows. Section-II presents the proposed problem formulation for the distribution substation siting and sizing optimization model. Parts of network losses are presented in Section-III. In Section-IV, load flow calculation is explained. Section-V presents the system under study. This section also presents the results generated from the proposed optimization model. In Section-VI, influence of energy cost change on distribution network planning is discussed. In Section-VII, influence of load change on distribution network planning is discussed. Finally, in Section-VIII, conclusions are presented.

II. MATHEMATICAL FORMULATION OF PROBLEM

The low voltage transformers are source nodes of the customers, and load nodes of the medium voltage power distribution system. Because of the large number of low voltage substations and the difficulty of precisely forecasting the locations and quantity of 380V customer demands, the determination of their sites and sizes will not be discussed in this paper together. The problem discussed in this paper is the determination of the number, sites and sizes of distribution transformers, which act not only as source points of the customers, but also load points of the medium voltage system. Many factors are included in such studies, and the wide range of options usually open to power system planners makes the determination of an optimal plan. Especially in recent years, rising growth rates, high load densities, ecological considerations, and the rareness of available land in urban areas have push the question of optimal substation placement beyond the resolving power of the human mind without help.

Determination of the load size and its geographic location is first requirement for distribution planners; then the distribution substations must be placed and sized to serve the load at maximum cost effectiveness by minimizing feeder losses [5].

As mentioned above, when planning to install a distribution system substation and its components, the main objective is to minimize the whole cost of equipment installation and energy losses. This cost depends on factors such as substation siting and transformer loading. Concerning the substation siting, increasing the number of installed substations or unsuitable selected site could extremely increase the overall system cost. Since the quantity of energy loss is dependent on the transformers loading, an increase in loading level will cause an increase in the whole cost [4].

The main objective is shown by (1).

$$\begin{aligned} \cos t &= \sum_{n=1}^{q} C(n) \\ &+ \frac{8760}{1000} * C * \sum_{n=1}^{q} \left(\frac{Pcu(n)}{Htr(n)} * S(n) + Pcore(n) \right) \\ &+ Closs \end{aligned} \tag{1}$$

$$Closs = 8760 * C * Wloss \tag{2}$$

Where:

q: number of installed transformers

$C(n)$: fixed cost for transformer n (rial)

C: cost of energy (rial/KWh)

$Pcu(n)$: transformer copper loss at rated power (w)

$Htr(n)$: rated capacity of transformer n (KVA)

$Pcore(n)$: iron losses (w)

$S(n)$: transformer loading (KVA)

$Closs(n)$: cost of lines loss (rial)

$Wloss(n)$: lines loss (KW)

III. PARTS OF NETWORK LOSSES

A. *Loss in Low-voltage Network*

In low-voltage system, voltage is low and current is high, so the low-voltage network is responsible for more than 75 % of the total loss of network and due to considerable voltage drop and high loss in this section, it is needed always for low-voltage lines to be designed short.

B. *Loss in Distribution Transformers*

This part is very important and it has the role of voltage converting from medium to low voltage. Although loss of distribution transformers is low due to low capacity of them comparing to medium and high voltage transformers, high number of installed transformers in network and also their relatively high loss with respect to rated power cause to high percent of loss every year. Loss of this section has two components: no-load and full-load loss. No-load loss, which is so called core losses, is a part of inherent and constant loss in transformer, which its value is dependent to the material technology of the magnetic core, and also low copper loss in no-load condition [9].

Full-load loss of transformer is because of the load consumption. This loss is composed of copper loss of windings, eddy current loss in windings and loss due to stray flux in metallic part like the tank of transformer [10]. Load imbalance with increasing in copper loss of phases and neutral point leads to an increase in foul-load condition where the only way to solve this is to select the phases accurately considering their general consumption.

Transformers are permitted to be loaded to 75% of its rated value and the maximum allowable voltage drop along each feeder is 2.5% of the system nominal voltage [4].

$$\Delta V(j) = \frac{Pload(j)}{Vn} Z(j) \tag{3}$$

Where ΔV(j) is the voltage drop along the feeder j (V), Pload(j) is the demand of bus j (KVA), Vn is the system nominal voltage (kV), Z(j) is the electrical impedance of the feeder j (Ω).

IV. LOAD FLOW CALCULATION

In load flow algorithm, two mutual processes are used named feedback and feed-forward transfer [11]. At first, calculated current of the branch in the feed-forward transfer is considered constant and current of the branches are updated. In feedback transfer process, voltage is calculated and in the feeder they are returned by feedback path.

In feed-forward transfer, current values are considered constant from feed-forward transfer and voltage of each node is updated. Feedback _feed-forward transfer is repeated until stop criterion is met and criterion of measured voltage is determined after one cycle of feedback -forward transfer. Voltage of each node and current of each branch are used for calculating the active and reactive power loss in distribution system. The stages for calculating the load flow of an imbalanced radial system is as follow:

a) Early assumption for whole buses voltage:

$$\begin{cases} V_{ai} = 1\angle 0 \\ V_{bi} = 1\angle -120 \\ V_{ci} = 1\angle +120 \end{cases} \quad i = 1,2,\ldots,n \tag{4}$$

Where i is number of buses.

b) Loads current calculation:

$$\begin{cases} I_{L_{ai}} = \dfrac{S^*_{L_{Ai}}}{V^*_{ai}} \\ I_{L_{bi}} = \dfrac{S^*_{L_{Bi}}}{V^*_{bi}} \\ I_{L_{ci}} = \dfrac{S^*_{L_{Ci}}}{V^*_{ci}} \end{cases} \tag{5}$$

c) Calculation of branches current to backward:

$$\begin{cases} I_{Ai} = I_{L_{Ai}} + \sum_{k\in m} I_{L_{Aj}} \\ I_{Bi} = I_{L_{Bi}} + \sum_{k\in m} I_{L_{Bj}} \\ I_{Ci} = I_{L_{Ci}} + \sum_{k\in m} I_{L_{Cj}} \end{cases} \tag{6}$$

Where m is buses set that are next of bus i.

d) Calculation of new buses voltage to forward

$$\begin{bmatrix} V_{\text{Ai}} \\ V_{\text{Bi}} \\ V_{Ci} \end{bmatrix} = \begin{bmatrix} V_{\text{Ai-1}} \\ V_{\text{Bi-1}} \\ V_{Ci-1} \end{bmatrix} - \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \begin{bmatrix} I_{\text{Ai}} \\ I_{Bi} \\ I_{Ci} \end{bmatrix} \tag{7}$$

e) Repetition of overhead level than converge.

V. CASE STUDY

Optimization algorithm in this paper is tested on the low-voltage 33-bus system. Length of low-voltage lines and load informations are given in Table 4 and 5, respectively. In order to evaluate the effects of load imbalance in low-voltage system, a group of balanced one-phase and three-phase and imbalanced three-phase in 4-wire system are used. Energy cost per each kW considered 350 Rials. Maximum efficiency of transformers achieved using 70% rated power of transformers specifications of the suggested transformers to schedule the distribution substations given in Table 3.

Number, capacity, location of the transformers, different parts of losses and overall cost for 33-bus system before and after balancing are given In Table 1. According to figure 1, load balancing on phases of low-voltage network led to a 62 % reduction in neutral point loss and finally a 48 % improvement in copper loss and resulting in 11 % decrease in costs of network scheduling subsequently.

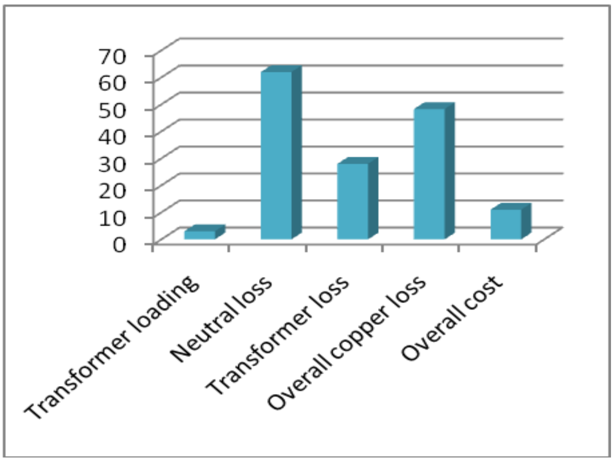


Fig. 1: Variables improvement percentage after balancing

Table I. Variables of 33 buses system

Variables	Before load balancing	After load balancing
Number and capacity of transformers *(KVA)*	1*1000	1*1000
Transformers location (bus number)	16	28
Transformer loading *(KVA)*	586	568
Neutral losses *(KW)*	30.88	11.86
Transformer losses *(KW)*	9.052	8.796
Overall copper losses *(KW)*	39.97	20.67
Overall cost *(rial)*	548	489

VI. INFLUENCE OF ENERGY COST CHANGE ON DISTRIBUTION NETWORK PLANNING

Here objective function based on cost is composed of two parts i.e. transformer cost and loss cost. Increase in energy cost causes the second component of the objective function i.e. losses cost to be highlighted and leads to a reduction of service area of each transformer. Therefore, number of transformers will increase. The effects of consumers pattern changes and consequently step variation of energy cost in a 33-bus system is investigated and results given in Table 2. As shown in Table 2 and Figure 2, increasing energy cost leads to the loss cost and consequently the number of transformers will increase.

Table II. Influence of energy cost change on case study

Cost of energy *(rial/KWh)*	Number and capacity of transformers *(KVA)*
350	1*1000
750	1*200 1*630
1350	1*250 1*630
1550	1*250 1*630

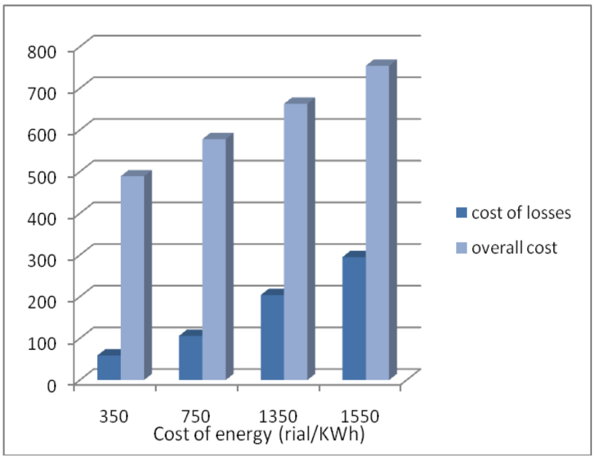


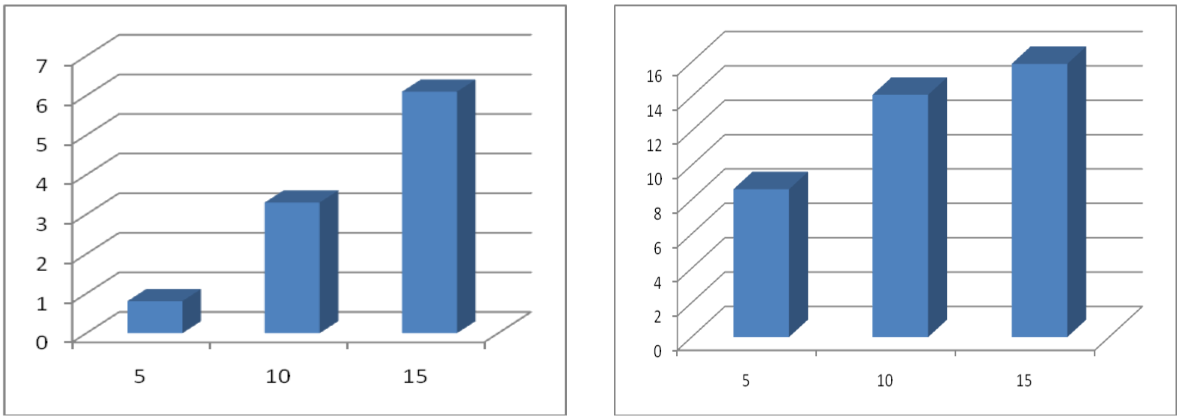
Fig 2: Influence of energy cost change on losses cost and overall cost

VII. INFLUENCE OF LOAD CHANGE ON DISTRIBUTION NETWORK PLANNING

In this study, load uncertainty is not considered. However, since loads of distribution system always facing variations [12], the proposed method is evaluated for different values of loads by investigating the effect of load variations on 33-bus system. In these investigations, 5, 10 and 15 % load variations are taken into account. As shown in Table 3, system is stable against slight load variations and can respond to them by using a 1000 kVA transformer. Percentage of cost variations due to load variations are shown in Figures 3.

Table III. influence of load change on distribution network planning

Load change	Number and capacity of transformers *(KVA)*
+5%	1*1000
+10%	1*1000
+15%	1*1000
-5%	1*800
-10%	1*800
-15%	1*800



(a) (b)

Fig 3: (a) cost increasing percentage at increasing 5, 10 and 15 percentage of loads (b) cost decreasing percentage at decreasing 5, 10 and 15 percentage of loads

V. CONCLUSIONS

Providing the required demand is often considered as a criterion for determining the optimal location of transformers and network and transformers loss are not taken into account. In this paper, a new method is presented in which selection of the proper capacity for transformers is performed considering demand of the area as the main constraint of the problem in addition to the cost of the network and losses.

Distribution network among all parts of the power system has highest copper loss due to its low voltage. Main component of this loss is occurred in the neutral wire due to imbalance distribution of the load on phases of the distribution network. This current in the neutral wire causes an increase in the copper loss of the network and other undesirable consequences such as electrifying the neutral point of the network, heating up the electric motors and transformers and saturation of magnetic cores. In this paper, system loss reduction of the case study leads to reduce the overall cost fulfilled by balancing load on the phases. This reduces harsh consequences on neutral wire. Results of the suggested Genetic Algorithm also confirm noticeable reduction in loss and overall cost. Moreover influence of energy cost change and load change on distribution network planning is evaluated by investigating on 33-bus system.

REFERENCES

[1] A. Jorge E. Mendoza ,"Low voltage distribution optimization: Site, quantity and size of distribution transformers" Electric Power Systems Research 91 52– 60, 2012.

[2] Gonen T. Electric power distribution system engineering. Book:McGraw-Hill; 1986.

[3] Willis HL, "Power Distribution Planning" refrence book, New York: Marcel Dekker Inc: 1997.

[4] A. T.H.M. El-Fouly and B. H.H.Zeineldin and C. E.F.El-Saadany and D. M.M.A. Salama, "A new optimization model for distribution substation siting, sizing and timing" Electrical Power and Energy Systems 30 308-315, 2008.

[5] A. Dai Hongwei and B. Yu Yixin and C. Huang Chunhua and D. Wang Chengshan and E. GeShaoyaun, "Optimal planning of distribution substation locations and sizes model and algorithm" Electrical Power & Energy Systems 18 353-357, 1996.

[6] A. H.K.Temraz and B. M.M.A. Salama, "A planning model for siting, sizing and timing of distribution substations and defining the associated service area" Electrical Power Systems Research 62 145-151, 2002.

[7] A. Khodr, H.M. "A probabilistic methodology for distribution substation location"IEEE Power & Energy Society 388-393, 2003.

[8] Carrano. E.G, Takahashi. R.H.C, Cardoso. E.P, Saldanha. R.R, Neto. O.M, "Optimal substation location and energy distribution network design using a hybrid GA-BFGS algorithm", Generation, Transmission and Distribution, IEEE Proceeding, Volume 152, 2005.

[9] Yadav. A.K, Azeem. A, Singh. A, Malik. H, Rahi. O.P, "Application Research Based on Artificial Neural Network (ANN) to Predict No-Load Loss for Transformer's Design", Communication Systems and Network Technologies, 2011 International Conference.

[10] Steinmetz. T, Cranganu-Cretu. B, Smajic. J, "Investigations of no-load and load losses in amorphous core dry-type transformers", Electrical Machines (ICEM), 2010 XIX International Conference.

[11] W. H. Kersting," Distribution system modeling and analysis", CRC Press LLC, New York, 2002.

[12] Rui Bo, Fangxing Li, "Probabilistic LMP Forecasting Considering Load Uncertainty", Power systems, IEEE Transaction, Volume 24, 2009.

Farzaneh Yazdani received the B.S. and M.S. degrees in electrical engineering from Babol Noshirvani University of Technology, Babol, Iran in 2010 and 2014 respectively.

Appendix A.

Table IV. Lines information

Bus number	Lines length *(meter)*	Bus number	Lines length *(meter)*	Bus number	Lines length *(meter)*	Bus number	Lines length *(meter)*
1	20	9	15	17	20	25	**15**
2	15	10	22	18	18	26	**14**
3	15	11	16	19	16	27	**20**
4	10	12	15	20	20	28	**19**
5	12	13	18	21	12	29	**15**
6	18	14	10	22	15	30	**18**
7	16	15	16	23	10	31	**16**
8	20	16	20	24	13	32	**15**

Table V. .Active and reactive powers of loads

Bus number	P1	Q1	P2	Q2	P3	Q3
1	4	2	6	3	4	1
2	4	1	6	2	6	1
3	7	3	6	2	5	3
4	7	3	6	3	6	2
5	6	2	5	3	7	2
6	4	2	4	1	2	1
7	2	1	3	1	4	2
8	6	2	5	3	7	3
9	5	3	6	2	3	1
10	4	1	5	3	3	1
11	6	3	2	1	6	4
12	6	3	4	1	5	2
13	8	3	6	3	7	4
14	6	1	3	2	7	3
15	6	2	6	2	6	2
16	6	3	1	1	7	2
17	9	3	4	2	2	1
18	3	1	5	2	7	2
19	6	2	3	1	8	4
20	6	5	3	1	6	2
21	4	1	8	3	4	5
22	3	2	6	4	6	2
23	4	1	5	2	7	4
24	4	1	4	1	4	1
25	6	2	7	4	5	3
26	6	2	3	2	9	4
27	6	2	3	1	5	2
28	9	4	6	4	1	0
29	7	4	7	4	7	4
30	5	7	2	1	6	2
31	6	3	5	1	4	2
32	5	2	4	2	6	4
33	5	1	6	3	2	1

Table VI. Transformer information

Transformer capacity (KVA)	No-load losses (W)	Full-load losses (W)
160	500	3050
200	570	3600
250	610	4450
315	720	5400
400	850	6450
500	1000	7800
630	1200	9300
800	1450	11000
1000	1750	13500
1250	2100	16400
1600	2550	19800

How to cite this paper: Farzaneh Yazdani, Seyyed Mehdy Hosseini, Taghi Barforuoshi, Syed Hamid Hasan,"A New Optimization Model for Distribution Siting and Sizing in Unbalanced Three-phase Networks for Loss and Cost Minimization", IJCNIS, vol.6, no.7, pp.35-41, 2014. DOI: 10.5815/ijcnis.2014.07.05