

Power Distribution Expansion Planning

Mokhtar Derakhshi¹, Javad Olamaei^{2*}

^{1,2} Electrical and Electronic Engineering Department, Islamic Azad University, South Tehran Branch, Tehran, Iran

Abstract

This paper presents a method for distribution network expansion planning. The two objectives are: loss reduction and Reliability improvement. First, neural network method is used for long term load forecasting. Then Genetic algorithm is utilized to solve simultaneous placement of power distribution transformers and feeders. The proposed method is applied on the green field. The effectiveness of the proposed method is tested on a green field system and the results are presented.

Keywords: Transformer placement, Feeder routing, Genetic algorithm, Neural network.

1. INTRODUCTION

Optimal designing of distribution networks is one of the most important issues in power systems which should be done in a way that the proposed structure, in addition to minimizing the cost of installation, operation and energy losses, provides limitations such as allowed drop in voltages of feeders, proper capacity of the transformers for supplying the load, etc. in the network. By long-term and optimal forecasts of distribution networks, such as long term a region's load forecasting, costs can be dramatically reduced.

So far, lots of research has been done to develop and plan distribution networks. The reference [1] examines the assignment and provision of multi-period transformers under separate probabilities. This proposed model was a linear programming one. The reference [2] offers a probabilistic method for choosing the distribution point location. In this method, the hourly load cycle (or daily) is considered. The reference [3] uses a hybrid algorithm to solve the distribution network

expansion problem.

In [4], a PSO-based comparative mutation algorithm is proposed for solving the optimal post-dimensional measurement problem. In [5], the mathematical clustering method and genetic algorithm are proposed for determining possible candidate locations and optimizing the problem, respectively. Reference [6] offers a new optimization model for planning. This programming model is formulated as a MIPP problem.

Reference [7] offers a comprehensive planning of distribution systems for urban / suburban areas. The location and the optimum size of transformers and posts with the route and type of feeders MV and LV are obtained. The cost of elements of the distributed system is assumed to be discrete, and also the DPSO (discrete partial-slight optimization) method is used to solve the programming problem.

Reference [8] provides the distribution feeder structure for minimizing losses by using modified honey bee mating optimization algorithm. Reference [9] optimizes the location of distribution transformers based on the minimizing peak losses

*Corresponding Author's Email: j_olamaei@azad.ac.ir

and voltage regulation by using the MiPower software and compares the result with the node removal method.

In reference [10], an exploratory algorithm is proposed which solves the problem of the location of the transformer and the design of the low voltage network (LV) and medium voltage (MV) within a single optimization framework. To determine the number of transformers, a dense hierarchy clustering method has been used. Besides, the CMST and MST algorithms are used for routing LV and MV feeders, respectively.

In this paper, a genetic algorithm is used for designing a distribution network. Genetic algorithm has also been used successfully in many cases such as capacitor location [11], economic load distribution [12], optimal load distribution [13], and so on. In this paper, neural network algorithm is used for long term load forecasting at first and then by the genetic algorithm, the optimal location of 20kV / 400V transformers and optimal routing of feeders of 20kV and 400V are simultaneously aimed for improving the system reliability, and reducing equipment costs, loss of feeders and transmissions. Finally, the proposed method on a new network has been evaluated in different scenarios.

2. NEURAL NETWORK

The neural networks has been very much considered for load forecasting due to its accuracy. Neural Networks is one of the computational methods which attempts to recognize the intrinsic relationships between the data by mapping the input space (input layer) and the optimal space (output layer) by means of the learning process, and using neural processors. The layers or hidden layers process the received information from the input layer and provide the output layer.

Each network receives training examples. Learning is a process that ultimately leads to learning. Network learning is performed when the communication weights between layers change so that the difference between predicted and calculated values are acceptable. By achieving these conditions, the learning process has been realized. These weights represent the memory and network

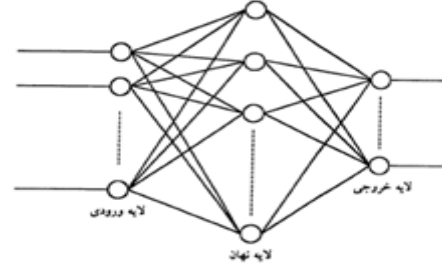


Fig. 1. General structure of Neural Network.

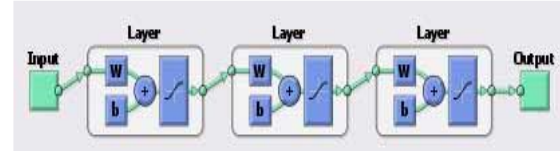


Fig. 2. Layer structure of Neural Network.

knowledge. The trained neural network can be used for predicting the appropriate outputs of the new data set. A neural network typically consists of three parts, including: an input layer, one or more hidden layers and an output layer.

2.1. Neural Network Structure

In this paper, a three-layer perceptron neural network with a back-propagation method is used for long-term load forecasting which is implemented in Matlab software environment. The main feature of the BP algorithm is creating a nonlinear mapping between an input set and an output set. The general model of perceptron networks is the progressive network with the reciprocation teaching principle. Fronting networks are those networks which the first-order inputs of its neurons are connected to the next layers and they are true on the surface of the problem to reach the output layer. The back propagation procedure means that once the network output is specified, the last layer weights are corrected and then the previous layer weights. The structure of this neural network is shown in Fig. 2. For the input, output and the middle layer, the non-linear Sigmoid Function is used.

$$f(x) = \frac{1}{1+e^{-x}} \quad (1)$$

The goal is to reduce the neural network error for data which are entered for the first time. Hence, 20% of the data is isolated and not interfere with the network computing in each step. When the training is completed, test data is applied to the network and by

calculating the mean squared error, the network performance is evaluated.

The data is normalized before entering to the network, due to the fact that entering raw data reduces speed and accuracy of the network. Owing to the fact that each of the parameter sets have their related divisions, data should be normalized for uniforming the range of their changes and prevent excessive over-weighting of the network. According to the use of sigmoid functions in the neural network, the normalization of the input vector components is carried out in such a way that all of these components lie in the interval between negative/positive one:

$$N_i = 2 \times \left(\frac{X_i - X_{min}}{X_{max} - X_{min}} \right) - 1 \quad (2)$$

The decision criteria of choosing the best network in each run are determination coefficient R2, Eq. (3), root mean square error (MSRE), Eq. (4), and the mean absolute error (MAE), Eq. (5).

$$R^2 = \frac{\sum_{i=0}^n (y_o - \bar{y}_f)^2}{\sum_{i=0}^n y_o^2 - \frac{\sum_{i=0}^n y_f^2}{n}} \quad (3)$$

$$RMSE = \sqrt{\frac{\sum_{i=0}^n (y_o - \bar{y}_f)^2}{n}} \quad (4)$$

$$MAE = \frac{\sum_{i=0}^n |y_o - y_f|}{n} \quad (5)$$

where:

Ni: normalized values

Xi: real values

Xmin: Minimum actual values

Xmax: Maximum actual values

yo and yf: observed size and desired parameter of the network respectively

N: The total number of data used

The best performance of the model basis on of the R2 criterion is one, and based on other criteria is zero, which indicates the closeness of observed and predicted values, and accuracy of the answers in each step.

2.2. Implementing Proposed Method

In this research, consumption data of Khorasan Razavi from 2006 to 2012 have been used as input for the neural network. Figure 3 shows the daily consumption during these years. As seen in the

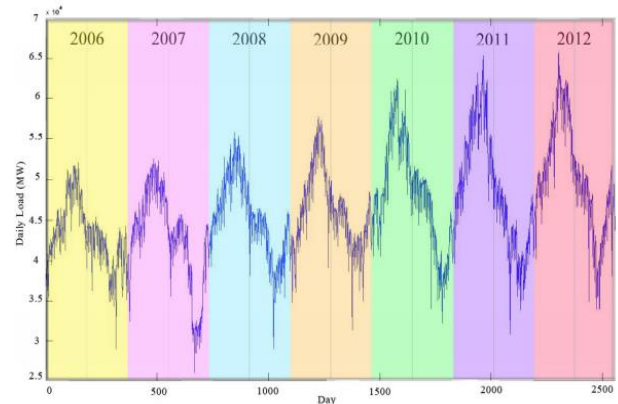


Fig. 3. Daily load consumption of central Khorasan electrical network.

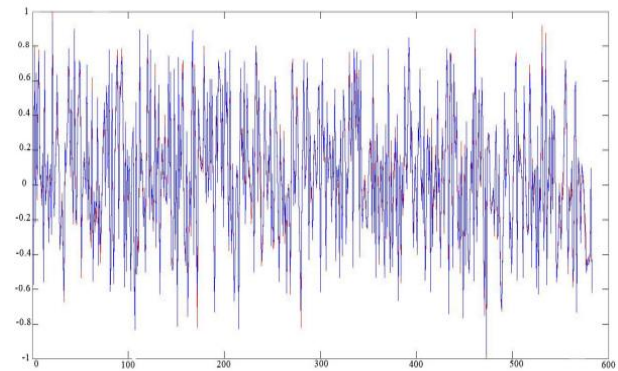


Fig. 4. Actual and trained data values.

mentioned figure, seasonal changes have been high over the course of the desired period.

Using the artificial neural network introduced in the previous section, incoming years load forecasting is obtained. In this model, input data of the neural network are as follows:

- Consumption in the same day of the past year
- Consumption in the same day of the past month
- Consumption in the same day of the last week
- Consumption in the last two days
- Consumption in the previous day

Figure 4 shows the actual values and values of the trained data, which indicates two more graphs coincide, the network is better trained. The horizontal axis is the education index.

In fig. 5, the vertical and horizontal axes depict real data and trained data, respectively. This diagram illustrates the network correct training for trained data owing to the fact that the closer the points and less scattered data are, the better network training is.

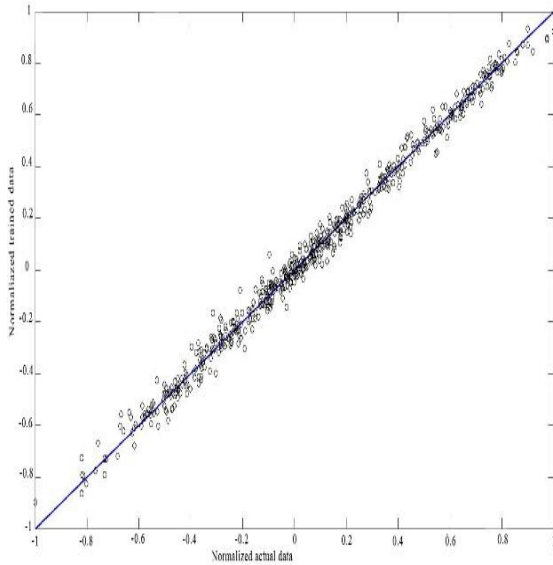


Fig. 5. Actual and trained values.

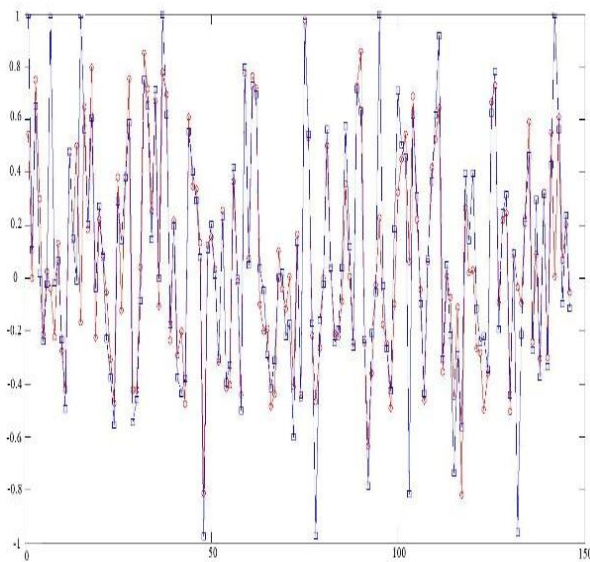


Fig. 6. Actual and test data values.

Fig. 6 compares the actual and test data values. As we know, our neural network has been well trained since the points of the two charts are almost on each other.

As the graphs show, the test and trained values are as good as real values. Hence, the long-term load forecasting result with a squared error of 0.0032 for the trained data and 0.381 for the test data is acceptable.

3. SIMULTANEOUS TRANSFORMERS OPTIMAL PLACEMENT

3.1.1. Process of Genetic Algorithm

Genetic Algorithms is implemented by variety of ways and different operators. What has been used in this project is the genetic algorithm which the block is shown in Fig. 7. The operation of the algorithm requires implementing three following steps:

- Initialization
- Rebuild
- Replacement

3.1.2. Initialization

In the initialization, points of searching space are randomly selected at first and then encoded (forming a chromosome), each of these chromosomes can be considered as an answer to the optimization problem. For each chromosome, we calculate the amount of target function, and assign it. The collection of these chromosomes forms the first generation. In the proposed algorithm, the number of chromosomes is 8.

3.1.3. Rebuild

At the rebuild stage, the current generation generates a new generation. For this purpose, a pair of from the current generation, with the probability proportional to the target function of the chromosome, is chosen (parents) and then by applying cutting and mating operators, a pair of new chromosome (children) is produced. These children are in the next generation. In the proposed algorithm, the rate of selection and the rate of mutation is considered to be 50% and 10% respectively.

3.1.4. Replacement

At this stage, new chromosomes (children) replace the previous (parent) chromosomes. In other words, the new generation replacing the previous generation. The rebuilding and replacing steps are repeated so often enough to get close to the optimal answer. The stopping condition for this algorithm is 1500 repetitions.

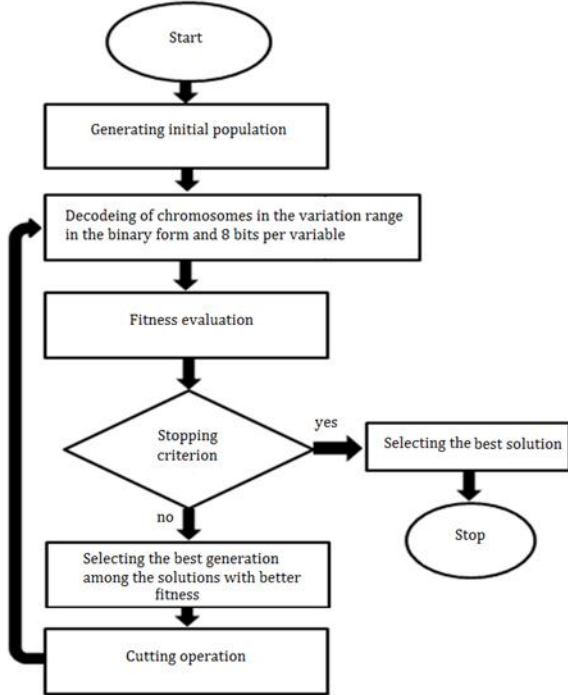


Fig. 7. Genetic algorithm procedure.

3.2. Cost Function

The purpose of this model is to optimally place 20kV / 400V transformers and optimize the routing of 20kV and 400V feeders simultaneously, with the goal of reducing losses and improving system reliability in a new network. In fact, by reducing the length of the MV and LV feeders and also increasing the reliability of the system, Eq. 6, this is achieved.

$$F = f_1 + f_2 - f_3 \quad (6)$$

where f_1 and f_2 are the lengths of MV and LV feeders and f_3 is the reliability of our system. In fact, the goal is to minimize the above objective function, where f_1 and f_2 must be reduced and f_3 must increase. In addition, different scenarios are examined by increasing and decreasing the number of transmissions with different nominal power, optimally locating them based on the minimum length of LV and MV feeders and improving system reliability. Then, after optimal placement of transformers and optimal routing of feeders, the cost of equipment, which includes the cost of transformers and feeders individually, the cost of losses, including the cost of loss of transformers and feeders individually, as well as the total cost

Table 1. Transformers and Feeders Costs

Feeder, 400 V	10 \$/m
Feeder, 20 KV	25 \$/m
Trans, 200 KV-A	800 \$
Trans, 400 KV-A	1200 \$
Trans, 1 MV-A	2000 \$
Trans, 2.8 MV-A	4200 \$

are calculated.

Table 1 shows the price of transformers and feeders:

The cost of transformers is obtained from Eq.7:

$$C_1 = \sum_{i=1}^{N_t} C_{transformator200} + \sum_{i=1}^{N_t} C_{transformator400} + \sum_{i=1}^{N_t} C_{transformator1000} + \sum_{i=1}^{N_t} C_{transformator2800} \quad (7)$$

The cost of feeders is also calculated from Eq.8:

$$C_2 = \sum_{i=1}^{N_c} (C_{up})l(:,i) + \sum_{i=1}^{N_c} (C_{down})l(:,i) \quad (8)$$

The cost of feeder loss is also calculated from Eq. 9:

$$C_3 = \alpha \sum_{i=1}^{N_t} \sum_{j=1}^{N_c} l(i,j) w_j^2 \quad (9)$$

where:

$C_{transformator200}$: Transformer cost 200 kV

$C_{transformator400}$: Transformer cost 400 kV

$C_{transformator1000}$: Transformer cost 1 megav

$C_{transformator2800}$: Transformer cost 2.8 MVA

N_t : Number of network transmissions

N_c : Number of Consumers

$L(:,i)$: Length of the lines

C_{up} : Construction cost of 20 kV line

C_{down} : The cost of building a 400v line

W_j : load factor load point j

α is the feed conversion rate which is equal to:

$$\alpha = \alpha_1 \times \alpha_2 \times \alpha_3 \quad (10)$$

α_1 : Electricity cost per kilowatt hour

α_2 : Resistance per kilometer of feeders

α_3 : Annual power loss (hours)

The 20kV feeder has a resistance of 0.023 ohms per kilometer, and 400V feeder has 0.127 ohms per kilometer. Besides, the estimated electricity cost is supposed \$12 per kilowatt-hour. The cost of transformer C_4 losses is also calculated.

Table 2. Economical Analysis of Transformers Costs in Different Loads.

	20%-40%	40%-60%	60%-70%	70%-80%	80%-100%
200	1.197	1.987	1.023	1.0211	1.0211
400	1.0102	1.0086	1.0073	1.007	1.007
800	1.0384	1.0294	1.0274	1.0168	1.0163
1000	1.0275	1.0217	1.0192	1.0184	1.0182
1200	1.0173	1.0152	1.0147	1.0143	1.0137
1500	1.0186	1.0162	1.0153	1.0148	1.0145
2000	1.0221	1.0203	1.0157	1.0132	1.0127
2800	1.0134	1.0131	1.0125	1.012	1.0119
3200	1.0123	1.0146	1.0146	1.0128	1.0121

According to Table 2, in order to better design the network, it should be tried to use 80% of the transformer's nominal power.

Therefore, the total cost of the system is obtained from Equation (11):

$$C_{Total} = C_1 + C_2 + C_3 + C_4 \quad (11)$$

Under the constraints:

1. The requirement for the supply of goods to consumers (Clause 12), so that the delivered charge of a transformer should not to be less than the total amount of customers connected to it.

$$P_i > \sum_{j=1}^{N_c} l_{c_j} n(i, j) \quad (12)$$

where:

L_{cj}: Consumer j required load

P_i: Delivered load by transformer I

N_c: Number of Consumers

If load j is not connected to transformer i, n(i,j) is zero and if it is connected, n(i,j) is one.

2. The feeder voltage limitation factor, which this requirement in 400 V line is considered to be less than 600 m.

One of the issues that was always important in network development projects is to maintain or enhance the reliability of the system in the implementation of these projects. Here's calculation of reliability:

Step 1: Elements are removed individually. In

fact, one element is removed at each repetition. (Elements include transformers, 20 kV and 400 volt feeders)

Step 2: Calculate how much of the system load is eliminated for deletion of each element

Step 3: Using Eq. 13, the reliability of the system is calculated for deletion of the element or, in other words, the sense of reliability for the amount of unloaded charge for the removal of that element.

$$1 - \frac{\text{KVA of omitted load}}{\text{KVA of total load}} \quad (13)$$

Step Four: If there is an element which is not removed, go back to the first step, otherwise go to step five.

Step Five: The average reliability is calculated in step three.

Step Six: End

3.3. Possible Scenarios of Replacement Theory

In this section, a new industrial city is being surveyed and simulated. All industrial city consumers have a history of production, and they need electrical energy to build their units. In this simulation, it is assumed that the mentioned industrial town location is strategically suitable for the construction of a factory or industrial load. Besides, land costs are not taken into account and there is no geographical constraint in the whole set.

Table 3. Location and Loads of New Grid.

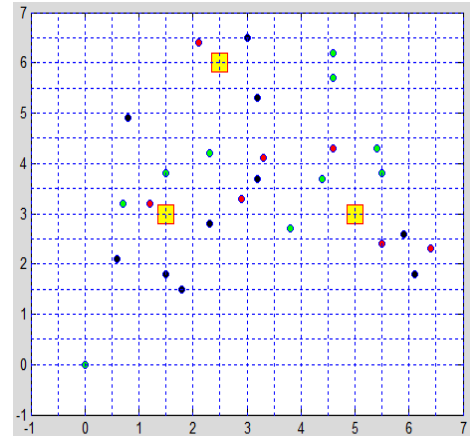
Load (KVA)	Y location (Km)	X location (Km)
0	0	0
200	3.2	1.2
200	1.8	1.5
200	6.4	2.1
200	2.8	2.3
200	.8	.6
200	4.9	.8
200	.6	2.8
200	2.1	.6
200	1.5	1.8
200	5.3	3.2
150	1.2	5.8
150	4.3	5.4
150	3.8	5.5
150	6.2	4.6
150	3.7	4.4
150	3.8	3.7
150	2.7	3.8
150	5.7	4.6
300	2.4	5.5
300	2.6	5.9
300	6.5	6.3
300	2.3	6.4
300	1.8	6.1
300	4.3	4.6
300	4.1	3.3
300	3.7	3.2
300	3.3	2.9
150	4.2	2.3
150	3.2	.7

In this section, according to the long-term load forecasting in the previous sections, the consumption of Green Field network load is simulated. Table 3 shows the load consumption, and the location of each assumed network load.

Table 4 shows the location of the resource, or, in other words, the location of the top posts. In this network, it is assumed that energy sources or high-power posts have the ability to supply the required power of the network, and the maximum capacity of production units is neglected.

Table 4. Location of Production Units (Upper Posts) In New Grid.

Y location (Km)	X location (Km)	Generating units in the upstream substations
3	1.5	1
6	2.5	2
3	5	3

**Fig. 8. Desired grid.**

In following, different scenarios are evaluated. Fig. 8 shows the studied network, which upper posts have shown by yellow squares, and loads of 150, 200, and 300 kV, by green, black and red dashes, respectively.

In all figures, positioned transformers are shown by red border circles, 20-kV feeder line with full blue lines, and 400-volt feeder path with different color lines for each transceiver. It should be noted that 400-volt feeders which are shown by red lines indicate that the feeder has experienced voltage drop.

3.3.1. First Scenario

In the first scenario, based on the network load values, three transformers 2.8MVA were used. Fig. 9 shows the location of transformers along with the feeders routing. As shown in Fig. 9, voltage drop has been occurred on some feeders which are marked in red. In this scenario, there are loads provided, but there is voltage drop problem. Therefore, in the second scenario, the number and type of transformers is changed.

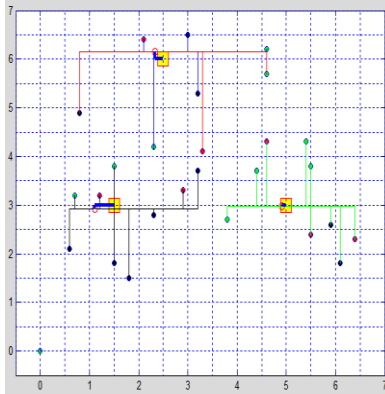


Fig. 9. Locating Transformers with routing feeders in first scenario.

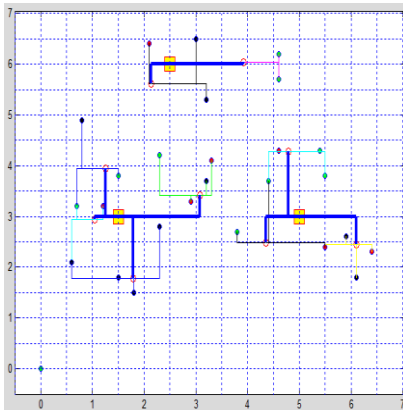


Fig. 10. Locating Transformers with routing feeders in second scenario.

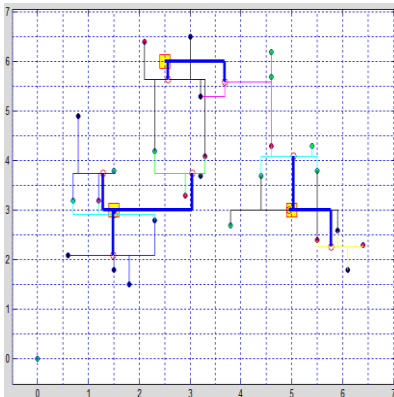


Fig. 11. Locating Transformers with routing feeders in third scenario.

3.3.2. Second Scenario

In this scenario, 9 1MVA transformers have been used. Fig. 10 illustrates the location of the transformers along with the routing of feeders. As shown in Fig. 10, all loads are provided and there is no voltage drop in the feeders. Table 5 shows the results of scenario 2.

Table 5. Results of Second Scenario.

Type and number of transformers	Nine transformers with 1 MVA rating
Feeder length, 400 V (km)	12.67
Feeder length, 20 kV(Km)	10.28
Cost of transformers (\$)	18000
Annual loss cost of transformers (\$)	331.2
Cost of 20 kV and 400 V feeders	383700
Annual loss cost of feeders (\$)	168586.2
Total cost (\$)	570617.4
Reliability (%)	79.8
Feeder loss (kWh)	192.45

Table 6. Results of Third Scenario.

Type and number of transformers	Nine transformers with 1 MVA rating
(km) Feeder length, 400 V	15.058
Feeder length, 20 kV(Km)	10.45
Cost of transformers (\$)	18000
Annual loss cost of transformers (\$)	327.6
Cost of 20 kV and 400 V feeders	411830
Annual loss cost of feeders (\$)	200360.77
Total cost (\$)	630518.37
Reliability (%)	86.1
Feeder loss (kWh)	228.72

3.3.3. Third Scenario

The purpose of defining the third scenario is increasing the reliability of the second scenario. In this scenario, the reliability of the system is improved by adding further feeds and the results are examined. Fig. 11 illustrates the location of the transformers along with the routing of feeders.

In this scenario, all loads are provided and there is no voltage drop in feeders. As it is known, some of the loads are supplied by two transformers, which increase the reliability of the system. Table 6 shows the results of this scenario. As expected, the total cost increased by improving system reliability.

4. CONCLUSION

In this research, in addition to optimizing the location of 20kV / 400V transformers and finding optimal routing of 20kV and 400V feeders at the same time, a precise long term load forecasting was done by using artificial neural network. In this algorithm, a three-layer perceptron network for long term load forecasting, a sigmoid function for input and output layers, and an error propagation method for training the neural network were used. The results of long term forecasting with squared error of 0.0032 for trained data and 0.381 are obtained which are acceptable for test data. The loss and equipment cost reduction, system reliability improvement through the optimal location of 20kV / 400V transformers and optimal routing of 20kV and 400V feeders were simultaneously provided in radial distribution grids.

The objective function, consisting lengths of the Lv and Mv feeders as well as the reliability of the system, are minimized at each step by genetic algorithm. The proposed method was then implemented on a Green Field network and various scenarios with different number and type of transformers were examined. Besides, the both cost and loss of feeders and transformers were calculated. It can be concluded that according to the mentioned results, the proposed algorithm describes the path of 20kV and 400V feeders well, as well as the optimal location of 20kV/ 400V transformers. On the other hand, the system reliability varies in different scenarios, which can be considered in the system designing based on the user's perspective and the dedicated budget.

REFERENCES

- [1] Suresh K. Khator, Lawrence C. Leung, "Power Distribution Planning: A Review of Models and Issues", IEEE Transactions on Power Systems, Vol. 12, No. 3, August 1997.
- [2] H. M. Khodr, Jorge A. Melián, Adolfo J. Quiroz, Daniela C. Picado, José María Yusta, and Alberto J. Urdaneta, "A Probabilistic Methodology for Distribution Substation Location", IEEE Transaction on Power Systems, Vol. 18, No. 1, February 2003.
- [3] E.G. Carrano, R.H.C. Takahashi, E.P. Cardoso, R.R. Saldanha and O.M. Neto, "Optimal substation location and energy distribution network design using a hybrid GA-BFGS algorithm", IEE Proc.-Gener. Transm. Distrib., Vol. 152, No. 6, November 2005.
- [4] Liu Zifa, Zhang Jianhua, "Optimal Planning of Substation of Locating and Sizing Based on GIS and Adaptive Mutation PSO Algorithm", Int Confer Power Syst Technol 2006:1-5.
- [5] Sepasian MS, Seifi H, Foroud AA, Hosseini SH, Kabir EM. A new approach for substation expansion planning. IEEE Trans Power Syst 2006;21(2):997–1004.
- [6] T.H.M. El-Fouly, H.H. Zeineldin, E.F. El-Saadany, M.M.A. Salama, "A new optimization model for distribution substation siting, sizing, and timing", Electrical Power and Energy Systems 30 (2008) 308–315.
- [7] Iman Ziari, Gerard Ledwich, Arindam Ghosh, " Optimal integrated planning of MV–LV distribution systems using DPSSO", Electric Power Systems Research 81 (2011) 1905– 1914.
- [8] Javad Olamaei, Taher Niknam, Sirous Badali and Arefi. A, "Distribution Feeder Reconfiguration for Loss Minimization Based on Modified honey Bee Mating Optimization Algorithm", Energy Procedia, Vol. 14, pp 304-311, March 2012.
- [9] Vishwanath Hegde, Raghavendra C.G, Prashanth Nayak, Pradeep S, Themchan Woleng,"Optimal Placement of Distribution Transformer for Loss Minimization in Radial Distribution System", IET Generation, Transmission & Distribution, Mar-2013.
- [10] Ayse Selin Kocaman, Woonghee Tim Huh, Vijay Modi, " Initial layout of power distribution systems for rural electrification: A heuristic algorithm for multilevel network design", Applied Energy 96 (2012) 302–315.
- [11] S. Sundharavajan and A. Pahwa, "Optimal Capacitor of capacitors for radial Distribution systems using Genetic Algorithm",

- IEEE Trans, Power systems, Vol.9, No.3, pp. 1499-1507, Aug 1994.
- [12] G.B.Shebe and K.Birttig, 'Refined Genetic Algorithm-Economic Example' ,IEEE Trans, Power systems, Vol.10, No.1, 1995.
- [13] K.Y. Lee, X.Bai, and Y.M.Park, 'Optimization Method for Reactive Power Planning by a Modified Simple Genetic Algorithm',IEEE Trans, Power systems, Vol.10, No.4, November, 1995.