Asian Journal of Convergence in Technology **Volume IV Issue I**
ISSN NO: 2350-1146 I.F-5.11

Optimal Placement and Sizing of Distribution Transformers of Existing Network using Genetic Algorithm and Simulated Annealing

Sunil T. Gaikwad, Priyanka S. Akotkar, Dr. N. Gopalakrishnan and Dr. Y. P. Nerkar
suniltgaikwad@rediffmail.com

Abstract—**The major part of losses in power system is contributed by transmission lines and distribution transformers (DTs). Failure of DT causes sudden outage and it is expensive to repair. Its failure affects Industry and consumers. Study related to DT is one of the essential areas for distribution side. The proposed work addresses the cost function optimization considering investment, operational, maintenance, insurance and depreciation costs of urban distribution network. The Genetic Algorithm (GA) which is best suited for optimum search is applied to the existing network under study. The results of GA are compared with Simulated Annealing (SA) as both methods handle bound-constrained optimization problems satisfactorily.**

Keywords— Distribution Transformer, Optimization, Location, Genetic Algorithm, Simulated Annealing.

I. INTRODUCTION

An electric power system is a network of electrical components organized to supply, transfer and use of electric energy. The distribution transformers (DTs) are the important components in such a system. They are large in number and of various ratings and types; and at least one DT is present in almost every place where people live and work. Its failure is expensive. In order to use the electrical energy efficiently distribution network planning is important in power system design. To achieve economic benefits, optimal placement, appropriate ratings and exact numbers of DT are essential to minimize the overall system cost.

Optimization solution to electrical distribution network is a challenging task. Different strategies, mathematical models and algorithms are developed for improving existing distribution network [1]. An optimization technique is proposed in [2] for location and sizing of the distribution substations and planning their service boundaries. A review on different heuristic optimization techniques applied for traditional and advanced distribution planning including cost is presented in [3], [4]. An interactive procedure using linear and integer programming to optimize the transformer capacities is considered in [5]. Advanced techniques such as neural networks, ant colony, fuzzy logic, particle swarm optimization including some traditional techniques are employed. Mathematical programming techniques such as linear and integer programming, genetic algorithm (GA) have been employed for distribution system planning of HV/MV substation [6] - [17]. Different crossover and mutation operators are used in genetic algorithm [18], [19]. A review of different genetic operators for solving problem of size, quantity and location of DTs is presented in [20]-[22]. Simulated annealing technique is presented in [23] - [25], for the configuration of radial distribution network.

The main contribution of this paper is the application of metaheuristic optimization methods as GA and simulated annealing (SA) to DTs connected to 11kV feeder located in a densely populated urban area. A novel algorithm to include insurance cost is developed using GA for cost effective optimal location of 21 pad mounted DTs considering its average demand (AD) and connected load (CL). The crossover cost comparison of single point cross over (SPC), two point cross over (TPC) and uniform cross over (UC) using GA are highlighted. The results are obtained by writing code in MATLAB as it permits an effective search to determine the variables simultaneously. The SA is best suited for bound constraints as that of GA, hence selected for comparison and verification of result. Finally, this work presents the solution considering realistic data for restructuring network under study by identifying optimal location for placing of DTs, reducing quantity of DTs, suggesting appropriate rating and type of DTs. Organization of the paper is as follows, the Problem formulation and different costs involved are discussed and calculated in section II. Section III describes the method of optimization. Application of problem is mentioned in section IV and results of case study are presented in section V. Section VI concludes the paper.

II. PROBLEM FORMULATION

The priority of today's aged electrical network is to upgrade it by providing techno economical solutions. In distribution network under study the rating and location of DTs depend on the connected load of consumers and available space. Replacement of all old DT's with required specification and location is a challenge for utility. In this work focus has been on restructuring the urban distribution system by; (i) allocation of cost effective optimal location of DTs using GA [1], (ii) allocation of required quantity and appropriate rating of DTs, (iii) allocation of DTs at suitable location (roof top and on ground) considering aesthetic and space constraint, (iv) retro filling of oil DTs with synthetic oil, (v) replacing oil with dry type DTs for safety purpose. This study is carried out on brown-field (existing) which can also be implemented for green-field (new) locations [2]. The objective function to be optimized consists of the total cost of DTs. The mathematical model of objective function is explained as follows;

$$TCDT = C_{Inv} + C_{Ope} + M_c + I_c + D_c \quad (1)$$

A. Investement Cost (C_{Inv})

The investment cost (C_{Inv}) considers costs of each DT along with cost of installation of DTs (*dti*), low voltage (*tplv*) line construction cost is considered from each DT to respective load point, and medium voltage (*tpmv*) line construction costs is considered from distribution substation to respective DT.

$$C_{Inv} = dti + tplv + tpmv \quad (1)$$

$$dti = \sum_{i=1}^{n} dtpi\ (sdti) \quad (2)$$

$$sdti = avgD_i \times k \quad (3)$$

$$k = \frac{(1+g)^T}{f_l \times f_{ol}} \quad (4)$$

$$tplv = llv \times plv \quad (5)$$

$$tpmv = lmv \times pmv \quad (6)$$

n, number of DT's; *sdti,* the selected DT *I; dtpi;* is the price of i^{th} DT, *avgDi,* average demand in kVA for i^{th} DT; k, oversizing factor; g, annual growth rate of load; *fl,* load factor of the system; *fol,* overload factor of DT; *T,* number of years of study; *tplv,* total price of low voltage line; *tpmv,* total price of medium voltage line; *llv,* length of low voltage line in (kms); *plv,* price of low voltage line in (Rs/kms); *lmv,* length of medium voltage line in (kms); *pmv*; price of medium voltage line in (Rs/kms).

B. Operational Cost (C_{Ope})

The network operational costs (C_{Ope}) considered here are cost of energy loss of low voltage lines (*ELLV*) and cost of energy loss of DTs (*ELTrans).*

$$C_{Ope} = ELLV + ELTrans \quad (7)$$

$$ELLV = Cnw \times \sum_{j=1}^{T} LossP \times \frac{(1+g)^j}{(1+r)^j} \quad (8)$$

$$ELTrans = \sum_{j=1}^{T} \left(\sum_{i=1}^{n} loi + lcui \cdot fu \cdot (1+g)^{2j} \right) \cdot \frac{1}{(1+r)^j} \quad (9)$$

Cnw, cost of network losses (Rs/kWh); Loss P, power losses in low voltage lines (kW); r, annual discount rate; *loi*, core losses of DT*i* (kW); *lcui*, copper losses(kW); *fu*, utilizaion factor.

C. Maintenance Cost (M_c)

Transformer manufacturing companies provide annual maintenance contract for oil filled transformers to SEDCL (State Electricity Distribution Company Limited). Contracts are of two types comprehensive (C_c) and non-comprehensive (N_c). Non-comprehensive maintenance includes only oil filtration and comprehensive maintenance includes oil filtration and replacement of material if damaged. Non-comprehensive maintenance is normally preferred by SEDCL in annual maintenance contract. Hence it is only considered in study.

$$M_c = N_c + C_c \quad (10)$$

D. Insurance Cost (Ic)

The insurance cost is considered in this study. Insurance covers DTs breakdown and fire. These policies are valid for one year and every year requires to be renewed. The insured have to pay 10% of the present cost of DT every year to renew the policy.

E. Depreciation Cost (D_c)

The distribution system can be upgraded only if existing equipments in system are also upgraded. The existing equipments have to be replaced by new one; hence depreciation cost is considered in study. Depreciation cost depends on cost of DT (d_{tp}) and its salvage value (s_v) which is 25% of total cost. Maximum years of operation (Y) are 25 years. The cost of depreciation of DT can be given as:

$$D_c = (d_{tp} - s_v) / Y \quad (11)$$

Total cost of distribution transformer (*TCDT*) includes investment costs, operational costs, maintenance costs, insurance costs and depreciation costs [16].

$$TCDT = C_{Inv} + C_{Ope} + M_c + I_c + D_c \quad (12)$$

III. GENETIC ALGORITHM

GA is a evolutionary optimization algorithm which finds optimal solution by stochastic rules. The algorithm repeatedly involves a population of individuals within search space, where each represents a possible solution to a given problem. GA is an optimization technique which can be used for solving both constrained and unconstrained optimization problems based on a natural selection process that imitates biological evolution. There are five types of constraints in GA as; linear equality, linear non-equality, non-linear equality, non-linear-inequality, and upper and lower bounds. The bound constraints are considered in this work as it limits the variables of the objective function. The steps involved in solving problem using GA are;

A. Encoding, Initialization and Selection

In GA, a chromosome is a set of parameters which defines a proposed solution to the problem that the GA is trying to solve with the help of binary alphabet. Each chromosome is associated with one binary string. Solution can be represented with the help of each bit present in the binary string. Each bit defines some characteristics of the solution. The formation of initial population is the next step after encoding. It requires at least a bit in the string. Selection is a fitness dependent process where solutions having more fitness are selected during successive generation. There are several methods of selection, among most known are (i) Roulette wheel, (ii) Tournament and (iii) Rank. In this work, tournament selection is used, as it choose two solutions and one with best fitness is allowed to reproduce [3]-[7].

B. Crossover Operator

The crossover is a process by which a string is divided into segments, which are exchanged with the segments corresponding to another string. Two new strings are formed with this process which is dissimilar from those who create them. This gives flexibility to increase, decrease and exchange placement of DTs. Various crossover types are discussed in [8],[16]. The SPC, TPC and UC are most known for optimization problems are considered in study.

C. Mutation Operator

Applying random changes to the individual population means Mutation. This is done to prevent the solution falling into a local optimum [9]-[11]. By changing the state of one bit from 0 to 1 and 1 to 0 may be insufficient to reach an optimum point.

IV. APPLICATION OF GA TO PROBLEM

The MATLAB environment is proposed for the development of algorithm as it permits an efficient search to minimize the objective function. The proposed GA is applied to 11kV feeder consisting of 21 pad mounted DTs with 18 oil and 3 dry type DTs. While optimizing certain constraints on objective function were considered. The maximum and minimum values preferred for bound constraints are; (i) the standard ratings available in market and related cost, (ii) core loss and copper losses, and (iii) average demand. The bound constraints for the medium voltage (MV) and low voltage (LV) lines are its length.

A. Network Optimization Flow Chart

The flow diagram explains procedure for implementation of proposed algorithm, shown in fig. 1. Initially required data is collected for area under study as Average demand on DTs, Losses and Length of LV and MV line. The total cost of existing network and optimum network is obtained with realistic data using GA. The cost comparison between SPC, TPC and UC is carried out to find the optimal cost of network. The parameter setting for algorithm are; GA: Population Size = 200, Maximum Number of generations = 600, Crossover Probability = 0.9, Mutation Probability = 0.05.

B. Features of developed Graphical User Interface (GUI)

The input parameters provided by the users through developed GUI are; upper and lower limit of present DT price, length of existing LV and MV lines, average demand, core losses and copper losses. The GUI displays the total cost for optimum layout of SPC, TPC and UC as shown in table I. GUI also generates the plot of existing and optimum network in terms of X and Y coordinates as shown in Fig. 2, and 3. The existing locations of 21 DTs is shown in Fig. 2 and optimal location of 21 DTs considering AD suggested by GA is shown in Fig. 3. The switching station, feeder pillars, feeder, MV lines and DTs are indicated with different shapes, colors and numbers for easy recognition. Locations of LV lines and load points are avoided for simplicity.

The dotted lines around each DT shown in Fig. 3 highlight the area in which DTs can be placed to achieve cost effective optimal location. The onsite feasibility study is required to know if any infrastructural constraint (obstacle) is available during DT installation. Suggested layout for optimal practically feasible locations of 21 DTs considering AD after site survey is shown in Fig. 4. The quantity of DTs is reduced from existing (over rated) 21 to suggested (required) 15, after studding AD on DTs as shown in Fig.5. The cost effective optimal feasible locations of 15 DTs are finalized after site visit. Similarly optimal location of DTs considering CL can be represented for Fig. 3, 4 and 5.

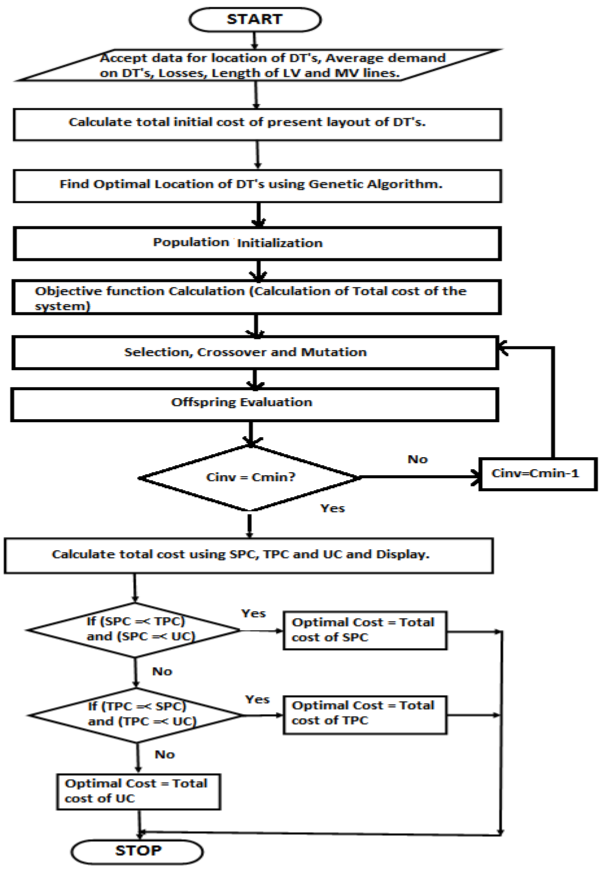

Fig. 1. Flow Chart of GA for optimal placing of DTs considering AD

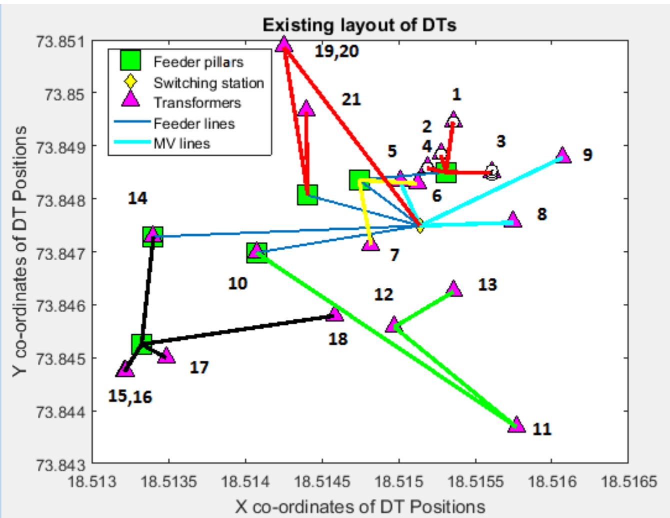

Fig.2. Existing position layout of 21 DTs

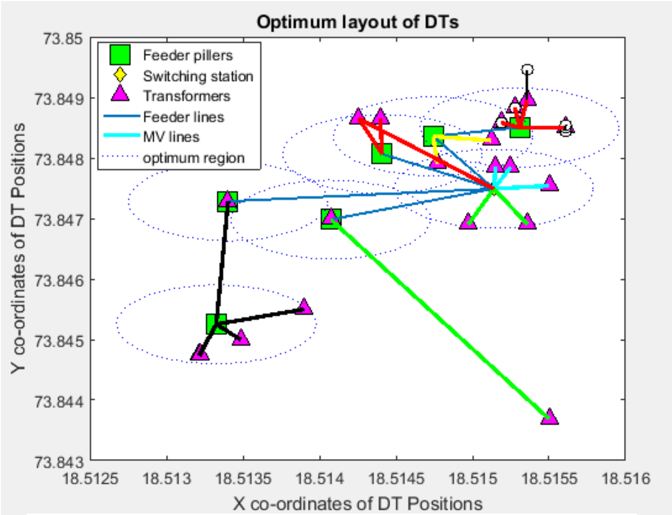

Fig.3. Optimum position layout of 21 DTs considering average demand

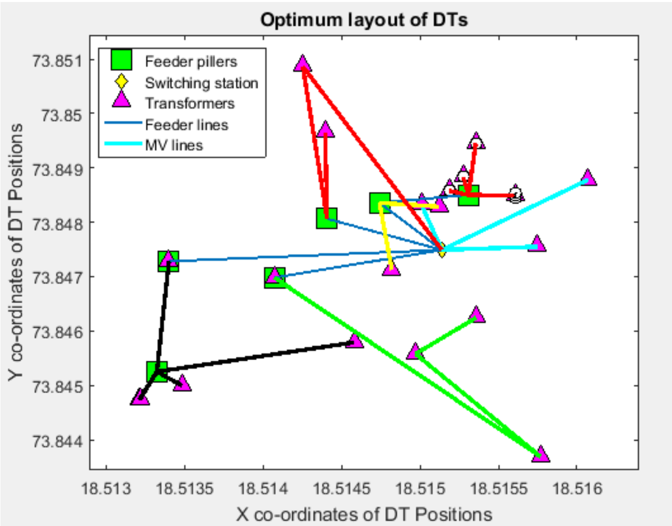

Fig. 4. Optimal and practically feasible locations of 21 DTs after survey

The total cost of optimum position of 21 DTs suggested by GA considering three crossovers as SPC, TPC and UC for AD and CL of DTs is shown in Table .I. The SPC gives optimum result compared to TPC and UC. Total cost is rounded up nearest to the rupee.

TABLE I. COST COMPARISON OF CROSSOVERS

Crossover Type	Total cost for Average Demand (Rs)	Total cost for Connected Load (Rs)
Single Point	3,80,86,58,894	3,99,15,98,949
Two point	3,94,38,09,347	4,00,39,62,913
Uniform	3,80,86,58,958	3,99,15,98,959

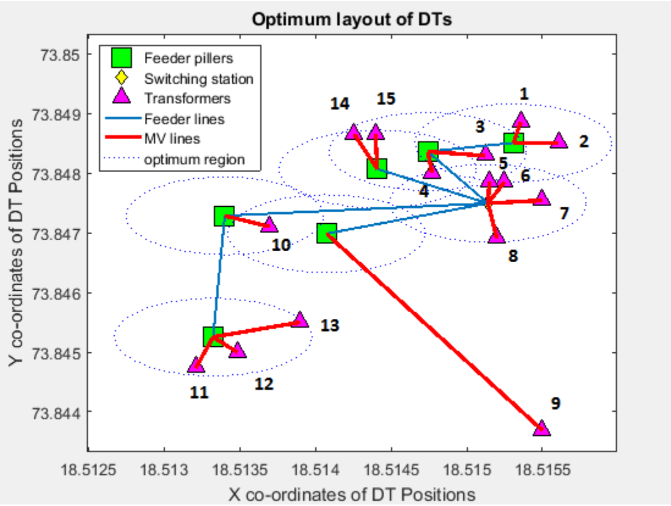

Fig. 5. Optimal and practically feasible locations after survey for 15 DTs

After studying the AD and CL on existing 21 DTs the suggested required quantity of DTs reduces to 15. The quantity of DTs remains 15 for AD and CL but rating differs, refer case V. The information of quantity and rating of DTs in existing and suggested network is given in table II.

TABLE II. DT RATIING AND QUANTITY

DT Rating (kVA)	Existing DT Quantity (Connected Load)	Suggested DT Quantity (Connected Load)	Suggested DT Quantity (Avg. Demand)
50	-	1	1
100	5	1	5
200	5	4	3
315	3	5	3
500	2	4	3
630	6	-	-

C. Simulated Annealing (SA)

This is a probabilistic technique for approximating the global optimum of a given function. SA reduces a minimization of a function of large number of variables to the statistical mechanics of equilibration of the mathematically equivalent artificial multiatomic system. SA serves purpose of solving unconstrained and bound-constrained optimization problems satisfactorily. The global optimization toolbox which handles bound constraints is used [13]-[14]. The convergence of the objective function considering AD is shown Fig.6. The best function and current values are shown but only best value of the function is considered. The best value found considering AD is 3,80,86,58,887 crores, and 3,99,15,98,944 crores considering CL. The best function considering AD and CL is shown in table III. In SA with the help of Reannealing consideration of higher value of objective functions is done by accepting new points and it searches again and hence optimum results are obtained and algorithm do not stuck in local minima.

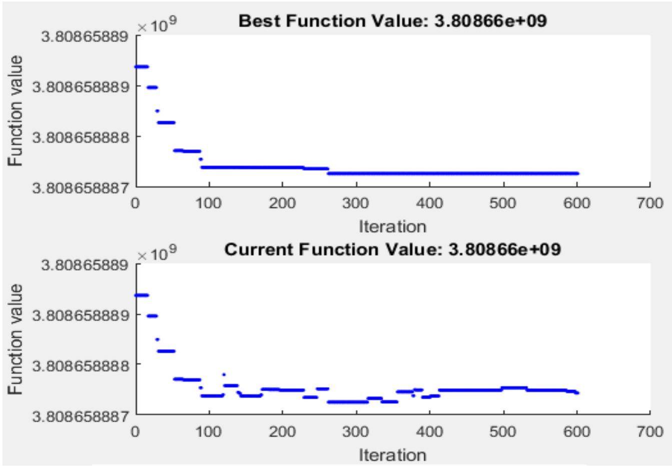

Fig.6. Convergence of function value for average demand

The cost calculation result of existing network obtained by GA is compared with SA method using Global optimization toolbox in MATLAB is shown in table III. Result shows that, the network costs get reduced significantly by placing DTs at optimum location and considering AD. Compared to existing network the GA and SA results are appreciably less and cost effective.

TABLE III. COMPARISON OF RESULTS FOR AD AND CL

Sr. No.	Method	Total Cost for Average Demand (Rs.)	Total Cost for Connected Load (Rs.)
1.	Genetic Algorithm	3,80,86,58,894	3,99,15,98,949
2.	Simulated Annealing	3,80,86,58,887	3,99,15,98,944
3.	Existing network	3,83,13,87,948	4,81,13,03,974

V. Results of Case Study

This section presents mainly five cases with different scenarios. The results will be discussed for cost effective optimal placing, rating, quantity and type of DTs taking into account AD and CL. Aspects as safety, relocation and aesthetic are also considered for optimum practical feasible placing of DTs. Optimization solution includes the practical facts as; (i) considering feasible distances between DTs and load points, (ii) onsite installation feasibility and existing electrical connections. Five cases are explained below;

Case I: This case considers cost of the existing network, as shown in fig.2. The total rating of DTs connected in network is 7225 kVA.
Case II: This case considers cost of the optimum network suggested by GA as shown in fig.3.
Case III: This case considers cost of optimum network suggested after actually site survey. Practically feasible DT locations are identified as shown in fig.4.The cost comparison results are shown in table IV.

In case I, II and III, the DT quantity and ratings remains same only location changes. Results of table IV highlights that case II provides cost effective solution compared to case I. Case III suggests optimum but practically feasible solution, hence recommended.

TABLE IV. DT TYPE, LOCATION AND COST

CASE	DT Placed	Oil Type DT	Dry Type DT	Cost in crores (AD)	Cost in crores (CL)
I	Ground	18	03	3,83,13,87,948	4,81,13,03,974
II	Ground	18	03	3,80,86,58,894	3,99,15,98,949
III	Ground	18	03	3,82,93,45,750	4,80,56,18,878

Case IV: In this case alternative cost solution scenarios are provided for placing of 21 DTs after feasibility study. Table V gives information about DT type (oil, dry and synthetic oil) and total cost when placed on ground and rooftop.

TABLE V. DT TYPE, LOCATION AND COST FOR EXISTING NETWORK

DT Placed	Oil Type DT	Dry Type DT	Synthetic Oil Type DT	Cost in crores (AD)	Cost in crores (CL)
Ground	18	03	00	3,82,93,45,750	4,80,56,18,878
Ground	21	00	00	3,65,52,20,342	4,26,01,21,114
Ground	00	21	00	4,35,23,83,851	5,03,61,01,072
Rooftop	21	00	00	3,65,52,38,399	4,26,01,39,171
Rooftop	00	21	00	4,35,24,01,908	5,03,61,19,128
Ground	00	03	18	4,31,73,55,972	5,54,68,93,015
Ground	00	00	21	4,43,23,00,006	5,10,46,22,285
Rooftop	00	00	21	4,43,23,18,062	5,10,46,40,342

Case V: In this case alternative cost solution scenarios are provided for suggested 15 DTs after performing feasibility study as shown in fig.5. The total rating of 15 DTs considering AD is 3595 kVA and considering CL is 4325 kVA. Table VI gives information as; DT type and total cost when placed on ground and rooftop.

Case IV and V results presented in Table V and VI highlights that; (i) the optimal cost effective solution can be obtained if DTs are replaced as per required quantity, location, rating, and type, (ii) if only oil type DTs are considered instead of dry or synthetic oil type DTs then network cost is less, (iii) the DTs placed on rooftop includes extra cable cost which depends on height of building.

TABLE VI. DTC TYPE, LOCATION AND COST FOR SUGGESTED NETWORK

DTC Placed	Oil Type DTC	Dry Type DTC	Synthetic Oil DTC	Cost in crores (AD)	Cost in crores (CL)
Ground	12	03	00	3,18,17,51,347	4,84,70,89,031
Ground	15	00	00	3,05,51,07,778	4,62,05,36,360
Ground	00	15	00	3,46,18,90,618	5,26,70,29,942
Rooftop	15	00	00	3,05,51,19,766	4,62,05,48,348
Rooftop	00	15	00	3,46,26,21,220	5,26,77,60,544
Ground	00	03	12	3,56,11,64,723	5,51,16,26,100
Ground	00	00	15	3,56,12,09,723	5,56,53,36,134
Rooftop	00	00	15	3,56,12,21,711	5,56,53,48,122

VI. CONCLUSION

A novel optimization model is proposed using GA and SA for DTs connected to 11kV feeder in distribution network considering realistic data. In the suggested model, choice of optimal placement of DTs is obtained by considering present worth of investment, operational, maintenance, insurance and depreciation costs of DTs as well as MV and LV line costs. The investigation of numerical results reveals that the;

●SPC gives optimum cost effective result,
●Cost of network and DT rating reduces appreciably if AD is considered instead of CL during DT installation planning,
●GA and SA suggests the similar results for cost effective optimal placement of DTs,
●The space and aesthetic constraints can be managed efficiently if DTs are placed on rooftop,
●Placing DTs on Rooftop can manage the space and aesthetic constraints efficiently as open space is a costly affair,
●The synthetic oil and dry type DTs have high fire point hence safe, as DTs are normally installed in densely populated area so strongly recommended even though costly.

The work proposes optimize placing, rating, quantity and type of DTs considering average demand and connected load. This model gives distribution planner a user-friendly tool, for getting cost effective results. The Approach presented has been carried out on brown-field, which can be easily adapted on green-field as well as for cost efficient network expansion.

REFERENCES

[1] Rodrigo Sempértegui, Joaquin Bautista, Robert Griño Cubero, Jordi Pereira, “Models and procedures for electric energy distribution planning. A review”, Elsevier IFAC publications, p.p. 395-400, 2002.

[2] Dale M. Crawford, Stewart B. Holt, " A mathematical optimization technique for locating *and* sizing distribution substations, *and* deriving their optimal service areas", IEEE Transactions on Power Apparatus and Systems, vol. PAS-94, no. 2, March/April 1975.

[3] Navpreet Singh Tung, Sandeep Chakravorty, "Optimized power distribution planning a review", International journal of electronics and electrical engineering vol. 2, no. 4, december, 2014.

[4] Hongwei Dai, Yixin Yu, Chunhua Huang,Chengshan Wang, Shaoyun Ge, "Optimal Planning of Distribution Substation Lacations and Sizes -- Model and Algorithm", IEEE,TENCON'93 BEIJING, 1993, pp.351-354.

[5] E. Masud, "An Interactive Procedure for Sizing and Timing Distribution Transformer Using Optimal Techniques", IEEE Trans. PAS 93. pp.1281-1286 January 27-February 1, 1974, New York.

[6] M.R. Haghifam, M. Shahabi, "Optimal location and sizing of HV/MV substations in uncertainly load environment using genetic algorithm", Electric Power Systems Research 63 (2002) 37–50.

[7] Crawford D.M., Holt Jr S.B., "A Mathematical Optimization Technique for locating and Sizing Distribution Substations, and Deriving their Optimal Service Areas", IEEE Trans. PAS, 94, 2, 1975, pp.230-234.

[8] Aoki K., Nara K., Satoh T., Kitagawa M., Yamanaka K., "New Aproximate Optimization Method for Distribution System Planning" , IEEE Trans.Power System, 5, 1, 1990, pp.126-132.

[9] Miranda V., Ranito J.V., Proença L.M., "Genetic Algorithms in Optimal Multistage Distribution Network Planning", IEEE Trans. Power System, 9, 4, 1994, pp.1927-1933.

[10] Lin W.M., Su Y.S., Tsay M.T., Genetic Algorithm for Optimal Distribution System Planning, IEEE, 1998, pp.241-245.

[11] Muhammad Humayun, Bruno Jorge Oliveira Sousa, Amir Safdarian, Mubbashir Ali, Merkebu Z. Degefa, Matti Lehtonen and Mahmud Fotuhi-Firuzabad, " Optimal Capacity Management of Substation Transformers Over Long-Run", IEEE Transactions on Power Systems, Vol.3, No.31, January 2016.

[12] IEEE guide for loading mineral-oil-immersed transformers and step voltage regulators, IEEE Std. C57.91-2011 (Revision of IEEE Std. C57.91-1995), Mar. 7, 2012.

[13] *Power transformers part 7: loading guide for oil-immersed power transformers*, Int. Std. IEC 60076-7, 2005.

[14] M. Ramezani, H. Falaghi, M. Parsa Moghaddam, and M.-R. Haghifam, "Genetic based algorithm for optimal placement of distribution transformer", IEEE Power Engineering Society General Meeting (2006),

[15] G. Thampson, D. Wall, "A branch and bound model for choosing optimal substation location", IEEE Transactions on PAS-100 5 (1981) 2683_/2687.

[16] Jorge E. Mendoza, Miguel E. López, Héctor E. Pe˜na, David A. Labra, "Low voltage distribution optimization: Site, Quantity and Size of distribution transformers", Elsevier Electric power system research publications, June 2012.

[17] H.M. Khodr, Jorge A. Melián, Adolfo J. Quiroz, Daniela C. Picado, José María Yusta, Alberto J. Urdaneta, "A probabilistic methodology for distribution substation location", IEEE Transactions on Power Systems 18 (February (1)) (2003) 388–393.

[18] Nitasha Soni, Dr. Tapas Kumar, "Study of various crossover operators in Genetic Algorithm", International Journal of Computer Science and Information Technologies, Vol. 5 (6) , 2014.

[19] I. Ramirez-Rosado, J.-L. Bernal-Agustin, Genetic algorithms applied to the design of large power distribution systems, IEEE Transactions on Power Systems 13 (May (2)) (1998) 696–703.

[20] Jamal Moshtagh, Hannah Jannaty, "An Enhanced Model for Siting, Sizing, Timing and Determining the Service Area of MV/LV Transformers, 2010 IEEE.

[21] Sasitharan Kannan, Mau Teng Au, "Probabilistic Approach in Sizing Distribution Transformers", 2010 IEEE.

[22] H. Lee Willis, Hahn Tram, Michael V. Engel, Linda Finley, "Selecting and applying distribution optimization methods", IEEE computer applications in power, 1996.

[23] Allan C. Nerves, Gonzalo B. Julian, Jr, "Optimal feeder configuration in expansion planning using simulated annealing", IEEE 2007.

[24] Victor Parada, Jacques A. Ferland, Miguel Arias, *Senior Member, IEEE*, and Keith Daniels, "Optimization of electrical distribution feeders using simulated annealing", IEEE transactions on power delivery, vol. 19, no. 3, July 2004.

[25] Jovan M. Nahman and Dragoslav M. Peric, " Optimal Planning of Radial Distribution Networks by Simulated Annealing Technique", IEEE Transactions on Power Systems, Vol.23, NO. 2, July 2008.