Optimal Placement of Feeder Automation Equipment (FRTU) by using Immune Algorithm

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Abstract— **The paper presents a technique to investigate the problem associated with the optimal location of feeder remote terminal units (FRTUs) within distribution networks. RTUs in a SCADA system gather information and are responsible for sending/receiving and executing the commands issued from the control center. Immune algorithm is used as an optimization technique to select the optimal locations of FRTUs. The objective function is to minimize the total cost including the investment costs and the customer interruption cost. The investment costs of FRTUs represent installing and relocating FRTUs. The optimal location of the FRTUs is based on the load type, load capacity, important customers and failure rate. The distribution network of Moulali located at Hyderabad A.P, India is taken to demonstrate the validity of the proposed method and the capability and efficiency of the algorithm in locating the FRTUs.**

Keywords: Optimization, Immune algorithm, FRTU, Distribution System Reliability.

I. INTRODUCTION

During recent years electrical power distribution systems are moving towards a new destination where reliability and quality of the supply got much importance. Most electricity interruptions are due to failures in the distribution network. In a competitive market, service quality and reliability have become an essential part of the business. Greater number of outages in addition of long outage durations requires great man power to resolve the problem, delaying the equipment services. Delay in equipment services would steeply increase the equipment failure rates consequently more number of interruptions.

Recently it has been noticed that electrical distribution automation mainly strives for deep decrease in interruption time, hence economical consequences.

In non-automated electrical distribution systems, for every outage, much time is spent to locate the fault, isolate it from the rest of the network, and restore supply to healthy section of network. This outage duration time, extends to hours even days depending on scale of the network, large scale or small scale, operation limits such as population density or congested areas.

In today's world even a few seconds of supply outage will cost irreversible technical and economical damage to industries.
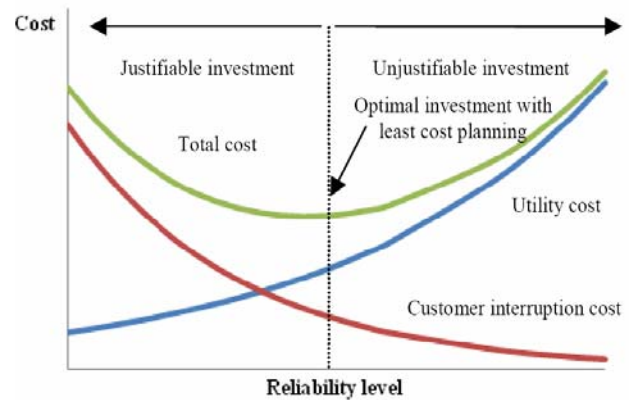

Figure 1. Basic concept in Power System Reliability

This outage time, though it depends on distribution system structure/topology, fault detection capability, network reconfiguration, can be reduced to a small value through some maneuver operations which are all dependent on Feeder Remote Terminal Unit (FRTU).Therefore need for supervisory control and a data acquisition of electrical power distribution system seems indisputable. It benefits or allows an automated system to remotely monitor and coordinate commands to have immediate response and switching. But at the same time we can observe from the figure 1 full automation is not economical. So placing them optimally is necessary [1].

RTUs in a SCADA system gather information and are responsible for sending/receiving and executing the commands issued from the control center. Practically approached, having faced with the huge number of loads in a real distribution power system, the complex and computationally demanding nature of the problem leaves the way to the optimal placement candidate faraway. Hence, finding the appropriate numbers and locations of FRTUs is exceedingly intricate in nowadays complicated power distribution system. Few papers which work towards optimal placement of RTUs are presented in [2]-[4].

The proposed algorithm, immune algorithm, was applied to a real distribution network. The effectiveness of the immune algorithm (IA) to solve complicated optimization problems has been illustrated in many previous case studies [5]-[8]. A genetic algorithm (GA) based procedure for solving the optimal placement of Remote Terminal Units is presented in [9].

On comparing to the genetic algorithm, the IA provides the following advantages [10] to solve the optimization problems.

1) It operates on the memory cell, guaranteeing rapid convergence.

2) The diversity of the immune system is embedded using an affinity calculation.

3) The injection of vaccines into the individuals of generations reveals a remarkably increased convergence process.

In this paper, the objective function for the optimal placement of FRTU's is expressed as the antigen inputs. The feasible solutions are represented as the antibody for the IA to solve the optimization problem. The genetic operators including crossover and mutation are then processed for producing antibodies in a feasible space. Through operating IA on the memory cell, a very rapid convergence will be obtained during the searching process by applying the information entropy as a measure of diversity for the population to avoid falling into a local optimal solution.

II. MODEL FORMULATION

The following basic assumptions are used to formulate the objective function:

• The main feeder has four different types of customers: residential, commercial, industrial and important-place customers such as hospitals and government.

• The known information of each load point is the type of customer, permanent failure rate (FR), mean repair time, and the connected kVA.

• The length of each section is given in meters.

The objective is to minimize the total cost of the system including the investment cost and the customer interruption cost. The investment cost represents the location and relocation of the FRTUs including life cycle cost of FRTUs that are installed on the main feeder. The customer interruption cost includes the summation of customer and electrical power utility outage costs. The outage costs are related to all possible faults at each section for different possibilities of FRTUs existence.

For a fault at section i, the objective function is to minimize the following equation:

$$Minimize\ TCS = CIC + INVC$$

Where TCS is the total system cost, CIC is the customer Interruption cost, INVC is the investment cost.

$$CIC = \sum_{i=1}^{n}[(UC_i] + UC_i)$$

And INVC includes the total cost for location and relocation of Feeder Remote Terminal Units.

Now the Objective function can be written as

$$Min\ TCS = \sum_{i=1}^{n}[(IC_i] + UC_i) + P \times CR + Q \times CRR$$

(1)

Where IC_i is the Customer outage cost due to outage in section i, UC_i is the utility outage cost due to outage of section i, P is the total number of FRTUs and Q is the total number of FRTUs initially installed and have to be relocated, CR is the cost of an FRTU and CRR is the cost of relocating an FRTU.

In the above objective function defined by Eq. (1) three terms can be defined, CIC representing the customer and utility costs, $P*CR$ representing the cost for installing FRTUs and $Q*CRR$ is the total cost for relocation during the process.

A. Customer outage cost due to a fault at section i

This cost is the summation of customer outage costs in every section due to a fault at section "i". Each section has its outage cost depending on its amount of load, proportion of load types, and corresponding outage durations.

$$IC_i = \lambda_i(C_{i1}L_1 + C_{i2}L_2 + C_{i3}L_3 + \cdots + C_{in}L_n)$$

(2)

Where λ_i is the failure rate of section i(failures/year) C_{ij} is the customer cost multiplier in every section due to a fault at section i, and L_j is the amount of load at each section.

B. Customer cost multiplier of load at section j due to a fault at section i.

Customer cost multiplier is the cost per kWH:

$$C_{ij} = \gamma_{ij}(f_{re} \times Re_i + f_{im} \times Im_i + f_{co} \times Co_i + f_{in} \times In_i)$$

(3)

Where γ_{ij} is the outage duration in section j due to a fault in section i. Re_i is the load percentage of residential customers, Im_i is the load percentage of important customers, Co_i is the load percentage of commercial customers, In_i is the load percentage of industrial customers. F_{re} is the average cost damage function of residential customers per kWH [11]. F_{im} is the average cost damage function of important customers per kWH. F_{co} is the average cost damage function of commercial customers per kWH. F_{in} is the average cost damage function of industrial customers per kWH.

C.   Utility outage cost due to a fault at section i

This cost is the summation of utility outage costs of all sections due to a fault at section "*i*".

$$UC_i = \lambda_i(B_{i1}L_1 + B_{i2}L_2 + B_{i3}L_3 + \cdots + B_{in}L_n)$$

(4)

Where B_{ij} is the utility cost multiplier of section *j* due to a fault at section *i*.

D.   Utility cost multiplier of load at section j due to a fault at section i

$$B_{ij} = \gamma_{ij}(C_{re}(Re_i + Im_i) + C_{co} \times Co_i + C_{in} \times In_i)$$

(5)

Where C_{re} is the average sales price of residential customer per kWH, C_{co} is the average sales price of commercial customer per kWH, C_{in} is the average sales price of industrial customer per kWH.

E.   The outage duration of service interruption of section j due to a fault at section i

The service duration of each section depends on the amount of load in this section, number of sections, position of sections and amount of load that can be transferred.

$$\gamma_{ij} = \begin{cases} T_f + T_{r'}, & i = j \\ T_f + T_r, & i > j, \sum_{k=j}^{n} L_k > L_T \\ T_f + T_{s'}, & i > j, \sum_{k=j}^{n} L_k \leq L_T \\ T_{f'}, & i < j \end{cases}$$

(6)

Where T_f is the time to find and isolate the fault location, T_r if the time taken to repair the fault. T_s is the time for switching to an alternate source.

III.   IMMUNE ALGORITHM

The immune algorithm (IA) has been widely used to solve the optimization problems by applying the same operating principle of human immune system. The capability of IA method for pattern recognition and memorization does provide a more efficient way to solve the discrete optimization problem as compared to the genetic algorithm. The objective function is represented as antigen inputs, while the solution process is simulated by antibody production in the feasible space through the genetic operation mechanism (i.e., crossover and mutation). During the actual operation, IA prevents the degenerative phenomena arising from the crossover and mutation processes, thus making the fitness of population increase steadily [12].The calculation of affinity

between antibodies is embedded within the algorithm to determine the promotion/suppression of antibody production. The immune operators including vaccine injection and immune selection are performed, in the IA process as shown in Fig.3. Through the IA computation, the antibody which

	1	2	…	J	…..	M-1	M
Antibody i	Bit 1	Bit 2		Bit j		Bit M-1	Bit M

Figure 2.   Data structure of genes during FRTU placement.

most fits the antigen is considered as the solution for the optimization problem.

TABLE I.   BINARY STRUCTURE AND DESCRIPTION OF A GENE.

Bit	Value	Description
Binary	0	FRTU doesn't exit
	1	FRTU exists

An immune algorithm based decision making [13] is proposed in this study to find the optimal locations of FRTUs for the new developing distribution system. The population of memory cells is a collection of the antibodies (feasible solutions) accessible toward the optimality, which is the key factor to achieve fast convergence for global optimization. In this paper, the genetic coding structure for the immune algorithm is adopted and the diversity and affinity of the antibodies are calculated during the decision making process to find the FRTU placement. The data structure of the gene is represented as a bit with binary coding in each gene

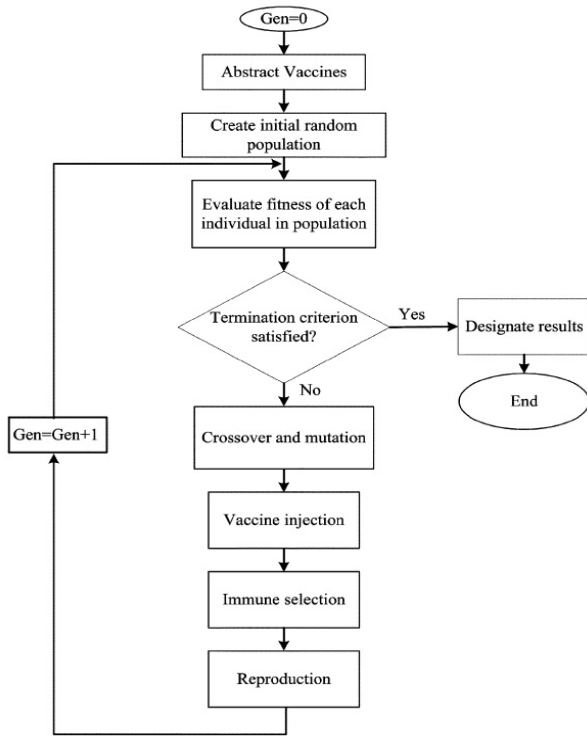structure. Data structure of a gene is as shown in fig 2.

Figure 4.   Flow chart to find optimal solution by using IA

A.   Abstraction of vaccines

Vaccines are abstracted from the prior knowledge or information of the problem. According the situation of case study following vaccines can be extracted

Vaccine 1: The node serving to highly loaded customer is considered for FRTU placement. This vaccine is injected into all the individuals with probability one.

Vaccine 2: The nodes which frequently experience outages in service zone is assigned with an FRTU. This vaccine is also injected into all individuals with probability one.

Vaccine 3: The nodes serving important customers and also customers which are remote as hard to access are considered for FRTU placement. This vaccine is injected into all individuals with probability one.

B.   Diversity

The diversity is measured between the antibodies and it is increased to prevent local optimization during the optimal FRTU placement search. For each evolving generation, the new antibodies are generated to strengthen the diversity of antibody population in the memory cell. The entropy E_j of the jth gene (j=1, 2,…, M) is defined as:

$$E_j = -\sum_{i=1}^{N} P_{ij} \log P_{ij}$$

(7)

where N is the quantity of antibodies and P_{ij} is the probability that the jth allele comes out at the jth gene. If all alleles at the jth gene are the same, the entropy of the jth becomes zero. From (7), the diversity of all genes is calculated as the mean value of informative entropy.

$$\bar{\bar{E}} = \frac{1}{M} \sum_{j=1}^{M} E_j$$

(8)

C.   Affinity

The affinity of antibodies is an important index for the immune algorithm during the optimization process. If the affinity of some antibodies is the same during immune process, it will influence the searching efficiency of optimization for the planning of FRTU placement. Two types of affinity are calculated for the proposed IA in this paper. One is the affinity between antibodies:

$$(AB)_{ij} = \frac{1}{1 + E(2)}$$

(9)

where $E(2)$ is the information entropy of these two antibodies. The genes of the ith antibody and the jth antibody will be the same when $E(2)$ is equal to zero. The affinity between the ith antibody and the jth antibody, $(AB)ij$, will be within the range [0, 1]. The other one is the affinity between antibody (candidate of optimal placement of FRTUs) and antigen (the objective function).

$$(Ag)_i = \frac{1}{1 + TCS_i}$$

(10)

where TCS_i is the total system cost evaluated by (1) to represent the connection between the antigen and antibody i. The antigen with the maximum affinity $(Ag)i$ will be the optimal FRTU placement within the feasible space.

D.   Computation procedures

The process to solve the objective function for optimal placement of FRTUs is simulated by the interaction of antibody and antigen in the immune algorithm. During evolution of genes, the candidates of FRTU placement planning with high affinity are selected and included in the memory cells, which will be used to generate new candidate planning. The computation procedure of IA method is executed as follows:

1)   Recognition of antigens

To solve the optimal FRTU placement planning, the total system cost of each possible solution subject to operation constraints is calculated in this step. The binary/integer mixed coding is adopted for the antigen pattern to represent

the relationship of genes and physical FRTU placement planning in the objective function for the computation
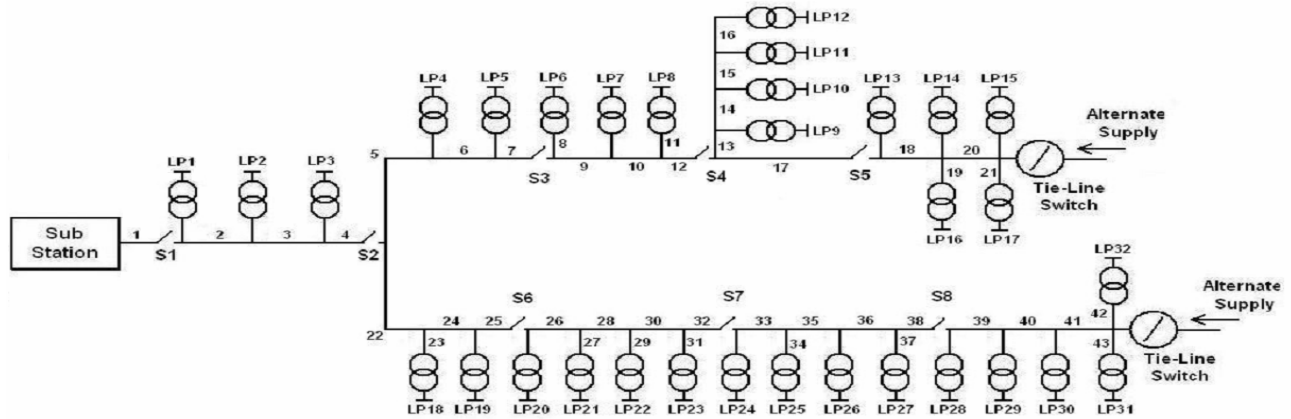

Figure 5.   Single Line Diagram of the test feeder

process.

2) Production of initial antibody population

A random number generator is applied to generate the antibodies in the feasible space. All of antibodies and a group of genes are considered to form the antibody pool. Some of the antibodies will be from the memory cells with higher affinity during the searching process to generate a new set of antibodies. Each antibody represents a possible solution for the optimal FRTU placement in a feeder.

3) Calculation of Affinity

In this step, the affinity between antibodies *(Ab)ij* and the affinity between antibodies and antigens *(Ag)i* are calculated by (9) and (10) respectively as the references in the following evaluation process.

4) Evaluation and selection

The antibody having high affinity with the antigen is added to the new memory cells. To maintain the size of memory cells and ensure the speed of convergence, the diversity of memory cells is calculated and the antibody with high affinity (namely, *(Ab)ij* close 1) is removed so that the violation of size constraint of memory cells can be prevented. A roulette selection algorithm is implemented by considering the affinity of antibodies to form a new antibody pool by spinning the desired roulette. Since most of the selected antibodies have higher affinities with the antigen, the average affinity of the new population pool will be higher than that of the original pool to obtain better evolution during IA optimization process.

5) Crossover and mutation

After the selection of antibody generation, the operations of crossover and mutation for the new generated antibodies are performed. The crossover operation is performed by applying the one-cut-point method, which randomly selects the mating point and exchanges the gene arrays of the righthand portion of the mating points between two antibodies. The mating operation will prevent the search

process from local optimization by increasing the diversity of antibody population. According to the predefined mutation rate, mutation is executed to perform the occasional random alteration of the value for an antibody position.

6) Decision of optimal FRTU placement

During the immune process, the antibody having high affinities with the antigen will be added to the new memory cell, which will be maintained after applying the operation of crossover, mutation and selection for the population. The search process of optimization continues until no further improvement in relative affinity can be obtained and the antibody with the highest affinity in the memory cell will be the optimal strategy for FRTU placement.

IV.   CASE STUDY

In this case study, the proposed immune algorithm is implemented with Matlab on an Intel Core 2 Duo personal computer. This method has a few parameters that are to be selected before execution. They include pool size, crossover rate and the mutation rate. Based on simulation tests and observation the values are selected for rapid convergence. Pool size, crossover rate and the mutation rate are determined as 60, 0.8, and 0.1 respectively.

A sample 33/11 KV (HCL feeder, Moulali Substation) feeder is selected for computer simulation in this study. Fig. 4 depicts the single-line diagram of the test feeder with 43 sections and 32 load points. This distribution feeder consists of small scale and large scale industrial loads. This feeder supplies power to 32 load points out of which 20 are small and 12 are large scale industries.

This feeder taken from Moulali substation located in Andhra Pradesh India, parameters for this feeder like failure rate of each section and amount of load at each load point are taken from [14][15] and proceeded for calculations. There are many technical parameters that affect the decision for the optimal locations of the FRTUs. The main factors include the loss minimization, failure rate and load importance (e.g. large hospitals and government). The observation of such special nodes may be necessary to ensure reliability operation.

Therefore, the important nodes are assigned special importance in the optimization process. In addition, the positions of the loop-open switch and sections, which has the highest failure rate, are considered as important nodes. Importance weights are defined for each important load centre to differentiate between their importances. These factors are included, through vaccination process, to achieve results that achieve most possible benefits of the optimization process.

TABLE II.   TCS WITH NO FRTU

Position	S1	S2	S3	S4	S5	S6	S7	S8	TCS (Rs)
Bit	0	0	0	0	0	0	0	0	48,55,368.0

Observing the table 2 we can have the TCS (Total System Cost) as 4855368.0 Rs, with no FRTUs installed. From table 3 we have TCS as 2927634.0 Rs, by placing FRTUs at all suitable locations. This is far less than TCS with no FRTUs.

A better performance can be achieved by placing FRTUs at optimal locations, with a low value of TCS which is 2774856.86Rs. Table 4 shows the optimal location of FRTUs and the corresponding TCS. By placing FRTUs optimally, it can be observed that there is a decrement in the TCS (Total System Cost) by about 43% when compared with no FRTUs installed.

TABLE III.   TCS WITH FRTUs AT ALL LOCATIONS

Position	S1	S2	S3	S4	S5	S6	S7	S8	TCS (Rs)
Bit	1	1	1	1	1	1	1	1	29,27,634.0

Table 4 shows the two combinations of FRTU placement, initial and optimal. Initial combination of FRTU placement is the best solution obtained using the deterministic method. Optimal combination is obtained using the immune algorithm. We can observe there is a change of 5% in the total system cost. From this change we can say immune algorithm gives the best solution than deterministic method.

TABLE IV.   TCS WITH INITIAL AND OPTIMAL FRTU LOCATIONS

Position	S1	S2	S3	S4	S5	S6	S7	S8	TCS (Rs)
Initial	1	1	0	0	0	1	0	0	29,05,803.99
Optimal	0	1	0	1	0	1	1	0	27,74,856.86

If we think to place multiple FRTUs, immune algorithm gives the solution for multiple placement of FRTUs also. Table 5 gives the best configurations for different number of

FRTU placement. For example, when placing two FRTUs only, we get 6, 2 as the best locations. Any other configuration would yield high Total system cost.

Plotting those values obtained in table 5 would yield a graph that can be depicted as in fig 5. From the graph we can observe that the bottom most point give the optimal solution and so the corresponding TCS (Total System Cost).

If we would like to plot the TCS (Total System Cost) for all the combinations we can obtain the graph as shown in the fig 7.

On the abscissa we have all the possible combinations after the vaccination process. On ordinate we have the TCS of the corresponding combination.

TABLE V.   TCS AGAINST NO. OF FRTUs AND ITS LOCATIONS

No of FRTUs	Best Configuration	TCS (Rs)
0	-	48,55,368.0
1	6	30,88,013.0
2	6,2	27,76,803.0
3	6,3,7	28,19,290.0
4	6,2,7,4	27,74,856.0
5	6,2,7,3,5	27,93,734.0
6	6,2,7,3,5,8	28,51,343.0
7	6,2,7,3,5,8,4	29,27,634.0
8	6,2,7,3,5,8,4,1	30,56,634.0

From figure 6, on observation, we can see that the optimal allocation of FRTUs using immune algorithm was different from the solution that was obtained from deterministic method.
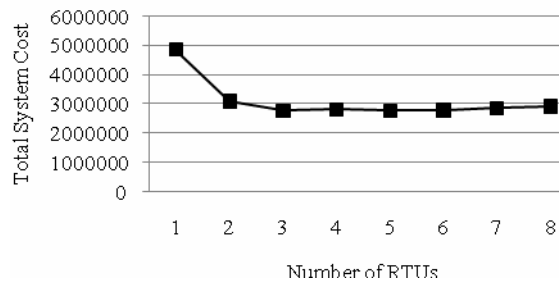

Figure 6.   TCS against no. of FRTUs

On comparing TCS (Total System Cost) of the solution obtained from both the methods, immune algorithm gave the best least solution. Thus from all the above, we can say that immune algorithm, by using all the operators (crossover, mutation, vaccination) would yield a best solution in least time.
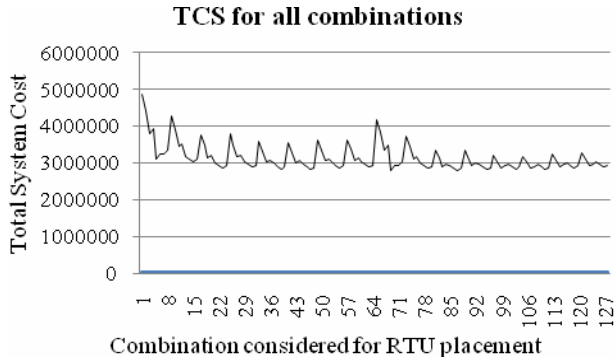
TCS for all combinations

Figure 10. TCS against all combinations

V. CONCLUSION

In this paper an attempt is made to achieve optimal FRTU placement, since power system economical pressures have led to the fact that complete feeder automation of a distribution power system is neither affordable nor economically justifiable. An immune algorithm has been successfully applied to a practical distribution network for finding the optimal location of FRTUs.

The proposed method takes into account the total system cost which includes the capital cost for installing, relocation of FRTUs and also the customer interruption cost. The priori knowledge of the problem is abstracted as some vaccines based on the levels of the priority customers. Rapid convergence is obtained during search process by injecting these vaccines into the individuals of generations. With the proposed placement of FRTUs, the customer interruption time has been reduced very effectively with enhanced service reliability. From the case study it is also observed that immune algorithm taking total cost of system as objective function resulted in a more optimal solution than that of deterministic method.

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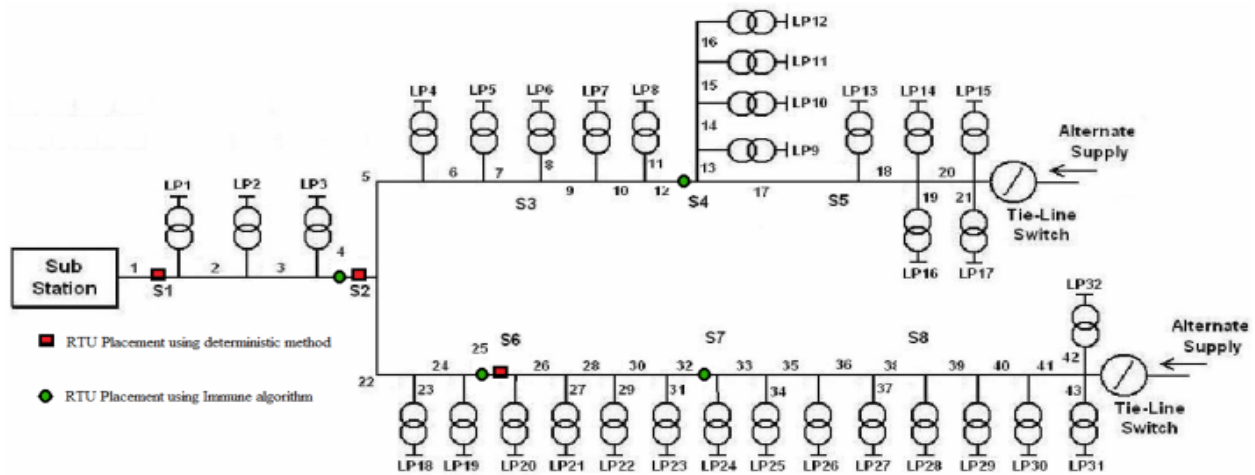
Figure 8.   Feeder indicating FRTU locations

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