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Reduction of Energy Loss Based On Network Reconfiguration and Distributed Generation in Radial Distribution System

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Abstract— This paper presents a new methodology of codification to the conventional genetic algorithm (GA) used in network reconfiguration method, to minimize the real power loss and as well as to improve the bus voltage profile of the given distribution system configuration in the presence of distributed generation (DG). In network reconfiguration for loss reduction, the solution involves a search over relevant radial configuration. The optimization problem is subjected to system constraints consisting of load-point voltage limits, radial configuration format, no load-point interruption and feeder capability limits. In this paper, a method, based on genetic algorithm (GA) to determine the minimum configuration is presented. A genetic algorithm (GA) is a search or optimization algorithm based on the mechanics of natural selection and natural genetics. But some problems, specially related to a codification that is able to represent and work with a complex multi constraint and combinatorial problem such as this one have prevented the use of the full potential of these algorithms to find quality solutions for large systems with minor computational effort. Hence, the main innovation of this method is that new types of crossover and mutation operators are proposed to generate the initial population (descendent), such that the best possible results are obtained, with an acceptable computational effort. This paper proposes a solution to the problem, with a new codification and using an efficient way for implementing the operator of recombination to guaranty, at all times, the production of new radial topologies. The developed methodology is demonstrated by a 33-bus radial distribution network with distributed generation (DG).

Index Terms—Loss reduction, distribution network reconfiguration, genetic algorithms, radial distribution, network representation, distributed generation.

I. INTRODUCTION

Electrification in the early 20th century dramatically improved productivity and increased the well-being of the industrialized world. No longer has luxury-now a necessity-electricity powered the machinery, the computers, health-care systems and the entertainment of modern society.

Electrical power distribution is the portion of the power delivery infrastructure that takes the electricity from the highly meshed, high voltage transmission circuits and delivers it to customers through the primary substation and distribution network/circuit (distribution system). Due to uncertainty of system loads on different feeders, which vary from time to time, the operation and control of distribution is more complex particularly in the areas where load density is high. Power loss in a distributed network will not minimum for a fixed network configuration for all cases of varying loads. Hence, there is a need for reconfiguration of the network from time to time and this can be done by switching mechanism, which will be discussed in the proceeding. So, the network management in this area has distinct features in power loss reduction and as well as voltage profile too.

The reconfiguration of a distribution system consists of changing its topology through resetting the status of the switches located at certain points of the network. Due to great number of switches that are present in the distribution systems, the determination of an optimal configuration in order to meet such objectives/features constitutes a very hard problem to be solved by the traditional optimization techniques. One of the major problem in the reconfiguration criteria is, the representation of radiality constraint in the mathematical calculations, which means the network must be operated in a radial manner, otherwise, the entire system will lose it's one of the operating constraint. In recent years several methods have been proposed for solving the reconfiguration problem. Civanlar *et al*. [2] developed a simple expression for the total real power losses variation in a radial network. Heuristics rules to reduce the number of switching options to be considered were used. In Shirmohammadi and Hong [3] the minimum real power losses for radial networks was obtained by a sensitivity index "Optimum Flow Pattern" (OFP). The OFP is computed on a purely resistive distribution network, neglecting the reactive components of the branch impedances, with all switches closed.In Goswami and Basu [5], the concept of OFP was also used; however, switches are closed to form one loop at a time. Thus, one tie-line is closed and, with the information of the OFP

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vector, one switch of the loop is opened to restore the radial structure.

Several works can be found in the literature using several artificial intelligence techniques. Among the most used techniques are the Genetic Algorithms. These algorithms were idealized by Holland in 1975, with the objective of explaining and formalizing mathematically the process of adaptation of natural systems. GAs have been increasingly applied to the resolution of electrical engineering problems due to its efficiency and relative simplicity of implementation. However, the success of a GA relies on an efficient coding of the solution process and on the correct application of the genetic operators (crossover and mutation). The traditional GA tries to mimic nature in the best possible way, considering the limitations imposed by the existing computational systems. An important such limitation is the time available for its processing.

In nature, the reproduction, selection, and mutation processes can last up to millions of years. In the case of electrical engineering applications, the answer to a problem must be found in some minutes, or even seconds. Therefore, it is necessary to develop the efficient algorithms to provide an answer to the problem within the smallest time possible. The traditional genetic algorithm uses a chromosome composed by binary numbers and the crossing among the chromosomes allow the change of the genetic material, preserving the population diversity. The mutation operator acts directly in chromosome, changing the value of one of their genes in way to provide an additional form of population diversity.

However, the traditional genetic algorithm can't be applied in the resolution of reconfiguration problem due to the fact the mutation and crossover operators, applied to the chromosome that represents a certain configuration, could destroy the radial structure of the system. Therefore, the main contribution of the new codification is that, always, generates radial topologies after the implementation of the genetic operators.

The genetic algorithm presented is set up to solve the reconfiguration problem, but the proposal can be easily generalized to solve other kinds of problems of the same family.

II. PROBLEM FORMULATION FOR DISTRIBUTION NETWORK RECONFIGURATION MODEL

The main intention of distributed line reconfiguration is to minimize the real power loss with taking the operating constraints into the consideration. Hence, the power loss can be formulated as

$$\text{M}in\ L = \sum_{i=1}^{nr} R_i \frac{P_i^2 + Q_i^2}{V_i^2} k_i \qquad (1)$$

Where L = Total power loss
nr = Number of branches
R_i = resistance of branch i
P_i = real power flow through branch i
Q_i = reactive power flow through branch i
V_i = voltage magnitude at bus i
k_i = thermal stability constraint.

The objective function in (1) is subject to the following constraints.

1) Power flow equations:

$$P_i = \sum_{j=1}^{nb} | Y_{ij} V_i V_j | \cos(\theta_{ij} + \delta_j - \delta_i) \qquad (2)$$

$$Q_i = -\sum_{j=1}^{nb} | Y_{ij} V_i V_j | \sin(\theta_{ij} + \delta_j - \delta_i) \qquad (3)$$

s.t. nb = number of buses
Y_{ij} = element (i,j) in bus admittance matrix
V_i , V_j = voltage of bus i and bus j
θ_{ij} = angle of Y_{ij}
δ_i , δ_j = voltage angle of bus i and bus j,

2) Bus voltage limits:

$$V_{min} \le V_i \le V_{max}$$

where V_{min} and V_{max} are the minimum and maximum voltage magnitudes at bus I,

3) Branch current thermal stability constraints:
Current magnitude of each branch should be within the limits

$$k_i|I_i| \le I_{i\,max}.$$

4) The network topology should always be radial,

5) The reconfiguration process can't result an island operation.

III. PROPOSED GENETIC ALGORITHM FOR RECONFIGURATION

A modified genetic algorithm has been implemented in this paper, which is to the genetic algorithm presented by Chu-Beasley [11] to solve the Generalized Assignment Problem (GAP). The Chu-Beasley algorithm presents significant changes in the characteristics when compared to the traditional genetic algorithm. This algorithm is mainly useful to solve multiconstraint problems, and also when, many unfeasible solutions are generated.

The proposal presented in this paper, modifies the algorithm presented in [11] in two ways: 1) the initial

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population generation must be carried out in an efficient way, 2) heuristic algorithms used in the local improvement step will improve the quality of the descendent by eliminating the unfeasibility, the diversity concept can also be extended additionally.

The flowchart of the algorithm used by MATLAB lab programming is shown in the below Figure.1.0.

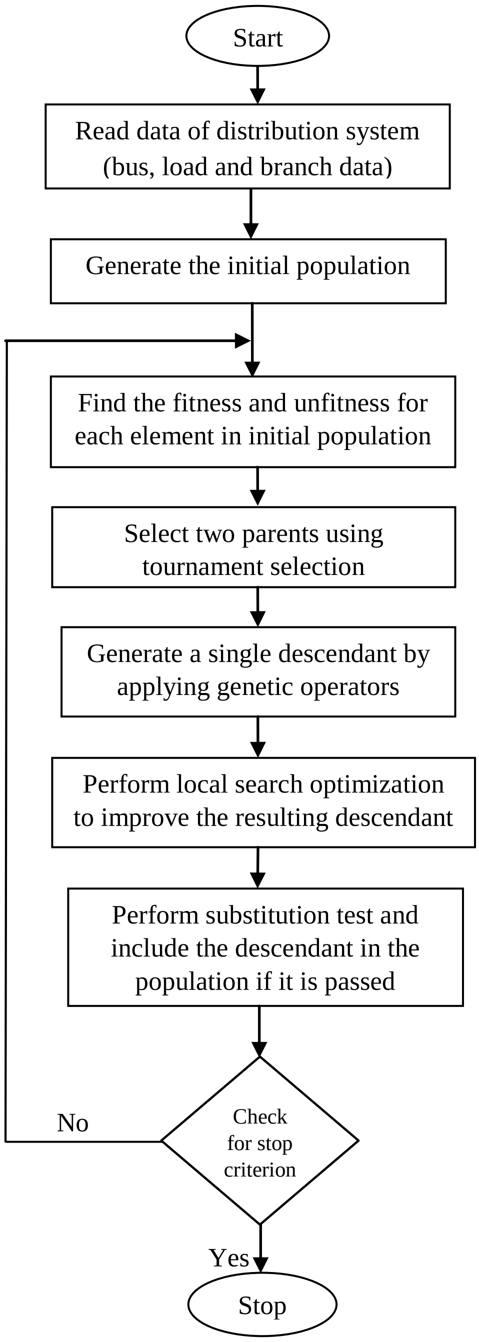

Fig. 1.0

The flowchart of the algorithm used by MATLAB lab programming is shown in above Figure.1.0.
The way in which the selection and the substitution tests are carried out is very important in the algorithm. In the selection, only the fitness vector is used (the original objective function), ranking the quality of the solutions without testing the unfeasibilities. In the substitution test, the quality and the diversities are ranked. Thus, the improved descendent generated could be included into the population, as long as it is unlike the other members in the population, insuring the diversity among the population elements.

The algorithm proposed presents several key factors, but the most important one is the strategy used to preserve the complete diversity of the current population. Consequently, a set of radial topologies for the network reconfiguration problem for loss reduction will be available in the final population. Hence, for highly complex problems it could be interesting to increase the size of the population.

IV. CODIFICATION PROBLEM

Codification is an adequate way to represent a single element which belongs to the search space of a problem, thus, it represents the information of a solution proposal. The codification should allow the solution proposal to be clearly identified and must allow the objective function of that particular solution to be found. For the particular case of genetic algorithms, the codification must also permit the genetic operators to be implemented in an efficient way.

Practically all the evolutionary algorithms presented in specialized literature, in terms of network reconfiguration for loss reduction problem, use a codification vector which, after being decoded, identifies a radial topology of the distribution system. Once the radial topology is identified, the objective function and the unfeasibilities can be calculated solving a radial power flow.

The main difficulty appears when the genetic operators are implemented, especially the recombination operator. In almost all the proposals presented previously in specialized literature, especially in the early works using genetic algorithms, the recombination of two vectors, which represents radial topologies, do not generate a new radial topology. On the other hand, the mutation operator can be easily modified to generate radial topologies. Because of this, several optimization proposals to solve the reconfiguration problem avoid using the recombination operator, and are implemented using only the mutation operator.

In this work, a new codification proposal is presented which permits the genetic operators of recombination and mutation to always generate radial topologies.

A). Individual configuration representation:

Fig. 2 shows a 33-bus radial distribution system. Switches 33,34,35,36 and 37 are tie switches, being initially open (dashed lines). Fig. 3 illustrates the chromosome coding used in this paper.

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In fact there are two ways of representation. The one at the upper part of the figure characterizes the simplified representation and the one at the lower part, the complete representation.

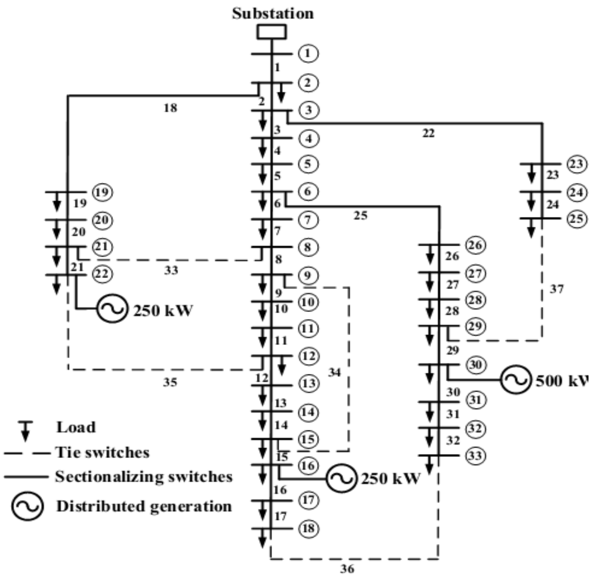

Fig.2.0 Single line diagram of 33 bus radial distribution system

Simplified Codification:

Parent 1

Ch =					
	33	34	35	36	37

Parent 2

Ch =					
	6	10	13	27	31

Complete Codification:

Parent 1

sch = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16............29 30 31 32 33 34 35 36 37

1	1	1	1	1	1	1	1	1	0	0	0	0	0	0

Parent 2

sch = 1 2 3... ...6 ..... 10......13 .... 20 .... 27.... 31 32 33 34 35 36 37

1	1	1	0	0	0	1	0	0	1	1	1	1	1	0

Fig.3.0. Individual configuration representation

In the complete coding system, closed switches and open switches are represented by 1 and 0, respectively. In the simplified coding, only the open switches are represented.

In the proposed method, the simplified coding system is used for storage purposes and also for presenting the results, whereas the complete coding is used in the computation process itself.

B) *Codification Proposed:*

The proposed codification consists, coding the branches of the distribution system in codification vector as shown in below Fig. 4.0.

Fig. 4.0 Codification Proposed

In this codification, for a system of *nb* buses and *nl* branches, the first (*nb* − 1) elements represent the branches in the radial topology, which are defined as the X_1 set and the other (nl − *nb* + 1) elements, represent the connecting branches and are defined as set X_2 , with '*s*' as the separation point between the two sets.

Using this codification, it is possible to generate an initial population formed only by radial topologies, and implement the recombination and mutation operators to generate new radial topologies from the radial topologies in the initial population. It is obvious that the decoding process for the codification proposal is trivial, because the radial topology is already formed by the elements of X_1.

An example with the 33-bus test system is used as shown in Fig. 4. This topology could be represented as follows in Fig. 5. It must be observed that in the codification shown in Fig. 5 the first (*nb* − 1)=32 branches correspond to the branches in the tree (continuous gross line in Fig. 4) and the (nl − *nb* + 1) = 5 remaining branches correspond to the linking branches (dotted thin line in Fig. 4). It must also be observed that the order in which the branches were ordered in the two subgroups X_1 and X_2 is irrelevant.

This proposal guarantees that if the initial population is made up of radial configurations, then it is possible to develop recombination and mutation operators that preserve the radial topology in the descendants generated. This codification proposal and the implemented recombination are the main contributions of this paper, since they eliminate the generation of loop topologies and allow descendants to be generated in a similar way of natural genetic recombination.

C). Generation of the initial population:

A simple algorithm to generate radial topologies in the initial population is given below.
N is the set of nodes that are added in the tree at initial stage and *B* is the set of branches of the system which not yet chosen in the processes of radial topology generation.

Step 1. $N = \emptyset$, $X_1 = X_2 = \emptyset$, *B* is initially formed by all branches.
Step 2. Assign the substation node to *N*.
Step 3. Find all the branches belonging to *B* with one of their vertex in *N*.
Step 4. Select one branch which identified in step (iii).
Step 5. If a loop is generated by the branch which is selected

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in step (iv), then include it in X_2 otherwise include it in X_1 and add it's opposite vertex in *N*.

Step 6. Update the *B* by removing the chosen branch.

Step 7. If the no of elements of X_1 is less than ($nb - 1$) then go to step (iii) Otherwise, go to step (viii).

Step 8. If $B = \varnothing$ add all the elements of *B* to X_2.

A simplified flow chart for proposed codification of genetic algorithm is given in below Fig.5.

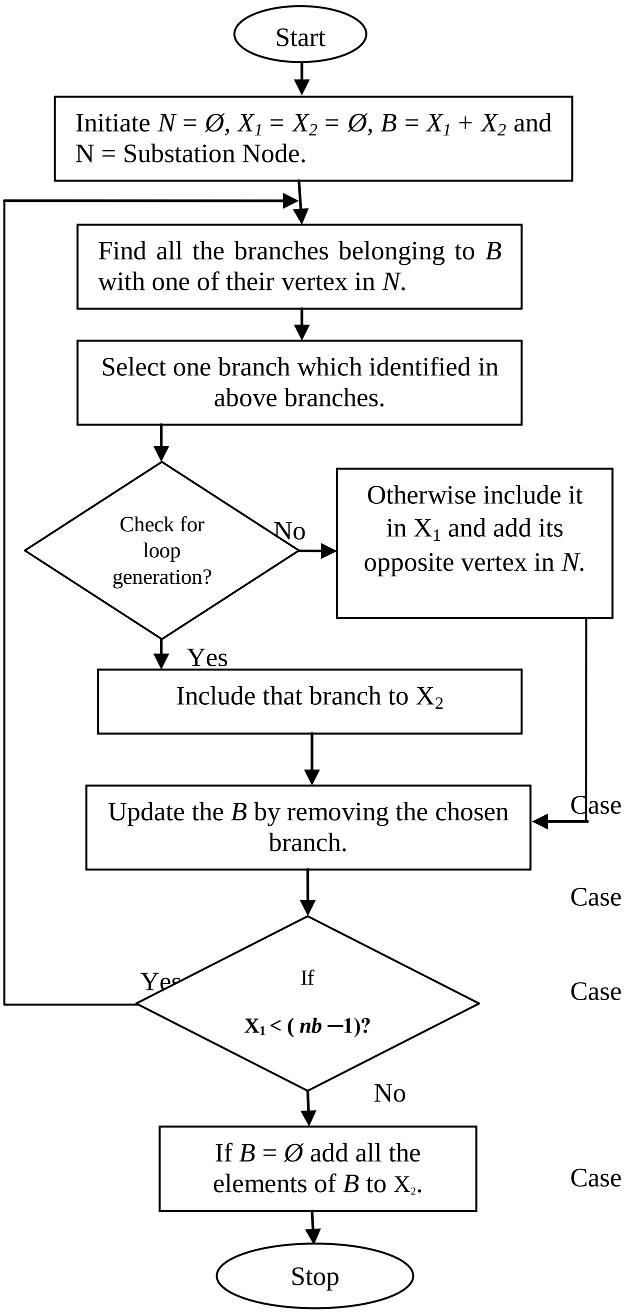

Fig.5.0. Flow Chart for proposed codification

At the end of the calculation, (X_1 , X_2) represents the radial topology. The algorithm proposed will always generate radial configuration.

D). Recombination and Local Improvement:

The recombination process used in traditional genetic algorithm concept is applied with this proposed codification is as given below.

1) Randomly select one parent as main generator and other will be second generator. Select one recombination point, *n* , randomly between *n*1% and *n*2% of the length X_1.

2) Copy all the first *p* elements from the first generator to form the descendent and in the secondary generator, eliminate all the elements which already exists in the descendent.

3) Each remaining branch in the secondary generator, which forms a loop, include it in X_1 otherwise in X_2.

After the recombination process, the descendant generated is submitted to a local improvement phase. For this step, heuristic derivation presented in [2] was used.

V. SIMULATION RESULTS

The proposed method is tested with 33-bus radial distribution system as shown in Fig. 2.0. The load and branch data are given in Table. A and Table. B respectively.

At the initial stage of the given system, all the sectionalizing switches are closed and tile line switches are opened. The total loads of the system are 3.71 MW and 2.3 MVAr. The current carrying capacity of branch No.1-9 is 400 A, and of other branches including tie lines are 200A. V_{min} and V_{max} are 0.95 p.u. and 1.05 p.u., respectively. A maximum iteration count of 100 is taken for the proposed genetic algorithm. Four types of conditions are examined and are as given below:

Case 1: The system is without feeder reconfiguration and distributed generation.

Case 2: In this condition, the feeder is reconfigured, just by the available sectionalizing and tie line switches.

Case 3: It is same as condition.1 given in above except that there are three small power producers who can supply only firm active power to the distribution system by their DG units. The locations of producers are shown in Fig. (2).

Case 4: Here, the feeder reconfiguration with proposed algorithm is combined with condition. 3.

The numerical results for the above mentioned four conditions are summarized in below given Table.1.0.

It is seen that, a considerable value of decrease in the real power loss when the network reconfiguration is done and is further decreased when both, the feeder reconfiguration

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and distributed generator (DG) are applied to the given network.

	Case1	Case 2	Case 3	Case 4
Sectionalizing switches to be open	--	6,10, 12, 31	--	6,10, 13,27, 31
Tie switches to be closed	--	33, 34, 35, 36	--	33,34, 35,36,37
Total power loss (KW)	202.80	127.60	119.50	73.70
Minimum voltage (p.u)	0.9466	0.9746	0.9714	0.9869
Percentage reduction of loss	--	37.08	41.07	63.65

Table 1.0 Results of cases studied

Distributed generation, from the perspective of losses, impacted positively on the performed distribution network, achieving values of 63.65%. This is due to the changes in the branch currents with the presence of DG units.

Normally, the DG units will helps in reduction of considerable value of current flow through the feeders. Hence DGs contributes to the power loss minimization, this is mainly because they are usually placed near to the load centers being supplied.

In case 4, where the feeders are reconfigured and the voltage profile is improved, all the constraints to be satisfied to achieve the objective function are not violated.The bus voltage profile for before and after reconfiguration along with DGs for 33-bus radial distribution system is shown in below Figure.6.0.

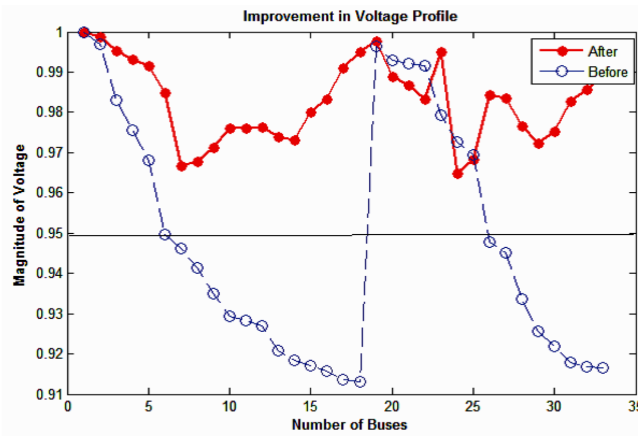

Fig.6.0. Bus voltage profile for before and after reconfiguration with DGs

VI. CONCLUSIONS

The main contributions of this work are the codification proposal and a new way to implement the recombination process. The codification proposal allows to represent and modify a radial topology, so that it is easy to generate other radial topologies without much effort.

The use of a metaheuristic algorithm for the generation of the initial population allowed the reduction of the search space, making the application of the algorithm possible for large distribution systems.

This process is accomplished with a simple but powerful recombination process that allows two parent configurations to share their characteristics in a radial descendent, and finally, the diversity of the population is maintained with an efficient local improvement step.

The distributed generation contributes to loss reduction in the obtained topology. But, some bus voltages violate the minimum voltage constraint. Such a problem can be remedied by network reconfiguration.

The result of all these elements can easily solve the distribution network reconfiguration problem using the proposed efficient codification to minimize the real power loss and voltage profile improvement in the presence of DGs, in real life networks.

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APPENDIX

Table. A. Load data for 33-bus distribution system

Bus No.	P_L (kW)	Q_L (kVAr)	Bus No.	P_L (kW)	Q_L (kVAr)
2	100	60	18	90	40
3	90	40	19	90	40
4	120	80	20	90	40
5	60	30	21	90	40
6	60	20	22	90	40
7	200	100	23	90	50
8	200	100	24	420	200
9	60	20	25	420	200
10	60	20	26	60	25
11	45	30	27	60	25
12	60	35	28	60	20
13	60	35	29	120	70
14	120	80	30	200	100
15	60	10	31	150	70
16	60	20	32	210	100
17	60	20	33	60	40

Table B. System data for 33-bus distribution system

Branch Number	Sending end bus	Receiving end bus	R (Ω)	X (Ω)
1	1	2	0.0922	0.0470
2	2	3	0.4930	0.2512
3	3	4	0.3661	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	0.7115	0.2351
8	8	9	1.0299	0.7400
9	9	10	1.0440	0.7400

Table B. (Continued)

Branch Number	Sending end bus	Receiving end bus	R (Ω)	X (Ω)
10	10	11	0.1967	0.0651
11	11	12	0.3744	0.1298
12	12	13	1.4680	1.1549
13	13	14	0.5416	0.7129
14	14	15	0.5909	0.5260
15	15	16	0.7462	0.5449
16	16	17	1.2889	1.7210
17	17	18	0.7320	0.5739
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3555
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3084
23	23	24	0.8980	0.7091
24	24	25	0.6960	0.7071
25	6	26	0.2030	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9338
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9629
31	31	32	0.3105	0.3619
32	32	33	0.3410	0.5302
34	8	21	0.0000	2.0000
36	9	15	0.0000	2.0000
35	12	22	0.0000	2.0000
37	18	33	0.0000	0.5000
33	25	29	0.0000	0.5000

BIOGRPAHIES

Santhosh Kumar Aspari pursuing his M.Tech in Electrical Power Systems Engineering from JNTUA college of Engineering, Pulivendula-516390, A.P, India. Currently, he is working on his project under the guidance of Mr. J. Sreenivasulu, Asst. Professor, JNTUACEP.

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