Restore Power Losses using the Hybrid of the Minimum Spanning Tree and Backward Forward Sweep

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Keywords: Backward Forward Sweep, Load Flow Analysis, Minimum Spanning Tree, Prim's Algorithm, Reconfiguration, Radial Distribution Network, Power Losses, Voltage Profile.

Abstract: Reconfiguration of the electrical network is a famous tool still used to reduce losses. This method focused on the changing of the topological state of the switching lines in the system. In this paper, the aim is to restore the active power loss and upgrade the voltage profile at each node. This problem will be solved for the case of the network without distribution generation units (DGs) and the case of the network with the presence of the DGs because the injection of this last one at a non-optimal node gives rise to unnecessary losses and the violation of the voltage out of the range limits. This reconfiguration will be done by using the prim's algorithm. Next, we apply the Backward Forward Sweep approach (BFS), aiming to check our proposed constraints. By selecting the algorithm, total losses were chosen as an objective function by considering the resistance of the edges as the weight of lines. The electrical network of 33 nodes with and without DGs was presented to prove the efficiency of our proposed method. The simulation results prove that this algorithm is perfect for finding good results (reduce losses, and improve voltage).

1 INTRODUCTION

For a few years, various electrical societies have been guided towards the optimising of the unnecessary expenses resulting from the higher losses in the distribution system due to the lower voltage in this section. This study based on the reconfiguration strategy by changing the topological state of the switching lines from 1- closed line to 0- open line and vice versa. This study treated two cases: network with and without the existence of the Distributed Generation units (DGs). For this reason, in the next part, we present much research concerning these two kinds of networks.

For instance, in the case of the electrical network without the presence of the DG units, we have the study of the author of (Alvarez-Hérault & Marie-Cécile, 2010), has select to use the problem of the travelling salesman to find the new reconfiguration-by using the Christofide algorithm. On another side, the author of (Ahuja & Pahwa, 2005) have tried to solve this problem by using the ant colony algorithm due to its maturity to converge quickly and the performance of the solution found. Furthermore, the authors of (Enacheanu, 2008)have noted that the genetic algorithm found the perfect results, by optimizing the power loss, improving the voltage profile, and minimizing the undistributed energy.

Besides, the authors of (Zhongfu Jiang, et al., 2017) have studied the optimization of the annual power generation cost and transmission cost; the suggested algorithm is a mixed-integer linear programming problem. Otherwise, it is important to present the study of (Dodu, 1978) where the author has chosen to solve the problem with the column generation method to minimize the investment, exploitation, and failure cost. Moreover, the authors of (Leonardo W. Oliveira, et al., 2015) have chosen to use the PSO algorithm which is an evolutionary technique, aiming to restore the active power loss in the radial electrical network. Even the authors of (Hasmaini, Zalnidzham, Salim, Shahbudin, & Yasin,

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M'dioud, M., Bannari, R. and Elkafazi, I.
Restore Power Losses using the Hybrid of the Minimum Spanning Tree and Backward Forward Sweep.
DOI: 10.5220/0010729400003101
In *Proceedings of the 2nd International Conference on Big Data, Modelling and Machine Learning (BML 2021)*, pages 108-118
ISBN: 978-989-758-559-3

2019) have proposed to apply the graph theory by using Kruskal's algorithm to find the minimum spanning tree, and they have compared their solution with (Leonardo W. Oliveira, et al., 2015). Always in the same vision, we found, the study of the authors (TD S. , 2017), where he considers the reactive power as weights of edges to minimize losses, on the other hand, the authors of (Tomoiaga, Chindris, Sumper, Villafafila-Robles, & Sudria-Andreu, 2013) have chosen the genetic algorithm that gives a perfect quality at a lesser time.

As already presented, this study examines even the network with the presence of the DG units. For this reason, we introduce in the next part some studies which solve this problem. However, it is important to note that the DG is still a good technology that provides power at or near the consumer, such as solar panels and combined heat and power (Peng, 2004). The integration of the DG units into the electrical system helps to minimize losses on the transmission and distribution lines (Carreno, Romero, & Padilha-Feltrin, 2008). This technology is even applied to reduce the quantity of power that must be produced at the centralized power plants. Also, the DG units have an important role in reducing the environmental impacts resulting from the centralized generation (Salama & El-Khattam, 2004).

To define the quantity of power demanded, the author (Multon, 1999) has defined the forecasts of power consumption. Furthermore, (Strasser, et al., 2014) have analyzed the injection of renewable energy sources, then they have followed a method to control the energy and request the demand; at the end, they have discussed the important role of the smart grid to check the consistency between the consumer demand and the supply of the electrical companies. In the same vision, the author of (Caire, 2004) have treated in their study the impacts of the injection of the DG units on the quality of the electrical system (risk of violation the voltage range limit), and it is important to find a solution which allows the injection of DG units in distribution systems with an elevated injection rate. Otherwise, the authors of (Le Xie & Marija D.Ilic, 2008) have proposed an optimal control algorithm for distribution systems by applying the Predictive Control Model to reduce the cost of production.

To detect an optimal reconfiguration of the network with the presence of the DG units, the electrical companies have selected to search for new strategies, aiming to enhance and minimize the exploitation of the energy by reducing the losses.

In this side, we find the study of the author (Juma, 2018) who has selected the shark smell optimization to minimize the total losses. Also, the authors (Sivkumar Mishra, Debapriya Das, & Subrata Paul, 2014) have presented a simple algorithm for a network with DG units by considering this last one as a negative load. Moreover, the authors (Gallego, Carreno, & Padilha-Feltrin, 2010) have discussed the difference between the PQ bus and the PV bus, with the first one is the case when the inserted power to the network is considered as a negative load, but the second one is where the reactive power of the DG units depends on the voltage requested and the active power injected is considered constant. Moreover, the authors (Ogunjuyigbe, Ayodele, & Akinola, 2016) have presented in their work the drawbacks resulting of the insertion of the DG units on the features of the network, such as the active power loss and the voltage profile.

In the same issue, the authors (Chidanandappa, Ananthapadmanabha, & H.C., 2015) have found a new reconfiguration of the electrical system with the presence of the DG units where the value of the losses and the voltage profile are reduced by using the combination of genetic algorithm and the backward/forward sweep. Otherwise, the authors (Ahmad, Asar, Sardar, & Noor, 2017) have examined in their study the reliability analysis of the radial electrical system in two cases (without and with the presence of the DG units). Nevertheless, regarding the study of the authors (Ma, Li, Zhang, Li, & han, 2017), where they have selected to use the hybrid of the prim algorithm and the particle swarm optimization algorithm aiming to reduce losses in the presence of the DG units.

The authors (Hasmaini, Zalnidzham, Salim, Shahbudin, & Yasin, 2019) and (TD s. , 2017) have proposed that the weight of the line is the reactive power to minimize losses. In this article, we have used the resistance of edge as the weight of line due to the effect of this factor on the power loss, and the objectives are to reduce losses and improve voltage profile.

To solve this issue, we have proposed to divide the paper into five main sections. Section two introduces the objective function and the constraints of our problem. The third section gives the flowchart of our proposed algorithm and presents case studies used to perform our algorithm. Section four gives the simulation results and presents a comparative study. Furthermore, in the end, we conclude our study and present the possible future research.

2 PROBLEMATIC

The origin of the problem comes at the peak demand, is means where the electrical companies operate at maximum; this last one gives rise to many losses that give unnecessary expenses. Furthermore, the lower value of voltage in the distribution network gives a significant loss in this part of the network compared with the transport network. When the load increases, these losses increase. In this study, we examine the issue of the reconfiguration of the distribution network by using MATLAB software to find the minimum spanning tree to automatically generate a network structure with fewer losses.

2.1 Objective Function and Constraints

Our main objective is to minimize the active losses cost, which is given by the equation:

$$\text{Min } K * P_j = \min K * \sum_{m \epsilon L} R_m * I_m^2 \quad (1)$$

Altenatively, K is the cost of the active losses; equal to 100$/MWh (Hossein Moarrefi, 2013). P_j is the total losses of the network, L is the set of network lines, and I_m is the current of the line m, R_m is the current of the line m.

Where the k is a constant, so minimize cost is mean to minimize the losses $\sum_{m \epsilon L} R_m * I_m^2$

Subject to the following constraints

a. Kirchhoff's law:

$$\sum I * A = 0 \quad (2)$$

Where; I: row vector of current of each line of network and A: incidence matrix of the network

b. Voltage range limit:

$$\left|(V_{jn} - V_j)/V_{jn}\right| \leq \varepsilon_{jmax} \quad (3)$$

V_{jn} nominal voltage, V_j is the voltage of bus j and ε_{jmax} is tolerance limit (Enacheanu, 2008) (+/-5% for HTA and +6%/-10%BT)

c. current range limit :

$$I_m \leq I_{m,maxadm} \quad (4)$$

I_m: current of edge m and $I_{m,maxadm}$: current limit of line m.

To find the solution, we combine the prim's algorithm to find the minimum spanning tree and the backward/ forward sweep to apply load flow aiming to check the constraints (Saad Ouali, 2020).

2.2 Proposed Algorithm

In this paper, we consider the network as a graph, and we use the graph theory to solve this problem by using the prim's algorithm; this last one is an algorithm applied to search the minimum spanning tree of a network. We select this method due to its feature of high-speed switching circuits.

The prim's algorithm helps to find the set of edges that constitute a tree with minimum total weight also connects all the nodes. In our case, it helps us to find a tree with the total resistance of the tree is optimized.

To apply the prim's algorithm, we start by selecting a random initial node from the bus set. Then we construct the tree by adding at each iteration the line of the minimum weight that connects the tree to another node. Figure 1 shows how the prim's algorithm operates.

```
Input: graph G = (X, E, W) & Output: tree A = (X, T) of minimum spanning
                    // Initialization
resistance = 0
S = {1} // set of nodes connected. The first node choosed arbitrarily
T = Ø     // set of edge
                   // main Loop
For iter from 1 to N-1 do
        Find edge [u, v] of weight minimum w (u, v), with u ∈ S and v ∉ T
resistance (iter +1) = resistance (iter)+w (u, v)
End for
Return
```

Figure 1: Prim's algorithm.

2.3 Backward Forward Sweep

This algorithm of the Backward Forward Sweep (BFS) is used to check the constraints that the system must respect. We choose this algorithm due to its advantages: it easy to implement and uses simple mathematic equations to find the current and the voltage. In this paper, we have used the method of BFS improved by the authors of (Saad Ouali, 2020).

To implement this method, the algorithm needs two inputs: line data and load data. Also, this algorithm is focused on three main steps:

1. First, we start from the last node.
2. After we used equation 5 to calculate the nodal current: at each node "i" is calculated by:

$$I_i^k = conj((P_{n-i} + Q_{n-i})/\ V_{n-i}^k),\quad i=1,2,\ldots n \tag{5}$$

Where $S_i = P_i + j * Q_i$ is the power inserted at node i, and V_i^k is the voltage of bus i from iteration k.

3. Then we apply the Backward sweep: we start from the last branch and do this calculation:

$$J_{n-i}^k = -\,conj((P_{n-i} + Q_{n-i})/\ V_{n-i}^k)\ + \sum_r J_{n-r}^k,\quad r=1,\ldots \tag{6}$$

Where $\sum_r J_{n-r}^k$ is current in edges downstream node "i".

4. Next, we apply the Forward sweep: we start from the origin node and calculate the bus voltage by employing the equation 7:

$$V_i^k = V_{i-1}^k - Z_i * J_i^k\quad i=2,3,\ldots,n \tag{7}$$

Where Z_i is the impedance of edges "i-1,i"

5. Go to step 2 and repeat all these steps until code checks constraints described in the above equations (2), (3), and (4).

2.4 Reduce Losses using Prim Algorithm

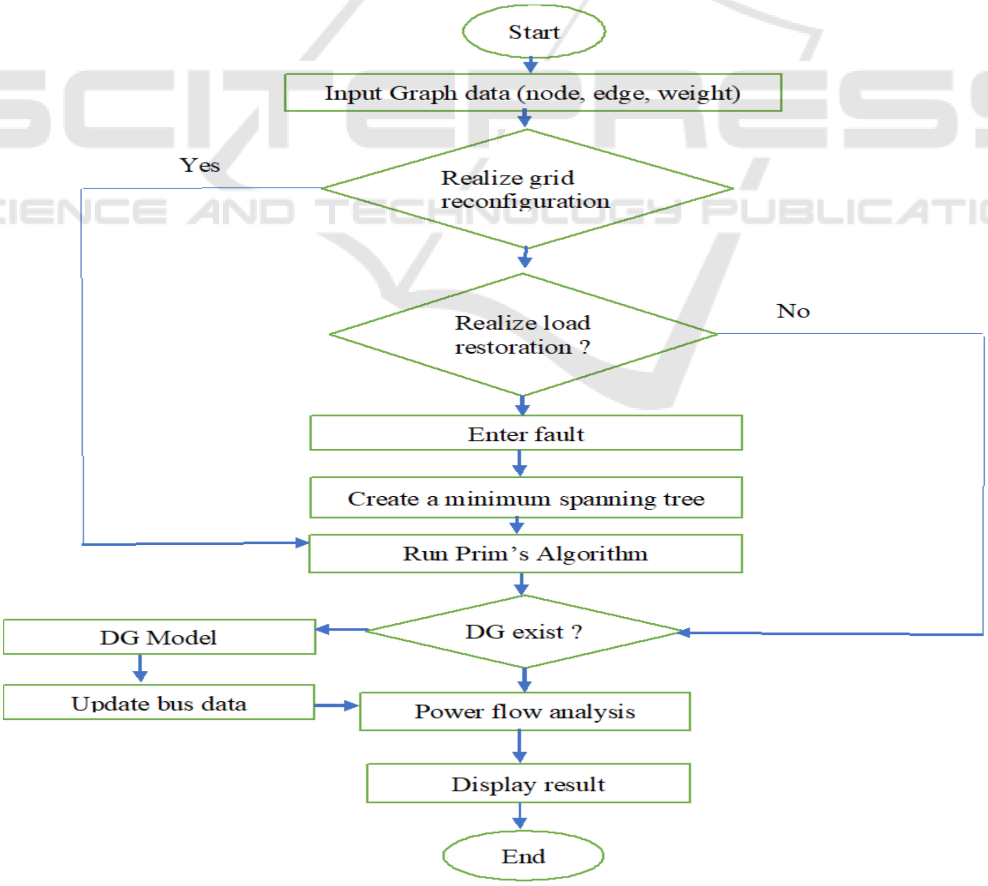

Figure 2: Flowchart of the proposed algorithm.

Figure 2 presents our suggested method to minimize losses. To apply this method, we need to have the line and load data of the network (impedance of edges, active power, and reactive power of the buses) also the location and size of the DG units.

Our proposed algorithm is focused on three main steps:

Step 1: start by initializing the line and load data.

Step 2: create the minimum spanning tree by using the prim's algorithm (already described – figure 1)

Step 3: if DG units exist, update the load data of the bus where DG is connected and apply load flow analysis described in section 2.3.

Else Run load flow analysis until the algorithm checks the constraints.

2.4.1 Networks without DGs

To check the reliability of our proposed algorithm, we apply the electrical distribution network of 33 buses. The electrical and topological features of this network are taken from the reference of (Baran & Wu, 1989), the table 4 in appendices shows the line data and load data of the standard electrical network.

Figure 3 presents the reconfiguration of the network of 33 buses before reconfiguration. With the total reactive power equal 2.3 Mvar, the losses value before reconfiguration equal 15.17% from the total power, and the total active power equal 3.715 MW. The network works at the nominal voltage 12.66 kV, and the apparent base power is 100 MVA.

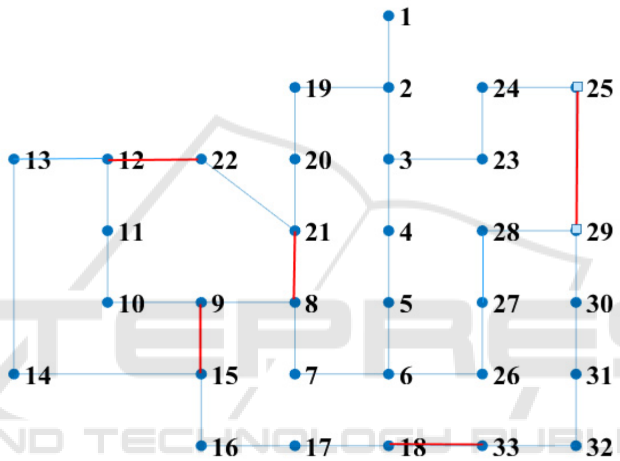

Figure 3: Network IEEE '' 33 bus before reconfiguration''.

This electrical system is constituted from 33 buses, and 37 edges, where we have 32 close edges, and 5 open edges. As shown in figure 4, the red lines are the set of the open switches.

2.4.2 Network with DGs

The second case is the network with the existence of the DG units, in this paper, we assume that we have 4 DGs. Table 1 gives the data of the DG units injected.

Table 1: DGs data (Hossein Moarrefi, 2013).

Location(bus)	Size (MW)	Power factor
28	0.1	0.95
17	0.2	0.95
2	0.14	0.98
32	0.25	0.85

As already described, the weight of the line, in this case, is the resistance. So, the result before and after the update of the line and load data is the same because the injection of the DG has not any impact on the resistance.

Otherwise, regarding the insertion of the DG units, we must update the new active power and reactive power of the node where the DG is injected, then we apply the load flow analysis. For this reason, we use the following equations 8, 9, and 10 (Seif, 2014).

$$P= P_{load} - P_{DG} \quad (8)$$

$$Q= Q_{load} - Q_{DG} \quad (9)$$

$$P_{DG} = a^* Q_{DG} \quad (10)$$

So, in this study, we consider the DG units as a negative load, as shown in figure 4:

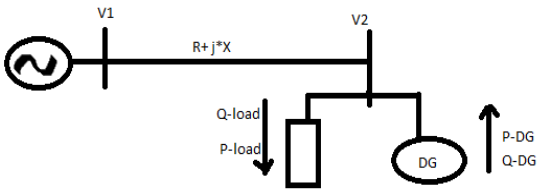

Figure 4: DG connected as a negative load to the bus.

After insertion of the DG unit, the new value of the losses defined by equation 11:

$$P_{line-loss} = \mathrm{R} * ((P_{load} - \mathrm{P}_{DG})^2 + ((Q_{load} - (\pm Q_{DG}))^2)/V_2^2 \quad (11)$$

with:

R is the line resistance.

$P_{line-loss}$ presents the line losses.

P_{load} is the active power consumption of the load.

Q_{load} is the reactive power consumption power.

(P_{DG}, Q_{DG}) present the active and reactive power output of distributed generation.

a: is the power factor of DG.

To check the performance of our proposed algorithm, a comparative study is done.

3 TEST AND RESULTS

3.1 Case without DGs

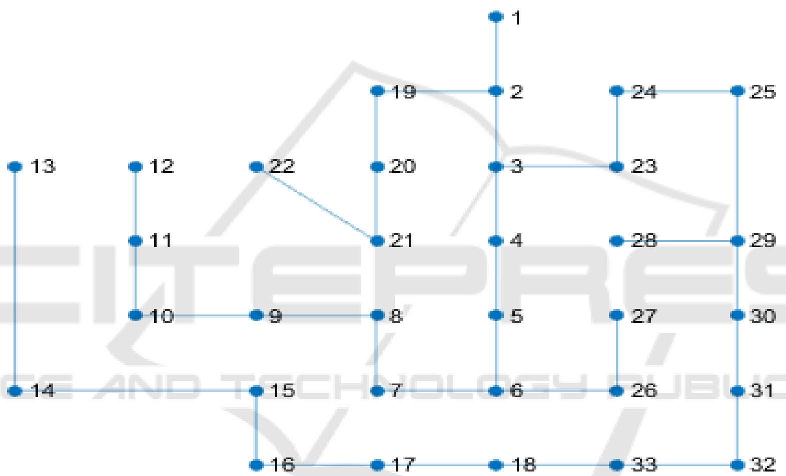

Figure 5: Test system in MATLAB.

Table 2: Comparative analysis.

	Tie line	Power losses Mw	Minimum p.u.Voltage	Bus No of minimum p.u. voltage	Time S
Base case	33- 34-35-36-37	0.2024	0.7717	33	-
Prim's (proposed)	12-27-33-34-35	0.12489	0.95133	25	0.2235
Prim's (TD s. , 2017)	7-8-13-29-37	0.1165	0.9446	30	-
Kruskal's (Mohamad, 2019)	16-27-33-34-35	0.1786	0.9282	17	0.8566
BPSO & MSSO (JUMA S. A., 2018)	7-9-14-32-37	0.139	0.9479	18	34.63
Redefined Genetic	7-10-14-36-37	0.2007	0.8330	33	-

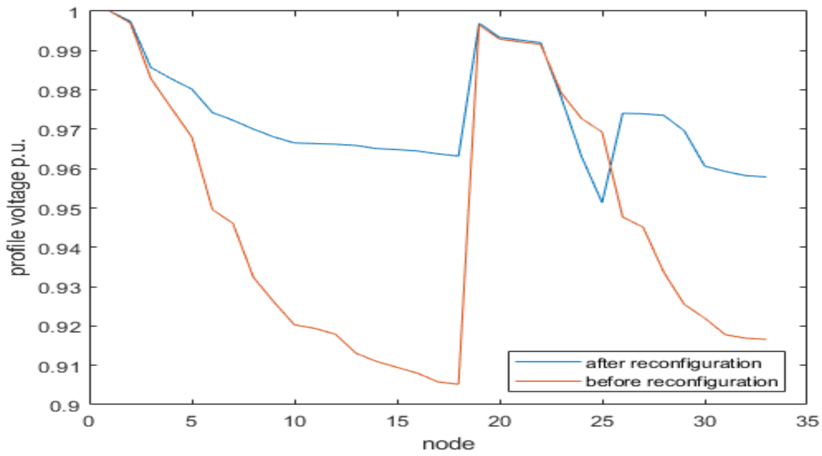

Figure 6: profile tension improvement.

After implementing of our line and load data, the new reconfiguration is 12-27-33-34-35, as shown in figure 5.

Table 2 presents the comparative study, and it is noticed that when we use our proposed algorithm, the losses are reduced and becomes 0.1248 Mw, instead of 0.2024 MW for the standard case and 0.178 MW for the case of new architecture using the Kruskal algorithm, 0.139 MW for the BPSO algorithm, and 0.2007 MW for the case of reconfiguration by using the redefined genetic algorithm.

Furthermore, table 2 indicates that the minimum voltage of our proposed algorithm is 0.95133 p.u. at node 18, this value respects the range limit of voltage. Also, it is improved compared with the standard case where the minimum voltage equal 0.7717 p.u. for the Kruskal's algorithm, the minimum voltage is 0.9282 p.u., for the BPSO it is noticed that the minimum voltage is equal 0.9479p.u., and for the redefined genetic, the minimum voltage is 0.8330p.u. So, we conclude that our suggested method improves the voltage profile better than the other recent studies.

Figure 6 and Table 2 present the performance of the suggested prim's algorithm compared with other recent articles. The table in appendix B gives the value found in each bus before and after the restoration of active power loss by using the reconfiguration of the network without DGs.

Finally, we conclude that our proposed algorithm helps to minimize the active power loss and enhance the voltage profile better than the other studies. Also, this algorithm gives result in this case after 0.2235s, this value it is lesser than the Kruskal's algorithm that finds result after 0.8566s and lesser than the BPSO algorithm that takes 34.64s. Appendix B gives the voltage profile of each bus for the standard case and our result.

3.2 Case with DGs

As presented previously, we consider that the weight of edges is their resistance. Furthermore, the insertion of the DG has not any impact on the impedance. So, the implementation of the line data, in this case, gives the same reconfiguration of the case of the network without the presence of the DG after applying the prim's algorithm, as shown in figure 5. After this step, we update the load data of the bus where the DG is injected by using the equation (8), (9), and (10). Then we apply the load flow method by using the main step of the backward/ forward sweep (equation (5), (6), and (7)).

Table 3 presents the simulation results of our proposed algorithm in this case and the results of other recent studies. Consequently, it is noted that the losses found using our proposed algorithm equal 0.1331 MW; this value is big than the losses found by (Hossein Moarrefi, 2013), where they have found 0.1241MW. However, it is important to note that the losses of the standard case equal 0.2465 MW, and this value is very big than our case.

Considering the voltage profile, our proposed method enhances the voltage at each node better than the base case and the (Hossein Moarrefi, 2013). Also, the minimum voltage of our case equals 0.95025 p.u. Nevertheless, in the case of the authors (Hossein Moarrefi, 2013), the minimum voltage is 0.9124 p.u. and 0.8950 p.u. for the base case. Furthermore, our proposed algorithm gives the results after 0.2235 s.

Figure 7 presents the voltage profile curve in two cases: the standard case and the case of our proposed algorithm. It is noticed that the value of the voltage of each node using our proposed algorithm is more improved than the base case.

Table 3: Comparative analysis for case network with DG

	Base case with DG	GA with DG (Hossein Moarrefi, 2013)	Proposed prim's algorithm with DG
Open branches	33-34-35-36-37	12-15-18-21-22	12-27-33-34-35
The node of minimum voltage	18	-	25
Minimum voltage profile (p.u)	0.8950	0.9124	0.95025
Total losses (MW)	0.2465	0.1241	0.1331

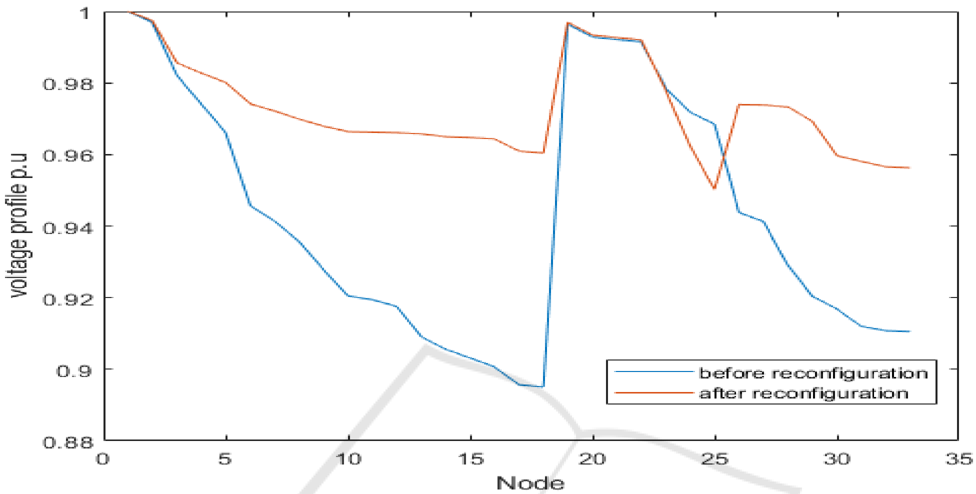

Figure 7: voltage profile for radial system distribution with DGs.

So, considering the improvement of the voltage profile, our study is perfect than the base case and the study (Hossein Moarrefi, 2013). Table 5 presents the value of the voltage before and after reconfiguration using our method.

4 CONCLUSION

In this article, our objective is to restore the losses aiming that the electrical plants can follow the customer's request. So, for this reason, this study proposes to use a combination of the prim's algorithm and the backward/ forward sweep due to their advantages to find the minimum spanning tree and to check the constraint with a higher speed to converge. For the Prim's algorithm, we have considered that the weight of edges is the resistance of lines also is used to check the constraint of the network have a radial topology, for the backward/ forward sweep is used to check the constraints of the current and voltage range limit also the first law of Kirchhoff.

To check the quality and the reliability of our study, we have used the electrical distribution network of 33 buses for two cases: network without and with the presence of the DG units. The simulation results of these two cases show that our hybrid method is perfect for minimizing losses and enhancing the voltage at a lesser time compared with other studies. For the next work, we advise using an evolutionary algorithm to solve the problem aiming to find the global optimum.

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APPENDIX

Table 4: line data and load data of IEEE 33 bus (Baran & Wu, 1989).

			Line data		Load data	
Branch N°	From bus	To bus	R (ohm)	X(ohm)	Pl(Kw)	Ql(kvar)
1	1	2	0,0922	0,047	100	60
2	2	3	0,493	0,2511	90	40
3	3	4	0,366	0,1864	120	80
4	4	5	0,3811	0,1941	60	30
5	5	6	0,819	0,707	60	20
6	6	7	0,1872	0,6188	200	100
7	7	8	0,7114	0,2351	200	100
8	8	9	1,03	0,74	60	20
9	9	10	1,04	0,74	60	20
10	10	11	0,1966	0,065	45	30
11	11	12	0,3744	0,1238	60	35
12	12	13	1,468	1,155	60	35
13	13	14	0,5416	0,7129	120	80
14	14	15	0,591	0,526	60	10
15	15	16	0,7463	0,545	60	20
16	16	17	1,289	1,721	60	20
17	17	18	0,732	0,574	90	40
18	2	19	0,164	0,1565	90	40
19	19	20	1,5042	1,3554	90	40
20	20	21	0,4095	0,4784	90	40
21	21	22	0,7089	0,9373	90	40
22	3	23	0,4512	0,3083	90	50
23	23	24	0,898	0,7091	420	200
24	24	25	0,896	0,7011	420	200
25	6	26	0,203	0,1034	60	25
26	26	27	0,2842	0,1447	60	25
27	27	28	1,059	0,9337	60	20
28	28	29	0,8042	0,7006	120	70
29	29	30	0,5075	0,2585	200	600
30	30	31	0,9744	0,963	150	70
31	31	32	0,3105	0,3619	210	100
32	32	33	0,341	0,5302	60	40
Tie Lines						
33	8	21	2	2		
34	9	15	2	2		
35	12	22	2	2		
36	18	33	0,5	0,5		
37	25	29	0,5	0,5		

Table 5: Bus voltage before and after reconfiguration without DGs.

	Network without DGs		Network with DGs	
Bus NO	Voltage profile before reconfiguration	Voltage profile after reconfiguration	Voltage profile before reconfiguration	Voltage profile after reconfiguration
1	1	1	1	1
2	0.997	0.9975	0.9969	0.9975
3	0.9829	0.9857	0.9821	0.9856
4	0.9754	0.9828	0.9741	0.9827
5	0.968	0.9802	0.9662	0.9701
6	0.9496	0.9743	0.9458	0.9742
7	0.9461	0.9723	0.9413	0.9722
8	0.9324	0.9700	0.9357	0.9699
9	0.9261	0.9680	0.9279	0.9679
10	0.9203	0.9665	0.9205	0.9664
11	0.9194	0.9664	0.9194	0.9663
12	0.9176	0.9662	0.9176	0.9661
13	0.9131	0.9659	0.9091	0.9658
14	0.911	0.9651	0.9056	0.9650
15	0.9095	0.9648	0.9031	0.9647
16	0.908	0.9648	0.9007	0.9644
17	0.9058	0.9638	0.8957	0.9610
18	0.9052	0.9632	0.8951	0.9604
19	0.9965	0.9969	0.9964	0.9969
20	0.9929	0.9931	0.9928	0.9934
21	0.9922	0.9927	0..9921	0.9927
22	0.9916	0.9920	0.9915	0.9920
23	0.9793	0.9782	0.9785	0.9779
24	0.9727	0.9630	0.9718	0.9623
25	0.9693	0.9513	0.9685	0.9503
26	0.9477	0.9741	0.9438	0.9740
27	0.9451	0.9739	0.9412	0.9738
28	0.9337	0.9735	0.9290	0.9733
29	0.9255	0.9696	0.9204	0.9693
30	0.922	0.9606	0.9168	0.9597
31	0.9178	0.9596	0.9120	0.9581
32	0.9169	0.9582	0.9108	0.9566
33	0.9166	0.9579	0.9105	0.9563