

# Proper insertion of DSTATCOM in distribution networks based on VSM with network reconfiguration

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## ABSTRACT

Voltage stability is necessary to maintain the grid system healthily. The load demand has been steadily increasing that causing high losses and voltage drops, endangering the system's stability. This study proposes the suitable insertion of distribution static compensator (DSTATCOM) based on voltage stability margin (VSM) with optimum network reconfiguration (ONR) to reduce losses and enhance the voltage profile. The findings are acquired utilizing recommended methodologies and test systems such as the IEEE-33 bus and 39 bus of an Iraqi distribution network, which are done using CYME and MATLAB software. The proposed approach may be able to solve the problem by aiding distribution network operators in estimating the size and location of DSTATCOM.

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## 1. INTRODUCTION

The electrical power distribution systems supply electricity to three different categories of loads: commercial, industrial, and residential. The feeders are overloaded at some intervals of the day and less loaded at other intervals due to the varied loading patterns of various kinds of loads. In addition, when the load changes, the distribution network's operational conditions alter as well. If the voltage on the separate buses is not effectively matched, the voltage on the nodes is outside of the acceptable boundaries, resulting in significant actual losses on feeders and expensive system operating costs. Losses in electricity transmission, excessive voltage drop, the growing demand for power throughout the world, a high number of power outages, and grid modernization are all factors that contribute to the overall power system's instability and unreliability [1]. Therefore, transmission losses, voltage regulation, frequency control, and equilibrium must be considered during normal operating circumstances and after any disruption to make the system more stable [2]. Moreover, consumers must be delivered electricity at an acceptable voltage and frequency at a reasonable cost for the distribution system to be dependable [3].

Numerous methods for improving distribution systems in the literature have been demonstrated to minimize power losses and maximize the voltage stability margin to be considered concurrently if FACTS devices are injected with network reconfiguration as will be explained successively. In Mtonga *et al.* [4], the multiverse optimizer (MVO) was utilized to search for the most appropriate buses to use the capacitor with the best location and size. In Babu *et al.* [5], suggested utilizing a genetic algorithm (GA) to improve network reconfiguration and decrease active power losses. In Montoya *et al.* [6], suggest using the Chu-Beasley genetic algorithm (CBGA), which employs the optimal power flow (OPF) approach through the vortex search

algorithm (VSA) to find the proper placement and size of the distribution generator (DG). In a multimodal strategy based on reconfiguration and distribution static compensator (DSTATCOM) allocation utilizing the multi-objective particle swarm optimization (MOPSO) algorithm is applied to minimize losses and improve bus voltages in distribution systems [7], [8]. In Ismail *et al.* [9], a load management approach was recommended for regulating loads, especially during peak hours to avoid tripping, the goal of the idea was to boost the economy and create a stable, balanced system while also reducing heat impacts and avoiding load shedding due to sudden overload. Occasionally, a mixture of these functions is used such as in [10], [11]. The different voltage stability indices (VSI) were also utilized in several studies to locate the FACTS device and DG [12]-[15].

According to the prior reasoning, constantly reconfiguring the system to more efficiently redistribute the load currents, shifting system loads, and alleviating overloading of network components all of these solutions will be contributing to reducing network losses and keeping the voltage in power distribution systems at the acceptable range [16]. At the beginning of this research paper, the network will be reconfigured and then a voltage stability margin (VSM) will be used to determine the appropriate location for DSTATCOM. The current article concentrated on the analysis and improvement of the Iraqi distribution system (ALBUSTAMIA feeder) in Al Anbar city and the usage of the IEEE 33 node test network. To limit the analysis error, the network analysis results are obtained by using the CYME program and MATLAB version 2017a. Also, utilize the CYME to choose the appropriate network reconfiguration. The voltage stability margin VSM was used to compute the proper position of DSTATCOM, but sizing was derived by varying the sizes in stages and comparing the power loss. Therefore, two methods will be proposed to enhance the stability of the network. These two strategies are utilized to lower the drop voltage and minimize power loss in the radial distributed system.

The remaining sections of this article are structured as follows. The section 2 described the optimal network reconfiguration (ONR). The definition of VSM is given in the section 3. In section 4, the recommended approach for achieving the research goal is described. The findings of the simulation, as well as the discussions, are detailed in section 5. Finally, the conclusions with future works are inserted in section 6.

## 2. OPTIMAL NETWORK RECONFIGURATION (ONR)

The radial design of distributed feeders can have their configurations modified manually or automatically [17]. The network reconfiguration can be obtained by opening the normally closed switches (sectionalizing switches) and closing the normally opened switches (tie switches) in the network. The switching activities are performed in such a way that the network radially is maintained and all loads are activated. Therefore, network re-configuration is the way of transforming the closed or opened state of sectionalizing and tie-switches to modify the topological structure of feeds. To decrease real power loss and relieve network stress, networks are frequently updated. The results of load flow calculations performed before and after the feeder Re-configuration can be used to determine the network's real losses and improve the voltage profile [18]-[22].

Any optimization strategy begins with a well-connected distribution network, which is achieved by presuming that closed all switches are. To eliminate the loops, the switches are then opened one by one [23]. The opening process is based on a minimum increase in total losses, which is computed utilizing a "Load-Flow program," as shown in Figure 1 (in Appendix).

## 3. VOLTAGE STABILITY MARGIN (VSM)

After a disturbance, voltage stability definition as the power system's capacity to keep the voltages on all network nodes within a reasonable range. In reality, increasing loads and the system's inability to deliver enough reactive power are the primary sources of voltage instability [15]. Therefore, the VSM is represented as a metric that spots nodes on the verge of collapsing. Poor nodes are those that have low stability ratings and need to be strengthened by injecting reactive power [13]. A simple radial distribution system is shown in Figure 2.

The voltage stability margin for each bus is calculated by using (1), and the node with the lowest VSM is identified. Each node's VSM is a quantity ranging from zero to one [24].

$$VSM = |V(i)|^4 - 4(P(j)X - Q(j)R)^2 - 4(P(j)R - Q(j)X)|V(i)|^2 \quad (1)$$

Where:

V(i): Voltage of sending end bus

R: Resistance of line

X: Reactance of line

Q(j): Reactive power of receiving bus

P(j): Real power of receiving bus

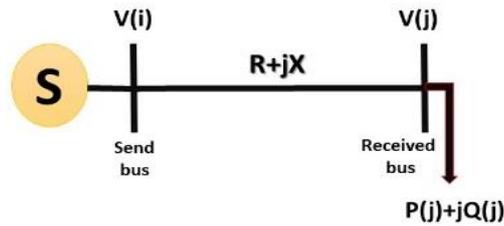


Figure 2. RDS equivalent circuit

#### 4. PROPER PLACEMENT AND SIZING OF DSTATCOM

In the beginning, the network will be reconfigured and then used DSTATCOM. As previously explained, dispersed sources of active and reactive power must be connected to the radial distribution system (RDS) to keep it healthy and resilient. Since the VSM indicates the weakest bus, which must be reinforced by injecting reactive power [25], the proposal used the VSM to find the ideal position for DSTATCOM. As a result, the bus with the lowest VSM value decides DSTATCOM's placement. DSTATCOM is injected at this bus to enhance the bus voltage and reduce total losses because this bus collapsed first. In addition, the suggested technique would inject DSTATCOM with size changes to find the ideal size with the least losses. The flowchart of the suggested technique for DSTATCOM placement and size is depicted in Figure 3.

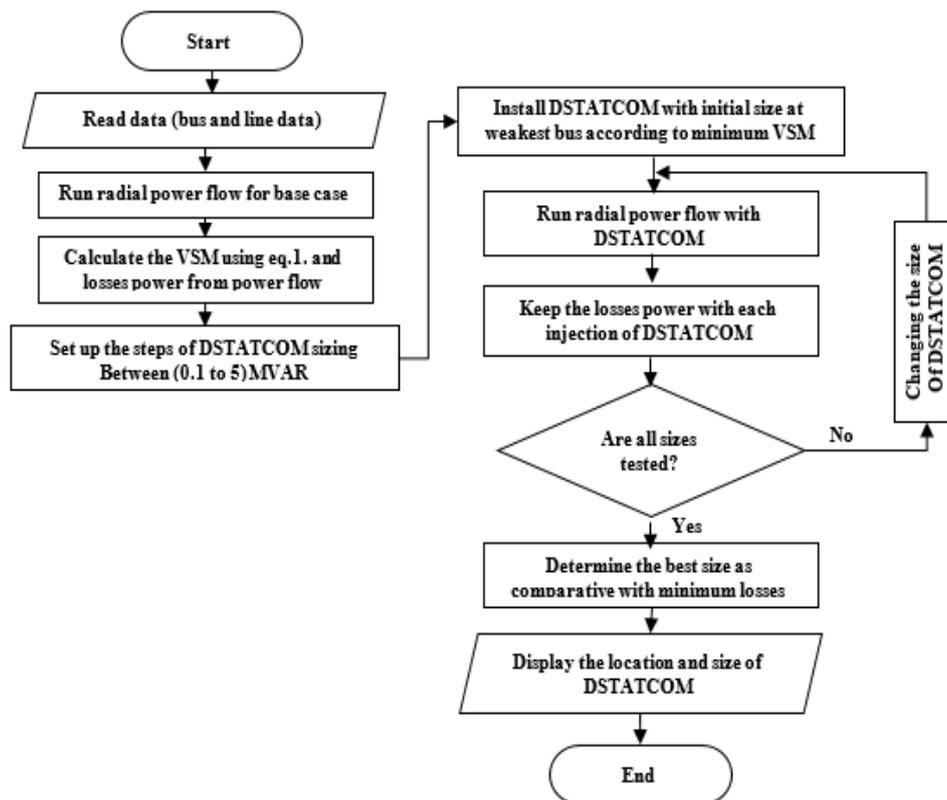


Figure 3. The flowchart for the proposed proper insertion of DSTATCOM

#### 5. SIMULATION RESULTS AND DISCUSSION

DSTATCOM is utilized to enhance bus voltage and reduce overall losses based on the suggested VSM strategy with ONR. The bus voltages, overall power losses, and voltage stability margin for the IEEE 33-bus and ALBUSTAMIA feeder of Iraqi distribution systems are obtained. The simulation results were obtained by using CYME software and MATLAB version 2017a. To obtain study objectives, each system was subjected to two methods in the following manner:

**Case1:** The system with ONR only.

**Case2:** The system with ONR and DSTATCOM injection.

**5.1. IEEE 33\_bus test system**

The initial configured network of the IEEE 33\_bus is shown in Figure 4. The system contains 33 buses with 32 main switches and five tie switches. Total active power is 3,715 kW and reactive power is 2,300 kVAR for the load. It is supplied from a synchronous generator with a base of 100 MVA and 12.66 kV at a frequency of 60 Hz. The 33-node test feeders' electrical data are obtained from [6]. Active and reactive losses are 210.774 kW and 142.855 kVAR, respectively for a 33-bus system without reconfiguration (sectionalizing or main switches are closed and tie or secondary switches are open) and DSTATCOM. It is showing the lowest voltage of 0.9038p.u on bus18. Moreover, the lowest value of VSM is 0.6674 on this bus.

**Case 1: The system with ONR only**

The proposed technique in this situation is a comparison with modified sequential switch opining (MSSO) [19] and moth flame optimization (MFO) [26]. After reconfiguration, actual and reactive power losses are decreased to 139.509 kW and 102.266 kVAR. Improved the minimum voltage to 0.9378 p.u occurred at bus 32. Table 1 shows the results of this case. The suggested technique, which makes use of the CYME software, produced the same results as the MSSO and MFO. Moreover, at bus 32, the minimum value of VSM has been adjusted to 0.7692.

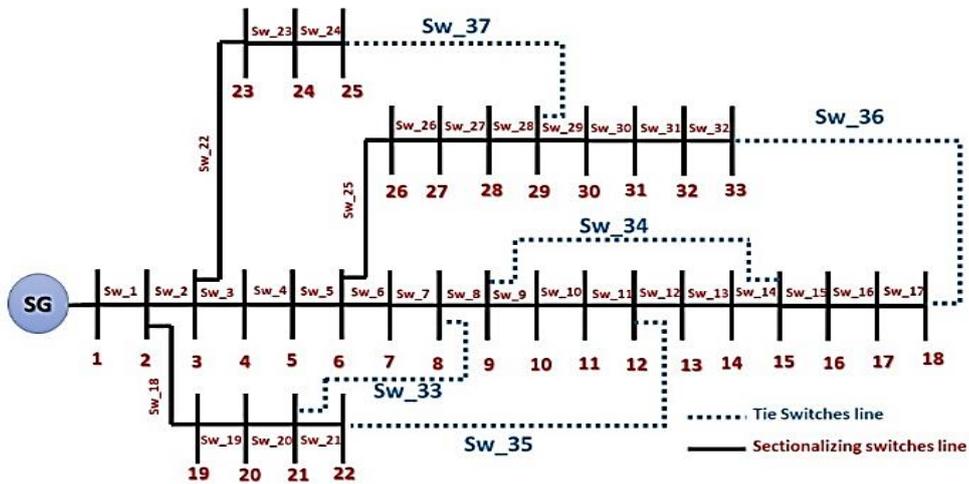


Figure 4. IEEE 33\_bus test system

Table 1. IEEE 33-bus reconfiguration performance induction

	Base case	Methods		
		MSSO[19]	MFO [26]	Proposed method
Switches are open	33,34,35,36 and 37	7,9,14,32 and 37	7,9,14,32 and 37	7,9,14,32 and 37
Real power loss	210.774KW	139.55KW	139.5KW	139.509KW
Minimum voltage	0.9038 p.u	0.9378 p.u	0.9378 p.u	0.9378 p.u
Location	18	32	32	32
Reduction in Losses %		33.79%	33.81%	33.81%

**Case 2: the system with ONR and DSTATCOM injection**

After network reconfiguration, the minimum value of VSM at bus 32 was found to be 0.7692, this bus will collapse first as indicated in the suggested procedure. For this reason, reactive power should support this bus. As a result, this bus is being used as DSTATCOM's preferred place. The proposed solution was also reported to decrease the actual and reactive power to 107.3 kW and 82 kVAR, respectively, by taking the size of DSTATCOM at 800 KVAR. In addition, the minimum voltage is 0.9474 occurred at bus 33 and the value of VSM is 0.8024. The proposed method is compared with two methods VSM [24] and bat algorithm [12] as shown in Table 2. Figure 5 shows how the IEEE 33 bus is improved when one DSTATCOM is injected and the network is reconfigured.

Table 2. IEEE 33-bus with ONR and DSTATCOM

	VSM [24]	Bat Algorithm [12]	Proposed Method
Size of DSTATCOM	500KVAR	1150KVAR	800 KVAR
(Location)	18	30	32
Total Losses [KVA]	182.62+j123.13	143.97+j96.47	107.3 + j82
Minimum Voltage[pu]	0.920	0.9244	0.9474
(Location)	33	18	33
VSM	0.819	0.7242	0.8024
(Location)	33	18	33
Reduction in Losses %	13.36%	31.69%	49.09%

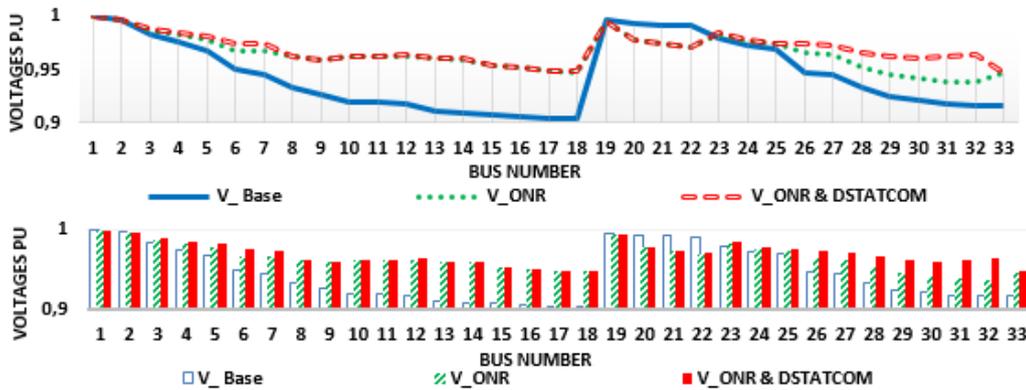


Figure 5. Voltages with bus number of IEEE 33 bus

**5.2. ALBUSTAMI feeder of Iraqi distribution network**

The ALBUSTAMIA feeder in Al\_Anbar city is one of the Iraqi distribution network's feeders. Figure 6 shows the fundamental arrangement. There are 39 buses in this network with 38 sectionalized switches and five tie switches. Total real power is 4383 kW and reactive power is 2752 kVAR for the load. It received power from a substation with a base capacity of 100 mVA and a voltage of 11 kV at a frequency of 50 Hz. The received voltage at bus 1 from the substation is equal to 0.972 p.u. Table 3 contains the parameter data for this system. Without reconfiguration and DSTATCOM, real and reactive power losses for the ALBUSTAMIA feeder are 194.2 kW and 252.7 kVAR, respectively. Bus 36 also has a 0.8752 p.u minimum voltage. Furthermore, the minimum VSM value for bus 36 is 0.5868.

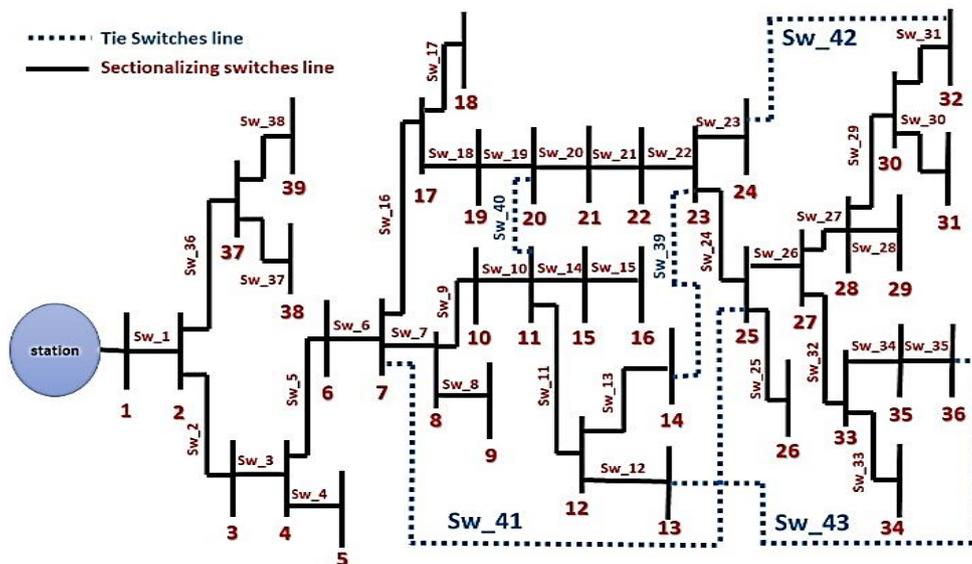


Figure 6. ALBUSTAMIA feeder of Iraqi distribution network

Table 3. ALBUSTAMIA data of the Iraqi distribution network

SW	From (i)	To (j)	R [ $\Omega$ ]	X [ $\Omega$ ]	P(j)[KW]	Q(j)[KVAR]
1	1	2	0.383086	0.498641	0	0
2	2	3	0.037389	0.048642	143.46	85.89
3	3	4	0.052151	0.06776	0	0
4	4	5	0.003146	0.004114	143.46	85.89
5	4	6	0.023837	0.030976	143.46	85.89
6	6	7	0.090992	0.118459	0	0
7	7	8	0.034243	0.044528	0	0
8	8	9	0.027346	0.035574	143.46	85.89
9	8	10	0.004719	0.00605	229.54	137.42
10	10	11	0.026983	0.03509	143.46	85.89
11	11	12	0.024926	0.032428	0	0
12	12	13	0.001573	0.003993	143.46	85.89
13	12	14	0.0363	0.04719	143.46	85.89
14	11	15	0.04235	0.055055	229.54	137.42
15	15	16	0.047916	0.062315	143.46	85.89
16	7	17	0.172667	0.224818	0	0
17	17	18	0.00242	0.003146	143.46	85.89
18	17	19	0.004477	0.005929	229.54	137.42
19	19	20	0.019481	0.02541	229.54	137.42
20	20	21	0.363121	0.472505	143.46	85.89
21	21	22	0.555027	0.722249	57.38	34.36
22	22	23	0.603185	0.784927	0	0
23	23	24	0.033154	0.043197	143.46	85.89
24	23	25	0.477466	0.621456	0	0
25	25	26	0.061831	0.080344	143.46	85.89
26	25	27	0.232078	0.302016	0	0
27	27	28	0.017908	0.023353	0	0
28	28	29	0.041987	0.054692	143.46	85.89
29	28	30	0.002299	0.003025	0	0
30	30	31	0.003872	0.005082	143.46	85.89
31	30	32	0.075746	0.098494	143.46	85.89
32	27	33	0.268136	0.348843	0	0
33	33	34	0.043802	0.056991	143.46	85.89
34	33	35	0.086757	0.113014	229.54	137.42
35	35	36	0.075262	0.09801	229.54	137.42
36	2	37	0.04114	0.053603	0	0
37	37	38	0.024442	0.031702	229.54	137.42
38	37	39	0.027951	0.036542	229.54	137.42
Tie switches						
39	14	23	0.068486	0.089056		
40	11	20	0.020812	0.026983		
41	7	25	0.325732	0.423863		
42	24	32	0.247808	0.322586		
43	13	36	0.536877	0.698654		

**Case 1: the system with ONR only**

Real and reactive losses are decreased to 126.6 kW and 164.7 kVAR, respectively, after reconfiguration. The minimum voltage at bus 35 is 0.9294 p.u. The study's findings are shown in Table 4. Furthermore, the minimum value of VSM on bus 35 has been modified to 0.7466.

Table 4. The study's findings of case 1

	Base case	Proposed method
Switches are open	39,40,41,42 and43	21,24,29,34 and40
Real power loss	194.2 KW	126.6 KW
Minimum voltage	0.8752 p.u	0.9294 p.u
Location	36	35
Reduction in losses %		34.81%

**Case 2: the system with ONR and DSTATCOM injection**

The minimum value of VSM at bus 35 was found to be 0.7466 after network reconfiguration. This bus will be the first to collapse, according to the suggested procedure. For this reason, reactive power should be used to sustain a healthy bus. As a result, DSTATCOM's prefer located at this bus. Getting the size of DSTATCOM is 1,400 kVAR by using the proposed method also reduced the real and reactive losses to 104.2 kW and 135.6 kVAR, respectively.

Furthermore, the voltage on bus 35 has been increased to 0.9487 p.u, and VSM has been adjusted to 0.8047. The justifications for these inductions are shown in Table 5. When one DSTATCOM is injected and the network is configured, Figure 7 demonstrates how the ALBUSTAMIA feeder improves.

Table 5. The inductions for this case

	Proposed Method
Size of DSTATCOM	1400
(Location)	35
Total Losses[KVA]	104.2 + j135.6
Minimum Voltage[p.u]	0.948737634
(Location)	35
VSM	0.804733323
(Location)	35
Reduction in Losses%	46.34%

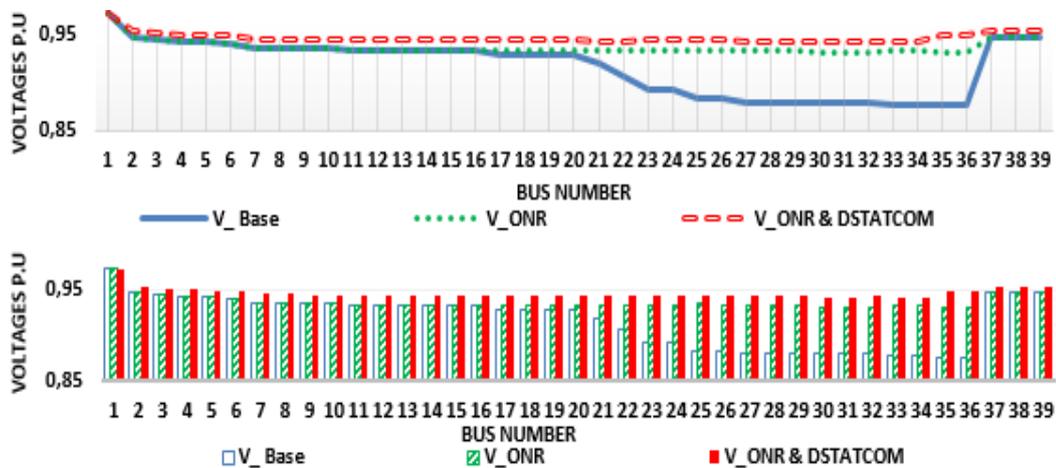


Figure 7. Voltages with bus number of ALBUSTAMIA feeder

## 6. CONCLUSIONS AND FUTURE WORKS

In this article, the use of CYME and MATLAB software to examine optimum network reconfiguration (ONR) and DSTATCOM insertion in the IEEE 33\_bus system and the Iraqi distribution system are investigated. The goals are to improve the bus voltages while lowering network total losses. DSTATCOM in a radial distribution network with network reconfiguration is the subject of the inquiry. VSM is used to determine the appropriate position for DSTATCOM. DSTATCOM's size is determined by varying the size for numerous injections to decrease overall losses and selecting the correct size if losses are at a minimum value. DSTATCOM with reconfiguration was utilized to enhance bus voltages and decrease power losses in the network, according to simulation findings.

In the IEEE 33\_bus test system, utilized DSTATCOM after reconfiguration with the size of 800 VAR at bus 32 improved voltage profiles and decreased losses. In addition, utilized DSTATCOM at bus 35 after reconfiguration with a 1,400 VAR capacity enhanced voltage profiles and decreased losses in the Iraqi distribution system. A future study might include introducing many DSTATCOM and distribution generator (DG) placements in the distribution network, as well as employing intelligent optimization strategies to determine the best location and size of DSTATCOM and DG.

APPENDIX

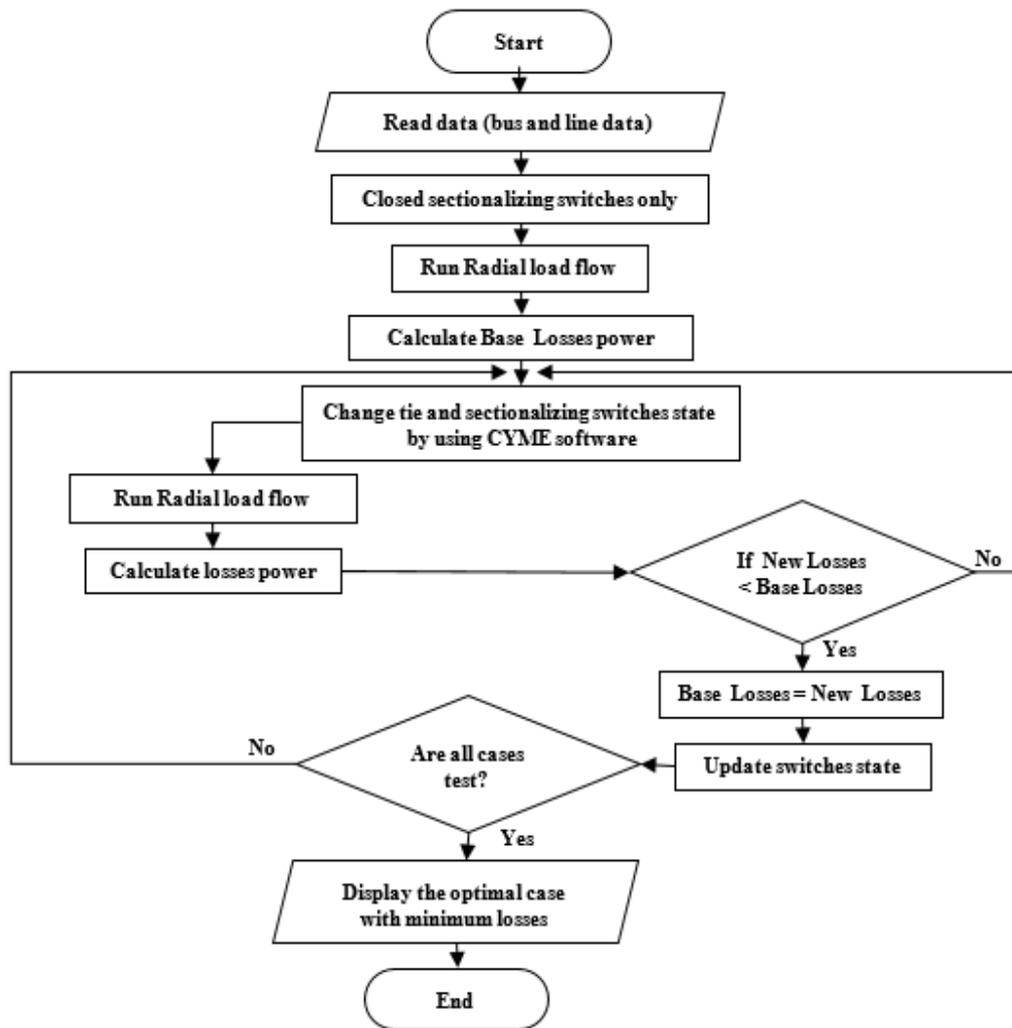


Figure 1. Flowchart of proposed optimal network reconfiguration

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