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Performance Analysis on Placement and Sizing of D-STATCOM in Radial Distribution Network:

A Case study in Begnas Feeder, Lekhnath

BY

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LIST OF ABBREVIATION

ABC	AERIAL BUNDLED CONDUCTOR
AC	ALTERNATING CURRENT
ACSR	ALUMINUM CONDUCTOR STEEL REINFORCED
DC	DIRECT CURRENT
DCS	DISTRIBUTED CONTROL SYSTEM
DG	DISTRIBUTED GENERATION
INPS	INTEGRATED NEPAL POWER SYSTEM
HT	HIGH TENSILE
NEA	NEPAL ELECTRICITY AUTHORITY
VSI	VOLTAGE STABILITY INDEX

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

To enhance voltage profiles, lower losses, and conserve energy, distribution systems integrating distributed generation (DG), custom power devices (CPDs), and capacitors must conduct an optimal load flow assessment. Reactive power management, loss reduction, distribution system pricing, and reserve management during peak loads are among the challenges that are addressed by the proper placement of these components. Reactive power demands rise in distribution systems because most loads are reactive. This reactive power can be provided by capacitors, but they may oscillate and their output is dependent on the system voltage. Originally designed for transmission systems, FACTS devices are now utilized in distribution to compensate for reactive power, taking on the role of capacitors or inductors as required.

CPDs that regulate voltage, phase angle, and line impedance effectively and dependably include DVR, D-STATCOM, and UPQC. D-STATCOM is a particularly useful one among them, providing better bus voltage profiles and continuously changing reactive power compensation. A transformer, PWM control technique, inverter modules, ac filter, and dc capacitor are among its primary parts. In both steady-state and dynamic scenarios, D-STATCOM improves voltage control, balancing, and power losses. The effectiveness of D-STATCOM in enhancing voltage profiles and lowering losses in distribution networks has been demonstrated by a number of studies that have suggested methods for appropriate D-STATCOM placement and sizing.

With size estimations made using a variational strategy, this article analyzes D-STATCOM allocation strategies for radial distribution networks using the voltage stability index (VSI) and power loss index (PLI) approaches. This technique enhances voltage profiles while reducing line losses. The load flow method consists of three basic steps: figuring out the load current, creating the BIBC matrix, and sweeping the line forward. The bus with the greatest VSI and PLI values is chosen as the candidate bus after a load flow study is performed. We then apply the variational technique to determine the D-STATCOM size. Lastly, using MATLAB, the load flow is reevaluated at the candidate bus for IEEE 33-bus test systems with the D-STATCOM.

1.2 PROBLEM STATEMENT

The electrical power distribution system is an essential part of the infrastructure that ensures the efficient and reliable transport of electricity from generation sources to end consumers. However, maintaining the optimal voltage profile and minimizing losses in the distribution network remain formidable obstacles. These issues could lead to excessive power consumption, increased operational costs, and a deterioration in the reliability and quality of the services.

Research paper's problem statement focuses on solving problems with reactive power management, improving voltage profiles, and lowering power losses in radial distribution systems. It draws attention to the drawbacks of employing capacitors for reactive power adjustment, including their propensity to cause oscillations and reliance on system voltage. As a substitute, the study suggests using D-STATCOM, a static compensator based on a shunt-connected voltage source converter. In order to improve the effectiveness and efficiency of radial distribution networks, the study intends to identify the ideal placement and size of D-STATCOM utilizing voltage stability index (VSI) and power loss index (PLI) methodologies, followed by size calculation through a variational technique.

1.3 RATIONALE OF PROJECT

Our everyday existence depends on the electrical power distribution system, which supplies energy to our residences, workplaces, and enterprises. On the other hand, preserving an ideal voltage profile and reducing distribution network losses are major obstacles that may affect the effectiveness, dependability, and affordability of power transmission.

The purpose of this research study is to discuss the necessity of loss reduction and efficient voltage profile management in radial distribution systems. This research investigates the best locations and sizes for Distribution Static Compensators (D-STATCOMs) by combining the Power Loss Index (PLI) and Voltage Stability Index (VSI) methodologies. The study's objectives are to improve voltage stability, lower power losses, and save energy overall by figuring out where and how big of D-STATCOMs to put. This is especially crucial since scattered generation sources and rising reactive loads need for sophisticated reactive power management techniques and effective system operation.

1.4 OBJECTIVES

The objectives of this research paper are:

- ✓ To compare the effectiveness of Voltage Stability Index (VSI) approach for the optimal allocation of D-STATCOM in a radial distribution network.
- ✓ To determine the corresponding sizes of D-STATCOM using a variational technique.
- ✓ To demonstrate the reduction of line losses and improvement in the voltage profile of the distribution network through the optimal placement and sizing of D-STATCOM.
- ✓ To conduct load flow analysis on a radial distribution system to identify candidate buses for D-STATCOM placement.
- ✓ To validate the proposed methodology using the IEEE 33-bus test system with MATLAB software and implement it in city feeder.
- ✓ To analysis the energy saving after placement of D-STATCOM

1.5 LIMITATIONS

- ✓ The paper assumes a constant load profile while calculating the optimal placement and size of D-STATCOM. In real-world scenarios, the load profile can vary significantly, which might affect the performance and effectiveness of the D-STATCOM installation.
- ✓ The study uses a simplified model of the distribution system, which may not capture all the complexities and interactions in an actual distribution network
- ✓ The study examines the placement of a single D-STATCOM device. In practical applications, multiple devices may be required, and their interactions could complicate the optimization process.

CHAPTER TWO : LITERATURE REVIEW

The increasing use of capacitors, custom power devices, and distributed generation in distribution systems necessitates a thorough load flow study to determine their optimal placement for improved voltage profile management, loss reduction, and overall energy savings. Reactive power compensation is crucial due to the prevalence of reactive loads like motors and pumps [9]. While capacitors are traditionally used for this purpose, their dependency on system voltage and potential for oscillations pose challenges. FACTS devices, including D-STATCOM, offer a more flexible solution by dynamically adjusting reactive power compensation based on system needs. D-STATCOM, a shunt-connected device, excels in voltage profile improvement and loss reduction. Its advantages include low harmonic distortion, compact size, and continuous operation. This paper focuses on comparing D-STATCOM allocation methods using voltage stability and power loss indices, along with size calculation using a variational technique, to enhance distribution system performance.

Flexible AC Transmission System (FACTS) devices, such as DSTATCOM and UPQC, are increasingly used to address issues in power systems, including low voltage distribution, power quality improvement, and reliability for sensitive loads. These devices offer solutions for reactive power compensation and unbalanced loading under various system conditions. Optimal placement of these devices is crucial for their effectiveness. DSTATCOM, a shunt-connected device, is favored for its advantages like low harmonic distortion, compact size, and continuous operation. Previous research has explored various optimization algorithms for DSTATCOM placement, including immune algorithms, Particle Swarm Optimization (PSO), hybrid heuristic techniques, gravitational search algorithms, firefly algorithms, and modified bat algorithms.

Paper presents two methods for allocating D-STATCOM in radial distribution networks: voltage stability index (VSI) and power loss index (PLI). The optimal size of the D-STATCOM is determined using a variational technique. The load flow method used in this paper involves calculating load current, forming a BIBC matrix, and performing a forward sweep across the line [10]. Initially, a load flow analysis is conducted to calculate line losses and voltage profiles, and the bus with the highest VSI and PLI values is chosen as the candidate bus. Subsequently, the size of the D-STATCOM is determined using a variational technique. Finally, a load flow analysis is performed again, this time with the calculated D-STATCOM size at the candidate bus. This method effectively reduces line losses and improves voltage profiles.

2.1 Overview of Distribution Network:

Distribution systems serve as the conduit between the consumers and the distribution substation. This system provides a range of clients with the safe and dependable transportation of electric energy throughout the service area. generally beginning as a medium-voltage three-phase circuit (between 30 and 60 KV), a distribution system terminates at the customer's location, typically at the meter, at a lower secondary three- or single-phase voltage (generally less than 11 kV).

A simple model of radial distribution feeder is as shown in Figure 1.

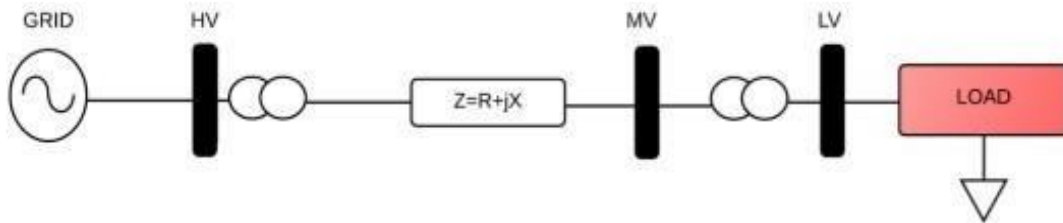


Figure 1:Radial DIstribution Network

2.2 D-STATCOM Allocation Technique for Loss Reduction

In essence, the D-STATCOM is a bespoke power device. All that is involved is the use of a STATCOM at the distribution level. A custom power device, the D-STATCOM is connected in series with the power supply and is based on an inverter that measures voltage or current. It is linked to the distribution systems in close proximity to the load. A power VSC that is built on high power electronics technologies is the essential part of the D-STATCOM. A VSC, a group of coupling reactors, and a controller make up the three primary components of the D-STATCOM system. A voltage source converter (VSC) coupled to a direct current capacitor (energy storage device) generates a programmable ac voltage source, which is the fundamental working principle of a D-STATCOM installed in a power system.

D-STATCOM is made up of an inverter, a control unit that produces PWM signals for the inverter switches, a coupling inductance L that is used for current filtering and reactive power exchange between D-STATCOM and the power system, and dc link capacitance C that supplies the inverter with dc voltage. R_{dc} and R stand for the coupling inductance's winding resistance and switching losses in the inverter, respectively. Reactive power exchange between the distribution system and D-STATCOM is accomplished by controlling the inverter output voltage V_i 's amplitude. The phasor graphs in Figure 2 provide an illustration of the D-STATCOM operation.

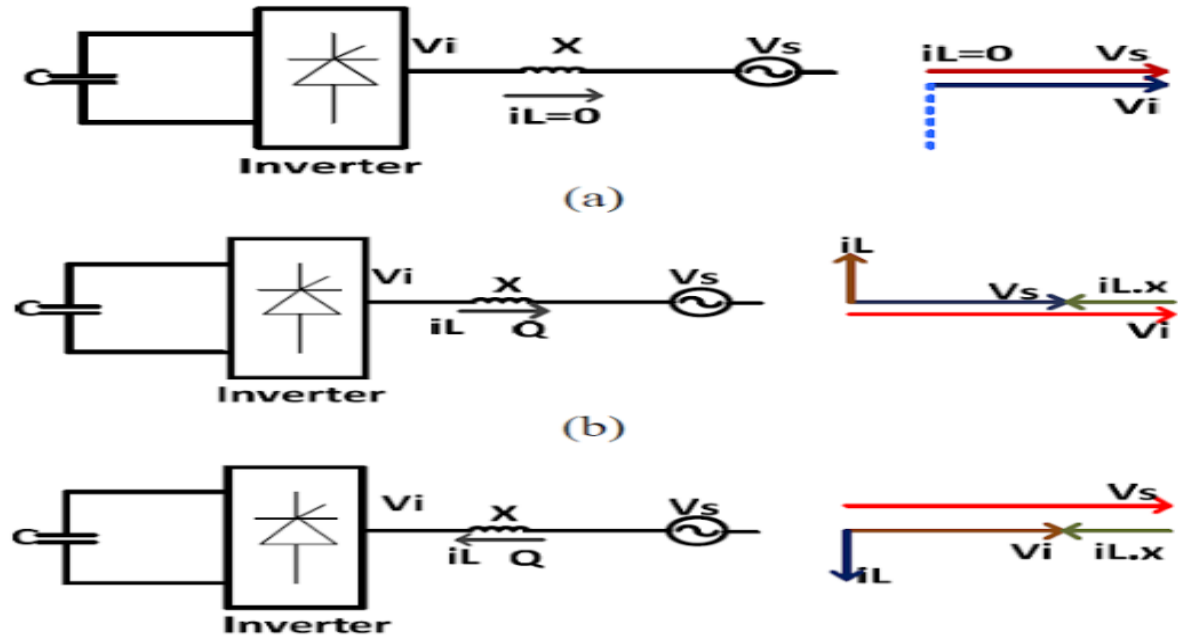


Figure 2: Phasor Graph of D-STATCOM

2.3 Power flow/Load Flow:

The computations of load flow can be solved in a variety of ways. To be deemed acceptable, a load flow approach must meet a number of requirements, such as quick speed, low storage requirements, high dependability, and widely acknowledged simplicity and adaptability, power transmission through the grid system from generators to consumers. Load flow analysis is a crucial precondition for power system research. Regarding the radial feeder for load flow, the backward-forward sweep method is employed.

2.3.1 Calculation of load current

The load current at any bus is given as:

$$I_{Ln} = (P_n - jQ_n) / V_n \text{ Where } n = 1, 2, \dots, N \dots (1) \text{ where,}$$

I_L = Load Current

N = total. No. of buses

P_n = Active power

Q_n = Reactive power

V_n = Bus Voltage

2.3.2 Backward Forward Sweep Method:

The relation between load current and branch current can be found by using KCL equation. The matrix can be written as:

$$[IB] = [BIBC] [IL]$$

Where,

IB= Branch Current

BIBC= Bus injection to Branch Current Matrix

Forward sweep algorithm is used to calculate the voltage at each bus starting from branches from first layer to last layer. Backward Sweep algorithm is used to calculate the branch current starting from the last layer towards the branches connected to root node.

$$V_n(K) = V_m(K) - IB(K) * Z_m(K) \dots\dots(3)$$

Where,

$$K = 1, 2, \dots, N_b$$

N_b = total no. of Branches = N

$V_n(K)$ = receiving end Voltage $V_m(K)$ = sending end Voltage

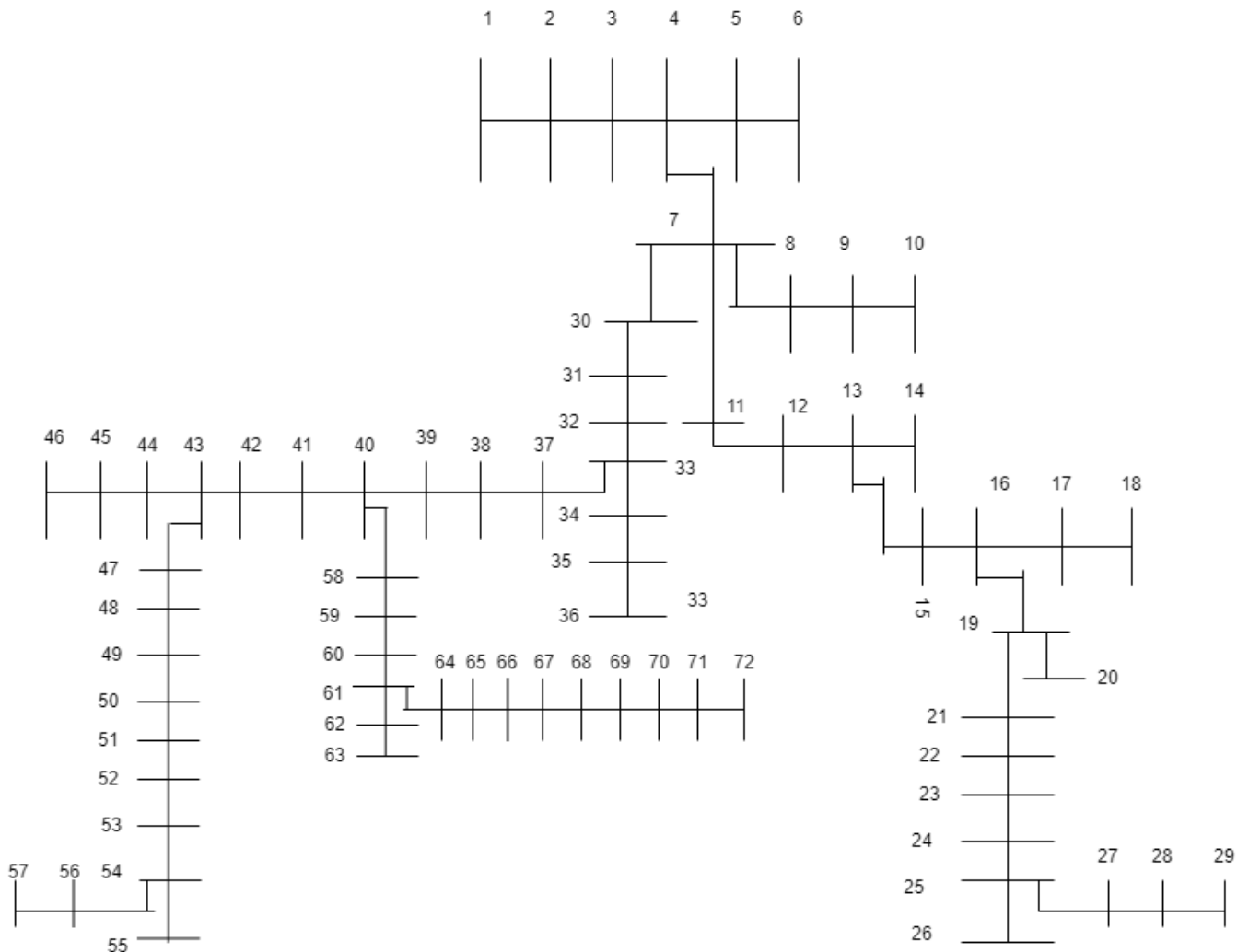
The power flow is calculated using backward and forward propagation using iterations. The forward sweep will provide the voltage magnitudes whereas the backward propagation provides the power of each branch. The iterative method has fast convergence as compared to conventional methods. The results for IEEE 33 bus test system are calculated for this Project. It is concluded that the following load flow method is an efficient method for fast convergence tendency in radial distribution networks.

CHAPTER THREE: METHODOLOGY

This section discusses the methods and case studies used in this project to evaluate the system performance. The power flow along with the optimization technique applied throughout the project are programmed and simulated in MATLAB software.

3.1 Collection of Data:

The process involves choosing an IEEE bus test system that can accurately simulate a low-voltage distribution feeder and reviewing relevant literature to address the issue. For this effort, the IEEE 33 bus test system has been selected. Collection of real feeder data (Substation feeder data, voltage level, resistance and reactance of line, daily monthly and annual loading condition, load and its line configuration) of 11 kV Begnas feeder and finding the low voltage point, nodes and their values at different location from DTR installed, HT metering unit, TOD meter installed in substation and industries.



3.2 Optimal Location of D-STATCOM

3.2.1 Voltage Stability Index for finding optimal location of D-STATCOM

Optimal location of D-STATCOM is found by calculating the voltage stability index of all the buses. The VSI is calculated from the following equation:

$$VSI = 4R_m(P_n^2 + Q_n^2) / (V_m^2 P_n) \dots\dots\dots(2)$$

Where V_m and V_n are sending and receiving end voltages respectively; I_m is the branch current; R_m & X_m are branch resistance and reactance respectively.

Voltage stability index has been obtained and the bus with highest value of VSI is most unstable and is selected as candidate bus for D-STATCOM. The steps for calculating VSI are described as follows:

Step 1: Read the radial distribution system line data and bus data.

Step 2: Perform the load flow to calculate voltages for all the buses and power losses for all the branches.

Step 3: Calculate VSI for all the buses using equation (2).

Step 4: Select the candidate bus with highest value of stability index.

Step 5: Stop.

3.2.2 Optimal size calculation by variational technique

The size of D-STATCOM is calculated using the variational technique. First the base case load flow is made for finding the losses. Then by following steps is used for finding the optimum size of D-STATCOM. Steps for calculating the optimum size of D-STATCOM by variational technique are as follows:

Step 1: Read the line data and bus data and find the candidate bus for D-STATCOM placement by sensitivity method (VSI).

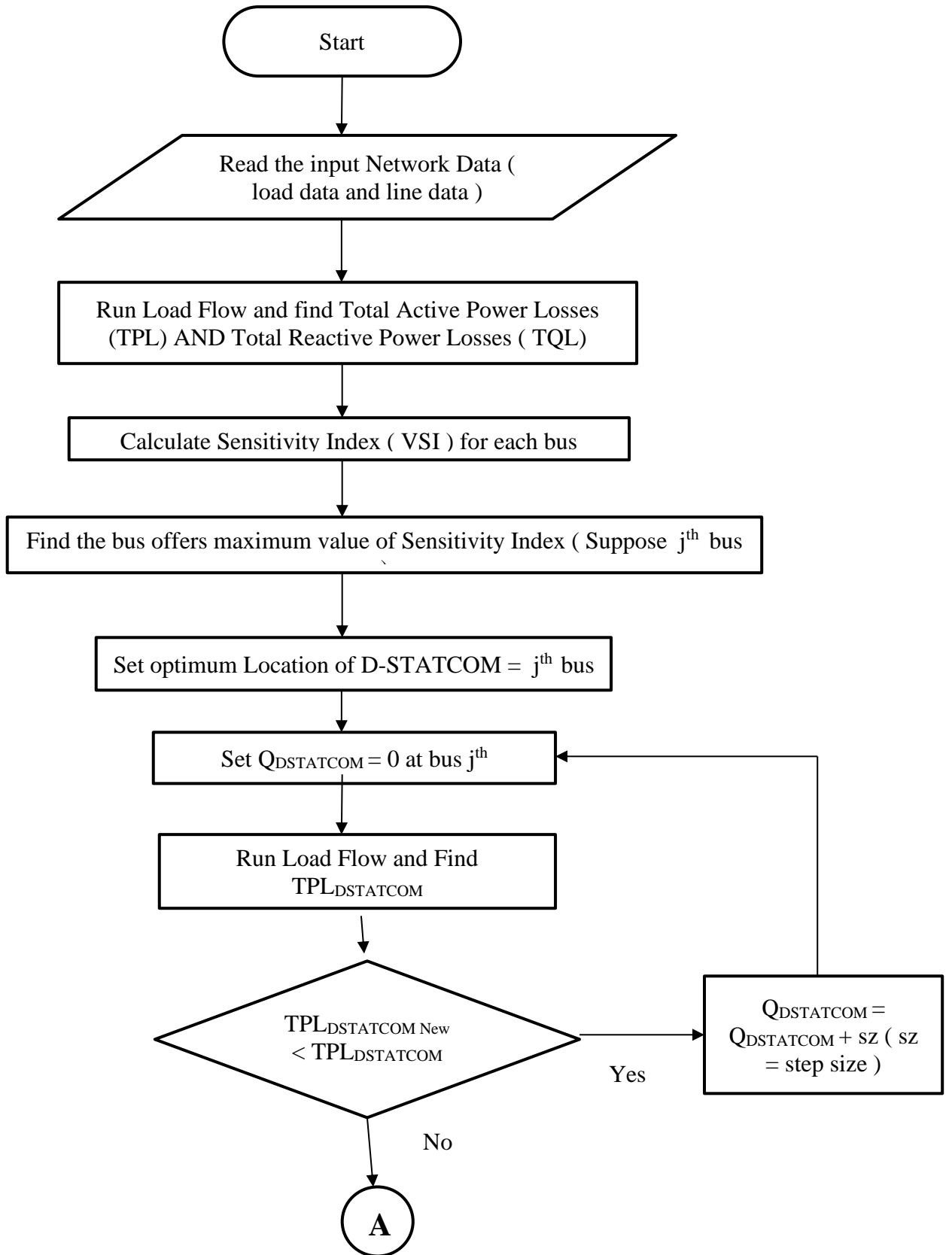
Step 2: Place the D-STATCOM at candidate bus with size varying in steps of 50 KVAR

Step 3: Find the losses after placement of D-STATCOM.

Step 4: Select the size of D-STATCOM which gives minimum losses.

Step 5: Stop.

3.3 Flow Chart of Proposed Methodology



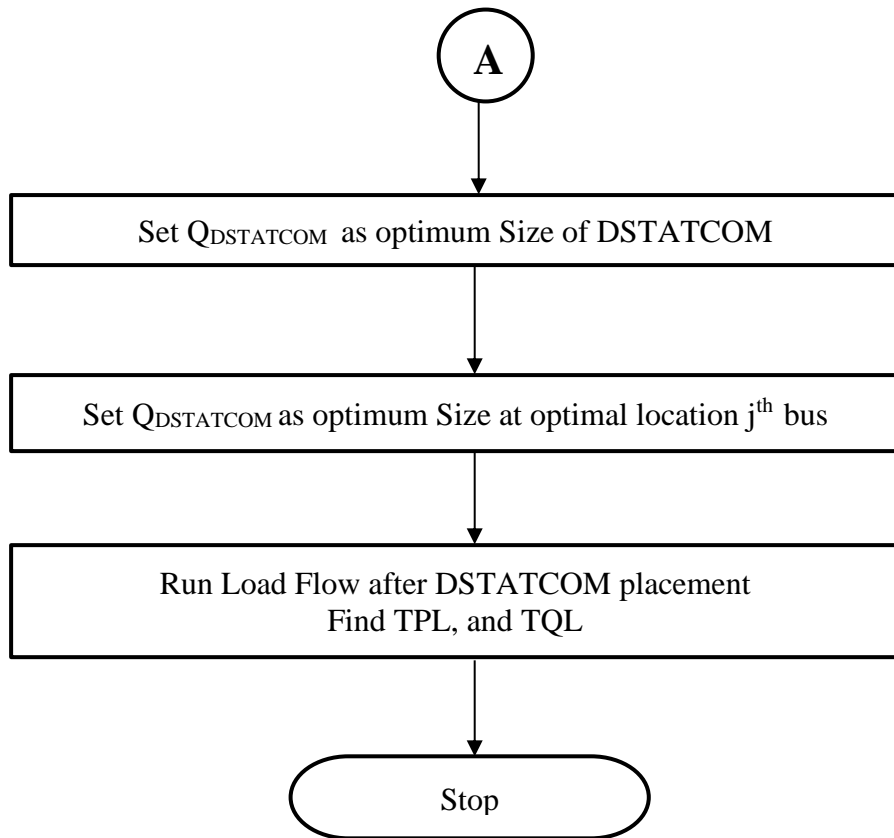


Figure 3:Flowchart of Proposed System

CHAPTER FOUR: EXPECTED OUTCOMES

- Improve distribution system by reducing power losses and improving voltage profiles using D-STATCOM devices in the optimal locations and sizes as determined by this proposed method.
- Energy savings are anticipated due to the lesser size of D- STATCOM required along with the reduction of line losses will enhance the power transmission capability.

CHAPTER FIVE: RESULT AND DISCUSSION

5.1 Load Flow Analysis of 33 Test Bus System

Table 8: Voltage Profile and Power loss in 33 Test Bus System

Bus No	Voltage (pu)	Branch No	Active Power Loss(KW)	Reactive Power Loss(KVAR)
1	1		0	0
2	0.997038547	1-2	12.19332189	15.36051758
3	0.982978213	2-3	51.5711351	48.29247661
4	0.975521707	3-4	19.79340576	21.65437072
5	0.968150394	4-5	18.59307931	21.03622619
6	0.949796508	5-6	38.02565427	74.06301088
7	0.94634273	6-7	1.913078362	52.05597305
8	0.941495231	7-8	4.834177391	17.24247674
9	0.935242526	8-9	4.177332944	38.60396591
10	0.929442973	9-10	3.557541344	36.72228607
11	0.928582046	10-11	0.553073448	3.060581379
12	0.927080926	11-12	0.880221606	1.337247846
13	0.920992127	12-13	2.663757376	3.38885528
14	0.918745444	13-14	0.728555663	1.622033486
15	0.917343326	14-15	0.356856434	0.623206166
16	0.915982221	15-16	0.281320134	0.452560561
17	0.913977769	16-17	0.251482745	0.899885446
18	0.913373718	17-18	0.053102918	0.172378172
19	0.996183863	2-19	0.25926263	3.940388191
20	0.992608821	19-20	0.832707742	18.27019756
21	0.991905277	20-21	0.10082228	5.592183727
22	0.991269024	21-22	0.043662262	9.181230293
23	0.979393336	3-23	3.181201344	2.4830946
24	0.97272481	23-24	5.143202368	4.699233982
25	0.969401695	24-25	1.287331231	1.317460163
26	0.947880076	6-26	2.594008193	0.08260666
27	0.945334416	26-27	3.321056189	0.074781348
28	0.933930866	27-28	11.27662095	0.276293464
29	0.925743161	28-29	7.817989336	0.0988582
30	0.92221882	29-30	3.888125789	1.988934441
31	0.918038551	30-31	1.592823445	1.58097857
32	0.917117945	31-32	0.213084662	0.249427438
33	0.916832579	32-33	0.013161647	0.020552165
			201.99	134.74

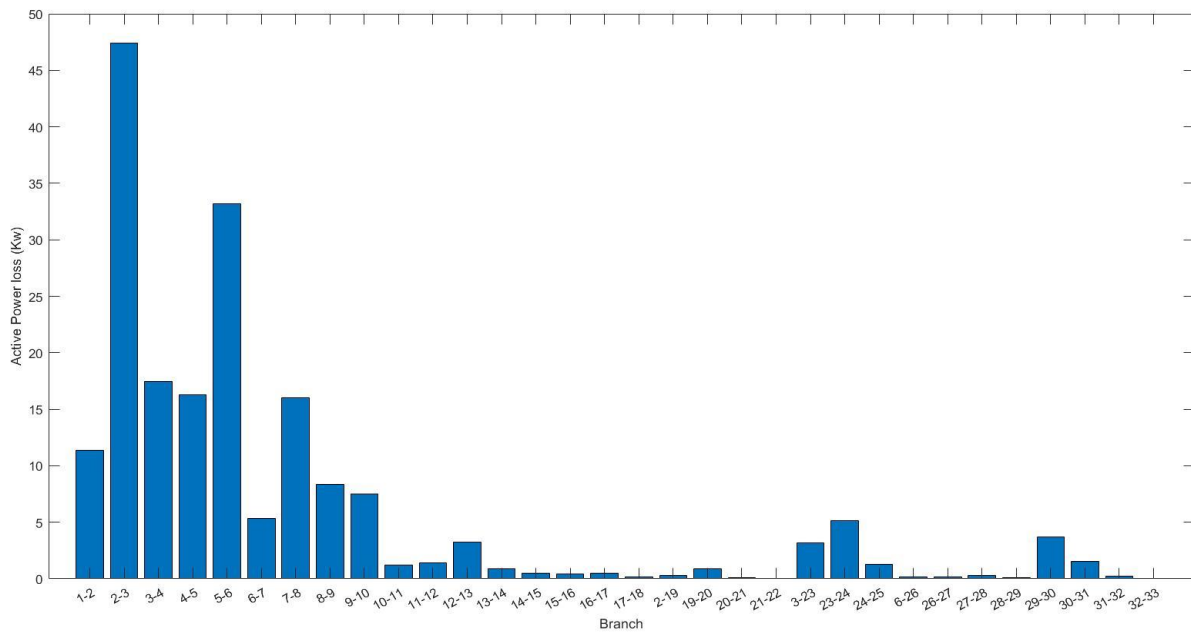


Figure 4:Active Power Loss in 33 Test Bus System

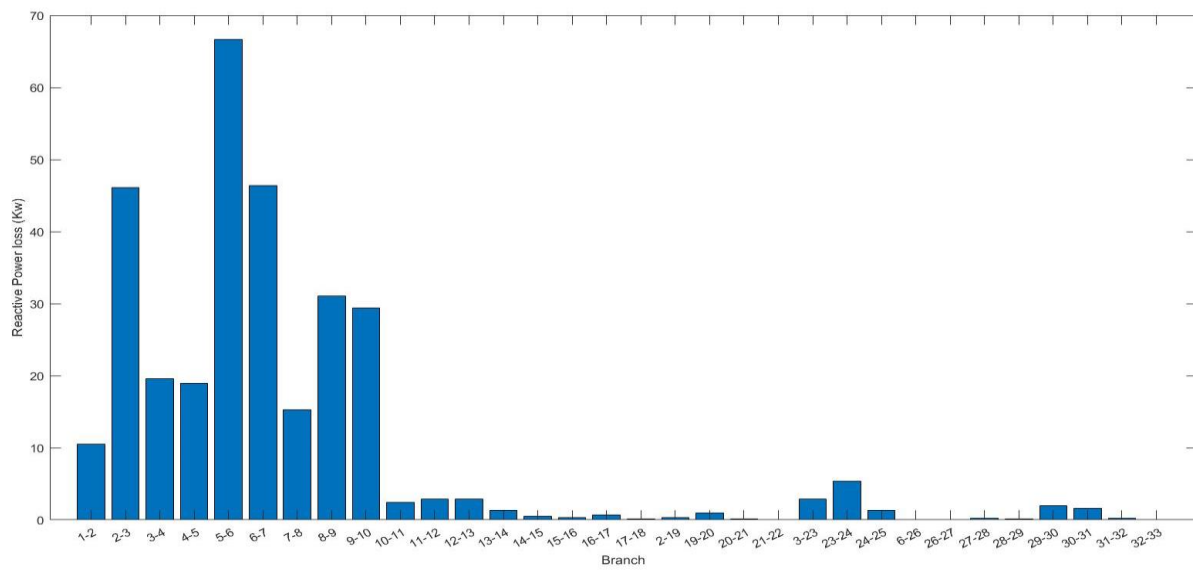


Figure 5:Reactive Power Loss in 33 Test Bus System

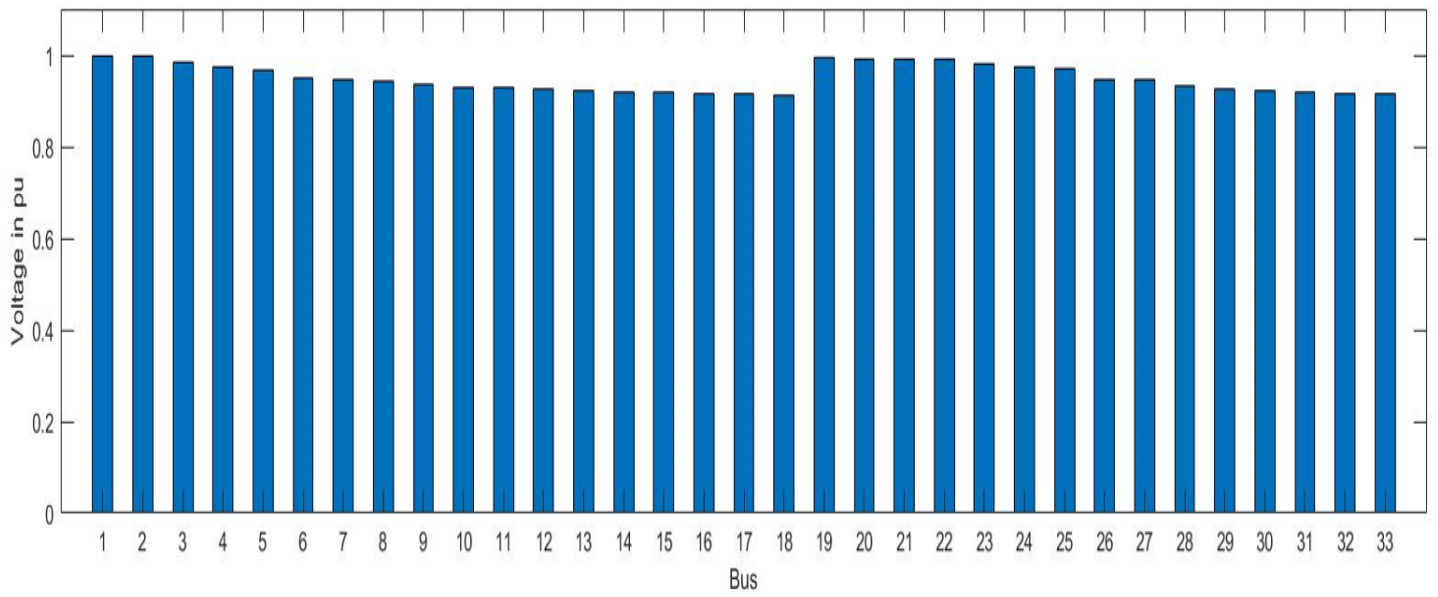


Figure 6: Voltage Profile of 33 Test Bus

Backward/Forward sweep algorithm is purposed in testing IEEE 33-bus radial distribution system using MATLAB coding. IEEE 33 bus radial distribution network consists of 33 nodes and 32 branches. The base voltage for this system is 12.66 kV and base MVA is 100. The Total Real power loss is 201.99KW and Total Reactive power loss is 134.74KVAR. The maximum voltage drop occurs in Bus no 18 which is of value 0.9133 pu and becomes 0.9168 pu at Bus no 33.

5.2 Load flow Analysis of Begnas Feeder

Table 9: Voltage Profile and Power loss in Begnas Feeder

Bus No	Voltage (pu)	Branch No	Active Power Loss(KW)	Reactive Power Loss(KVAR)
1	1	1	0	0
2	0.994313148	1-2	25.98540153	29.81931323
3	0.986543414	2-3	35.12130338	40.30313502
4	0.982950887	3-4	16.16423758	18.54912509
5	0.982617885	4-5	0.035539319	0.021849279
6	0.982361875	5-6	0.018216972	0.011199643
7	0.976623293	4-7	27.15561829	31.16218492
8	0.976233884	7-8	0.121884953	0.139867979
9	0.976163065	8-9	0.013301777	0.015264334
10	0.976077885	9-10	0.005333521	0.006120434
11	0.973325205	7-11	4.31250971	2.651295197
12	0.970971121	11-12	2.739771982	1.684389088
13	0.969435339	12-13	1.676767618	1.030862823
14	0.969386135	13-14	0.003557572	0.002187166
15	0.966985927	13-15	2.497482506	1.535431528
16	0.966012486	15-16	0.851490205	0.523489115
17	0.965058247	16-17	0.138725945	0.08528756
18	0.964397768	17-18	0.048029566	0.029528178
19	0.964905768	16-19	0.706216649	0.810412548
20	0.964684293	19-20	0.008051787	0.004950172
21	0.963651534	19-21	0.681071554	0.781557521
22	0.962876956	21-22	0.371414576	0.426213448
23	0.962129183	22-23	0.382401834	0.235097475
24	0.961017212	23-24	0.32530236	0.199993192
25	0.960272808	24-25	0.163405398	0.100460283
26	0.95999463	25-26	0.010855688	0.004108394
27	0.959494598	25-27	0.121578347	0.046011989
28	0.95918261	27-28	0.036559866	0.013836281
29	0.958897404	28-29	0.011142728	0.004217026
30	0.955846744	29-30	8.710958792	9.99618222
31	0.951252375	30-31	12.84529369	14.74050096
32	0.947446504	31-32	10.41370752	11.95015617
33	0.944042486	32-33	9.106792226	10.45041731
34	0.943709067	33-34	0.06603901	0.07578247
35	0.94350606	34-35	0.020110158	0.023077231
36	0.94341839	35-36	0.002895373	0.00332256
37	0.940436875	33-37	8.948138897	10.26835611
38	0.935785205	37-38	10.94908656	12.56452556
39	0.928418329	38-39	16.89773465	19.39084304
40	0.922072188	39-40	14.39158268	16.51493095
41	0.920273036	40-41	1.893130829	2.172445214
42	0.919357118	41-42	0.90099725	1.033931271
43	0.918155344	42-43	1.141147237	1.309513222
44	0.917203796	43-44	0.09767931	0.036967268
45	0.916706085	44-45	0.030662629	0.011604439

46	0.916558504	45-46	0.003031051	0.001147118
47	0.915902638	43-47	1.944711275	2.23163589
48	0.914006525	47-48	1.572383353	1.804374339
49	0.91174654	48-49	1.79687188	2.061984125
50	0.910367051	49-50	0.611116283	0.701280981
51	0.909612124	50-51	0.174337775	0.200059742
52	0.908294913	51-52	0.246607544	0.093329972
53	0.907072223	52-53	0.178155637	0.067423974
54	0.905924804	53-54	0.119489368	0.045221404
55	0.905518884	54-55	0.016905176	0.006397856
56	0.90526275	54-56	0.04137339	0.015657985
57	0.905072053	56-57	0.003972961	0.001503589
58	0.919032137	40-58	3.711482937	4.25907878
59	0.914356977	58-59	5.993611825	3.684822832
60	0.908681704	59-60	6.393444671	3.930636749
61	0.901386576	60-61	7.937571636	4.879953199
62	0.900804347	61-62	0.04874443	0.018447596
63	0.900399541	62-63	0.016949278	0.006414547
64	0.895738511	61-64	5.252013787	3.22889451
65	0.89122954	64-65	4.105217855	2.523853884
66	0.888738105	65-66	2.068583638	1.271748061
67	0.883913519	66-67	3.812577377	2.343940945
68	0.880336771	67-68	2.536859384	1.559640106
69	0.877560601	68-69	1.856311186	1.141244719
70	0.873831146	69-70	2.41826034	1.486726398
71	0.870953993	70-71	1.628862987	1.001411453
72	0.867303993	71-72	1.916012357	1.177948504
			272.5285894	280.4847242

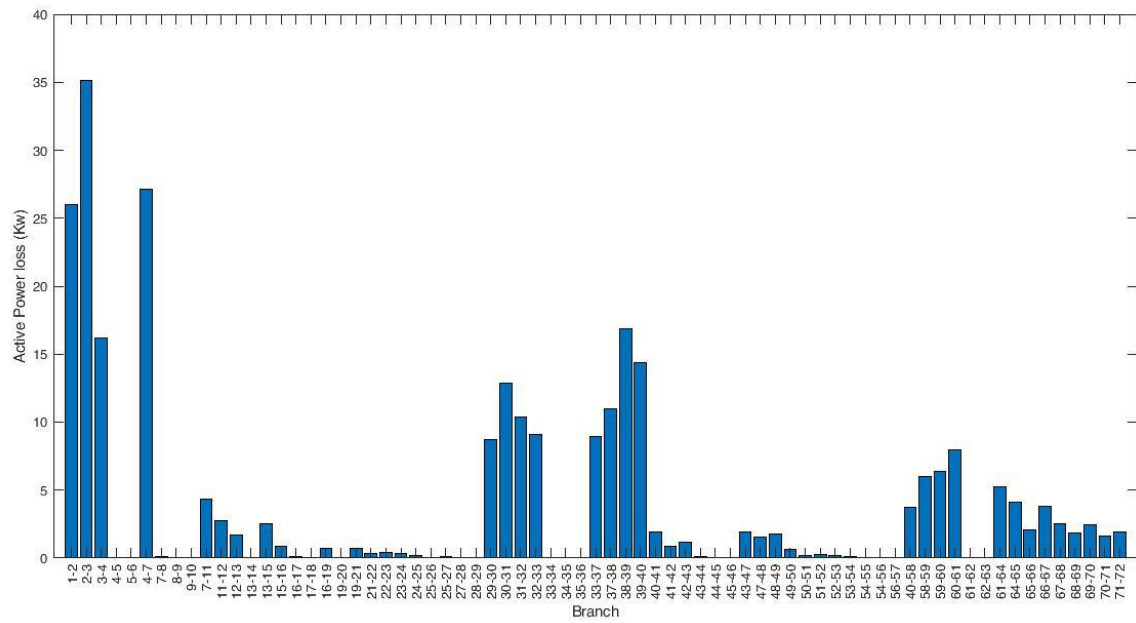


Figure 7: Active Power Loss in Begnas Feeder

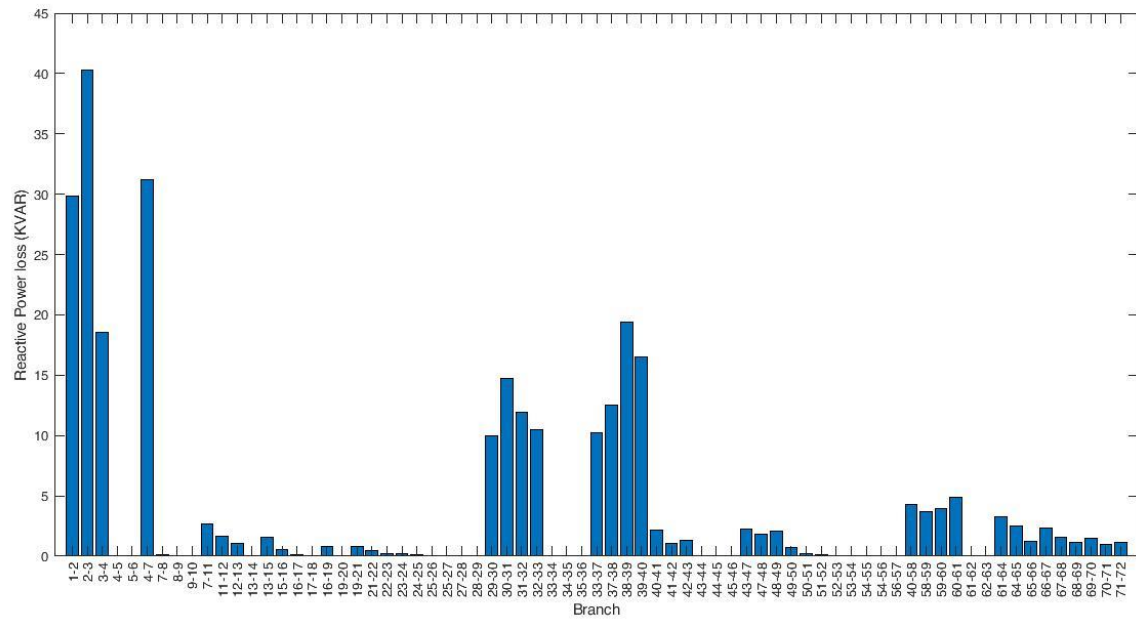


Figure 8: Reactive Power Loss of Begnas Feeder

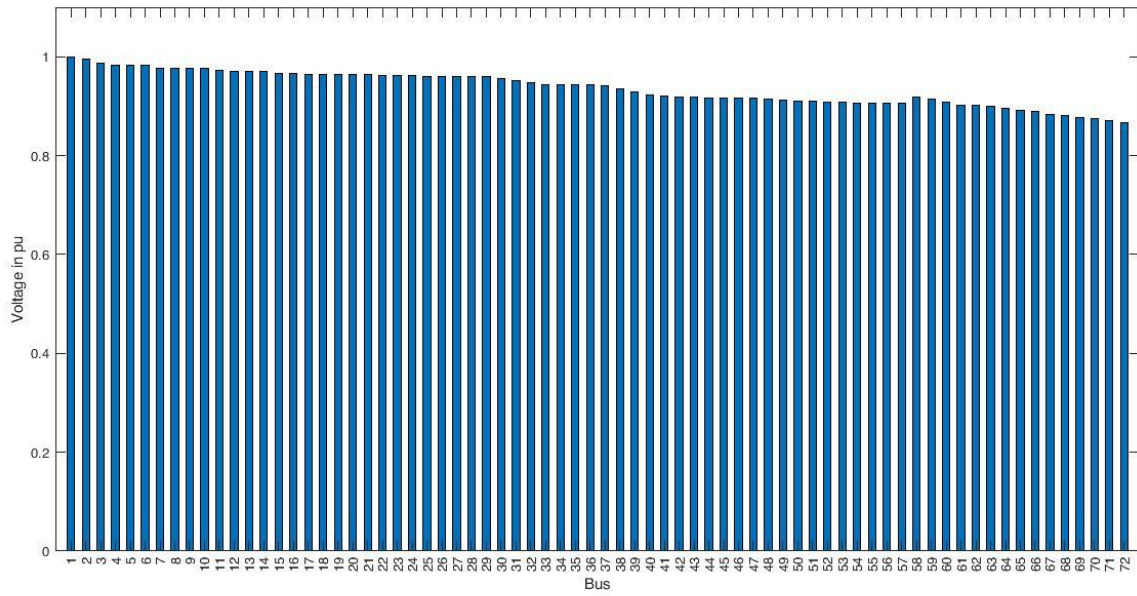


Figure 9 : Voltage Profile of Begnas Feeder

For the load flow in the 11 kv Begnas feeder, The base voltage for this system is 11 kV and base MVA is 100. The Total Real power loss is 272.528 KW and Total Reactive power loss is 280.484 KVAR. The maximum voltage drop occurs in Bus no 72 which is of value 0.8673 pu .

CHAPTER SIX : REMAINING WORKS

The remaining works in the project are:

- Calculation of VSI for all the buses and selection of candidate bus with the highest value of VSI for the optimal placement of D-STATCOM in Begnas Feeder .
- Calculation of Losses after placement of D-STATCOM in the candidate bus with the size varying in the steps of 50 kVAR and select the size of D-STATCOM which gives the minimum losses
- Compare Power loss and load flow in a bus before and after placement of D-STATCOM in Begnas Feeder .

CHAPTER SEVEN : WORK SCHEDULE

Tasks	June 14	June 21	Jun 30	July 10	July31	Aug 10	Aug20	Aug 25	Sep5
Project Selection & Proposal writing									
Proposal Defense									
Literature review									
Data Collection									
Load Flow Analysis of IEEE 33 Bus System									
Load Flow Analysis in the Real Feeder System									
Load Flow Analysis and Optimal Size / location selection in real feeder system after D-STATCOM penetration.									
Documentation and report writing									

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APPENDIX

Table 10: Specification of ACSR Conductor

Data for Aluminium Conductors Steel Reinforced (ACSR) As per IS 398 (Part-II): 1996																
Code Words	Aluminium Area (Sq.mm)		Total Sectional Area (Sq.mm)	Stranding & Wire Diameter				Overall Dia (mm) (Approximate)	Weight Mass			Resistance at 20°C (ohm/ km) (Max)	Ultimate Breaking Load (N)	Current Carrying Capacity		
	Sectional Area	Nominal Area		Conductor (Al)		Conductor (Steel)			Al kg/ km	Steel kg/ km	Total kg/ km			90°C	75°C	65°C
				No.	Dia (mm)	No.	Dia (mm)									
Kundah	404.1	400	425.2	42	1.96	7	1.96	26.88	1119	163	1282	0.07311	88790	-	705	566
Zebra	428.9	420	484.5	54	3.18	7	3.18	28.62	1182	439	1621	0.06868	130320	-	737	590
Moose	528.5	520	597	54	3.53	7	3.53	31.77	1463	535	1998	0.05595	159600	-	836	667
Racoon	78.83	80	91.97	6	4.09	1	4.09	12.27	215	103	318	0.3712	26910	-	244	200
Panther	212.1	200	261.5	30	3	7	3	21	588.5	387.5	976	0.139	89670	-	487	395
Squirrel	20.98	20	24.48	6	2.11	1	2.11	6.33	58	27	85	1.394	7610	-	107	89
Weasel	31.61	30	36.88	6	2.59	1	2.59	7.77	87	41	128	0.9289	11120	-	138	114
Mole	10.6	10	12.37	6	1.5	1	1.5	4.5	29	14	43	2.78	3970	-	70	58
Dog	105	100	118.5	6	4.72	7	1.57	14.15	288.3	105.7	394	0.2792	32410	-	291	239
Rabbit	52.88	50	61.7	6	3.35	1	3.35	10.05	145	69	214	0.5524	18250	-	190	157
Wolf	158.1	150	194.9	30	2.59	7	2.59	18.13	438	289	727	0.1871	67340	-	405	329

ACSR Code Number	Type of ACSR	Calculated Resistance at 20°C (ohms/km) (Max)	Current Rating Max. (Amps)	Nominal Aluminium Area (sq. mm)	Inductive Reactance (ohm/km)	Weight (kg/km)
1	Squirrel	1.374	76	20	0.355	80
2	Gopher	1.098	85	25	0.349	106
3	Weasel	0.9116	95	30	0.345	128
4	Rabbit	0.5449	135	50	0.335	214
5	Otter	0.3434	185	80	0.328	339
6	Dog	0.2792	205	100	0.315	394

Table 11 : Line Data of 33 Test Bus System

Branch No	From	To	R (ohm)	X (ohm)
1	1	2	0.0922	0.047
2	2	3	0.493	0.2511
3	3	4	0.366	0.1864
4	4	5	0.3811	0.1941
4	5	6	0.819	0.707
6	6	7	0.1872	0.6188
7	7	8	0.7114	0.2351
8	8	9	1.03	0.74
9	9	10	1.044	0.74
10	10	11	0.1966	0.065
11	11	12	0.3744	0.1238
12	12	13	1.468	1.155
13	13	14	0.5416	0.7129
14	14	15	0.591	0.526
15	15	16	0.7463	0.545
16	16	17	1.289	1.721
17	17	18	0.732	0.574
18	2	19	0.264	0.2565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.898	0.7091
24	24	25	0.896	0.7011
25	6	26	0.203	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.059	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.963
31	31	32	0.3105	0.3619
32	32	33	0.341	0.5302

Table 12: Load Data 33 Test Bus System

Branch No	P (KW)	Q (KVAR)
1	0	0
2	100	60
3	90	40
4	120	80
4	60	30
6	60	20
7	200	100
8	200	100
9	60	20
10	60	20
11	45	30
12	60	35
13	60	35
14	120	80
15	60	10
16	60	20
17	60	20
18	90	40
19	90	40
20	90	40
21	90	40
22	90	40
23	90	50
24	420	200
25	420	200
26	60	25
27	60	25
28	60	20
29	120	70
30	200	600
31	150	70
32	210	100
33	60	40

Table 13: Line Data of Begnas Feeder

Branch Number	From Bus	To Bus	Length(km)	R(ohm)	X(ohm)
		1			
1	1	2	0.324	0.088938	0.10206
2	2	3	0.45	0.123525	0.14175
3	3	4	0.21	0.057645	0.06615
4	4	5	0.529	0.288252	0.177215
5	5	6	0.61	0.332389	0.20435
6	4	7	0.39	0.107055	0.12285
7	7	8	0.32	0.08784	0.1008
8	8	9	0.097	0.026627	0.030555
9	9	10	0.35	0.096075	0.11025
10	7	11	0.43	0.234307	0.14405
11	11	12	0.345	0.187991	0.115575
12	12	13	0.24	0.130776	0.0804
13	13	14	0.116	0.063208	0.03886
14	13	15	0.41	0.223409	0.13735
15	15	16	0.19	0.103531	0.06365
16	16	17	1.12	0.610288	0.3752
17	17	18	1.55	0.844595	0.51925
18	16	19	0.45	0.123525	0.14175
19	19	20	1.04	0.566696	0.3484
20	19	21	0.6	0.1647	0.189
21	21	22	0.42	0.11529	0.1323
22	22	23	0.25	0.136225	0.08375
23	23	24	0.65	0.354185	0.21775
24	24	25	0.58	0.316042	0.1943
25	25	26	0.83	0.756628	0.28635
26	25	27	0.58	0.528728	0.2001
27	27	28	0.31	0.282596	0.10695
28	28	29	0.85	0.77486	0.29325
29	7	30	0.29	0.079605	0.09135
30	30	31	0.448	0.122976	0.14112
31	31	32	0.381	0.104585	0.120015
32	32	33	0.35	0.096075	0.11025
33	33	34	0.45	0.123525	0.14175
34	34	35	0.548	0.150426	0.17262
35	35	36	0.71	0.194895	0.22365
36	33	37	0.402	0.110349	0.12663

37	37	38	0.55	0.150975	0.17325
38	38	39	0.9	0.24705	0.2835
39	39	40	0.79	0.216855	0.24885
40	40	41	0.482	0.132309	0.15183
41	41	42	0.263	0.072194	0.082845
42	42	43	0.358	0.098271	0.11277
43	43	44	1.09	0.993644	0.37605
44	44	45	0.95	0.86602	0.32775
45	45	46	0.845	0.770302	0.291525
46	43	47	0.74	0.20313	0.2331
47	47	48	0.65	0.178425	0.20475
48	48	49	0.81	0.222345	0.25515
49	49	50	0.89	0.244305	0.28035
50	50	51	0.936	0.256932	0.29484
51	51	52	0.83	0.756628	0.28635
52	52	53	0.99	0.902484	0.34155
53	53	54	1.3	1.18508	0.4485
54	54	55	1.15	1.04834	0.39675
55	54	56	1.25	1.1395	0.43125
56	56	57	1.08	0.984528	0.3726
57	40	58	0.71	0.194895	0.22365
58	58	59	0.65	0.354185	0.21775
59	59	60	0.9	0.49041	0.3015
60	60	61	1.2	0.65388	0.402
61	61	62	0.82	0.747512	0.2829
62	62	63	1.14	1.039224	0.3933
63	61	64	1.09	0.593941	0.36515
64	64	65	0.89	0.484961	0.29815
65	65	66	0.54	0.294246	0.1809
66	66	67	1.1	0.59939	0.3685
67	67	68	0.91	0.495859	0.30485
68	68	69	0.75	0.408675	0.25125
69	69	70	1.04	0.566696	0.3484
70	70	71	0.92	0.501308	0.3082
71	71	72	1.26	0.686574	0.4221

Table 14: Load Data of Begnas Feeder

Branch Number	From Bus	To Bus	PL (KW)	QL(KVAR)
		1	0	0
1	1	2	75.2	27.288
2	2	3	37.6	13.644
3	3	4	150.4	54.576
4	4	5	37.6	13.644
5	5	6	75.2	27.288
6	4	7	0	0
7	7	8	150.4	54.576
8	8	9	150.4	54.576
9	9	10	75.2	27.288
10	7	11	150.4	54.576
11	11	12	75.2	27.288
12	12	13	0	0
13	13	14	75.2	27.288
14	13	15	150.4	54.576
15	15	16	0	0
16	16	17	75.2	27.288
17	17	18	75.2	27.288
18	16	19	75.2	27.288
19	19	20	37.6	13.644
20	19	21	75.2	27.288
21	21	22	37.6	13.644
22	22	23	225.6	81.864
23	23	24	75.2	27.288
24	24	25	37.6	13.644
25	25	26	37.6	13.644
26	25	27	37.6	13.644
27	27	28	75.2	27.288
28	28	29	37.6	13.644
29	7	30	75.2	27.288
30	30	31	75.2	27.288
31	31	32	75.2	27.288
32	32	33	0	0
33	33	34	112.8	40.932
34	34	35	75.2	27.288
35	35	36	37.6	13.644
36	33	37	150.4	54.576

37	37	38	75.2	27.288
38	38	39	37.6	13.644
39	39	40	0	0
40	40	41	75.2	27.288
41	41	42	37.6	13.644
42	42	43	0	0
43	43	44	37.6	13.644
44	44	45	37.6	13.644
45	45	46	18.8	6.822
46	43	47	37.6	13.644
47	47	48	37.6	13.644
48	48	49	376	136.44
49	49	50	225.6	81.864
50	50	51	75.2	27.288
51	51	52	37.6	13.644
52	52	53	37.6	13.644
53	53	54	0	0
54	54	55	37.6	13.644
55	54	56	37.6	13.644
56	56	57	18.8	6.822
57	40	58	75.2	27.288
58	58	59	150.4	54.576
59	59	60	37.6	13.644
60	60	61	75.2	27.288
61	61	62	37.6	13.644
62	62	63	37.6	13.644
63	61	64	18.8	6.822
64	64	65	75.2	27.288
65	65	66	37.6	13.644
66	66	67	75.2	27.288
67	67	68	37.6	13.644
68	68	69	18.8	6.822
69	69	70	75.2	27.288
70	70	71	37.6	13.644
71	71	72	473.76	171.9144