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The Reconfiguration of Kaduna Municipal Area Distribution Network For Power Loss Reduction And Voltage Profile Improvement Using Static Var Compensators (SVC)

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ABSTRACT

The increase in global and Nigerian demand for electricity due to technological advancements has brought about numerous challenges, including voltage instability, power factor problems, and high-power losses in electrical power distribution networks. This paper presents the placement of a Static Var Compensator (SVC) in the power distribution network of Town One Station, Kaduna, Nigeria, to investigate its impact on improving and addressing the network's poor voltage profile and reducing the active power loss experienced by the network. For analysis, the bus voltage, power, and the current passing through the chosen feeders were measured and noted appropriately. The network parameters, including route length, transformer parameters, and maximum power flow, were obtained from the Kaduna Electricity Distribution Company in Kaduna, Nigeria. The distribution network was modelled and simulated in the ETAP software environment, both with and without Static Var Compensator (SVCs). The results obtained from the simulation indicated that buses 5, 7, 8, and 47, among others, have a voltage magnitude of 0.743– 0.932 pu, which is clearly outside the acceptable limit of 0.95– 1.05 pu. Further results showed that the network experienced real and reactive power losses of 8,527 kW and 23,535 kVAr, respectively. After the placement of the SVC with a 5.75MVAR rating, the active power loss decreased from 8527 kW to 6751 kW, indicating a 20.82% reduction in total active power loss experienced by the network. Additionally, the minimum network's bus voltage improved from 0.743 to 1.02 p.u.

1. INTRODUCTION

The world population's demand for electrical energy is steadily increasing, resulting in increased energy usage across a range of activities, including farming, businesses, household purposes, clinics, and more [1][2]. Network connection systems must be robust and optimized to meet the required power needs [3][4]. Electrical energy has become the backbone of the world economy, thus necessitating its proper utilization, as power demand continues to grow globally [5][6]. Its rapid growth and complexity of high- and low-voltage electricity distribution systems, in addition to its attendant losses, underscore the need for efficient distribution network reconfiguration techniques to adapt to changing operational conditions and, by extension, minimize its losses [7]-[10]. These distribution systems comprise interconnected nodes, which often encounter issues such as network congestion, suboptimal routing, losses, and component failures, which affect their overall performance. By implementing distribution network enhancement through FACTS controller devices, which involves identifying the weakest individual nodes and their interconnections for optimal reconfiguration of the network [11]. Network reconfiguration consists of the installation, monitoring, and management of systems to enhance the behavior, resilience, and overall performance of the network [12][13]. The total power loss in a distribution system can be high for large-scale systems. According to [14] power losses on transmission and sub-transmission lines made up 30% of the total power losses. In comparison, losses in the distribution network

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system accounted for 70% of the total losses in the power system network. Power loss directly affects the operational cost of a power system. In [15][16], it was estimated that operational losses amounted to USD 5,851.85 million, which was attributed to power system losses. Technically, power losses could also reduce the voltage profile of the distribution system, especially in heavily loaded systems [17]-[19]. The Town One Power network of the Kaduna Municipal area is radiated from the 5X150MVA, 330/132 kV Mando transmission station. The 132/33/11 kV Town One network receives its supply from the 150 MVA power transformer T5 at the 330/132 kV Mando transmission station in Kaduna. In Nigeria, according to Nigerian Electricity Regulatory Commission (NERC) data, power losses in the electricity distribution network represent the single most significant component of its supply chain. These distribution network losses have become a massive concern to the system, as it has become necessary to improve power quality and efficiency in distribution networks, thereby minimizing losses. To enhance the efficiency of the distribution system, loss minimization is the only alternative [20][21]. Thus, it is found that, for the last three decades, research in distribution systems has been focused on line loss minimization and voltage regulation [22][23]. This research is poised to identify efficient ways to minimize the losses by utilizing distribution network reconfiguration using optimal placement of a FACTS controller device, specifically the Static Var Compensator (SVC) device, due to its proven effectiveness, fast response time, and cost efficiency for reactive power compensation and voltage regulation on the Town One power network of the Kaduna municipal area distribution network.

2. LITERATURE SURVEY

An optimal placement of distributed generation in an 11 kV distribution network was carried out. This work primarily focuses on assessing the reliability of the distribution network to evaluate the impact of optimally sizing and placing distributed generation (DG) in the Ikwerre Road 11 kV distribution network. The results obtained showed that total branch losses without DG are 113.668 kW and 64.41 kVAr; with DG at the optimal bus, the branch losses are 27.046 kW and 16.277 kVAr. Voltage at the least bus improved from 0.943 pu to 1.003 pu. The work done by [24] proposed an approach that employed the ABC algorithm to determine the size and location of the DG unit, aiming to reduce the system's real power loss and enhance the voltage profile. The result obtained is then tested on the IEEE 34-bus system using MATLAB and ETAP 12.6 to assess the reliability of the algorithm. The authors achieved a significant reduction in active power losses and a substantial improvement in the voltage profile.

2.1 Power Flow Analysis

To determine the intricate electrical power system, load flow analysis is an appropriate method [25][26]. It is a useful tool for efficient planning and behavior monitoring, as well as for determining the ideal size and placement of shunt devices to raise voltage levels, improve power factor, and reduce network power loss [27][28].

2.2 The Flexible AC Transmission System (FACTS) Controllers

These are devices (controllers) that are used for improving the controllability and raising transferability of electrical energy in a power network [22]. FACTS controllers are of several types and configurations, some of which include: Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor-controlled series compensator (TCSC), Thyristor-controlled phase shifter (TCPS), and Static Synchronous Series Compensator (SSSC)[29][30]. The FACTS controller considered in this study is the Static Var Compensator.

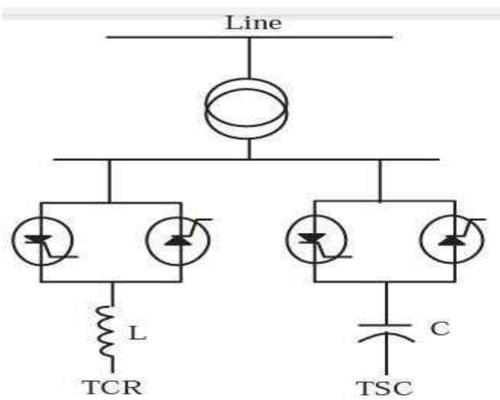

Figure 1. Static Var Compensator

2.3 General Classification of FACTS Devices

FACTs devices are classified into four types. These are: Series Compensation Devices, Shunt Compensation Devices, Series-Shunt Compensation, and Series-Series Compensation [31]-[33]. They are further classified in Figure 2 below.

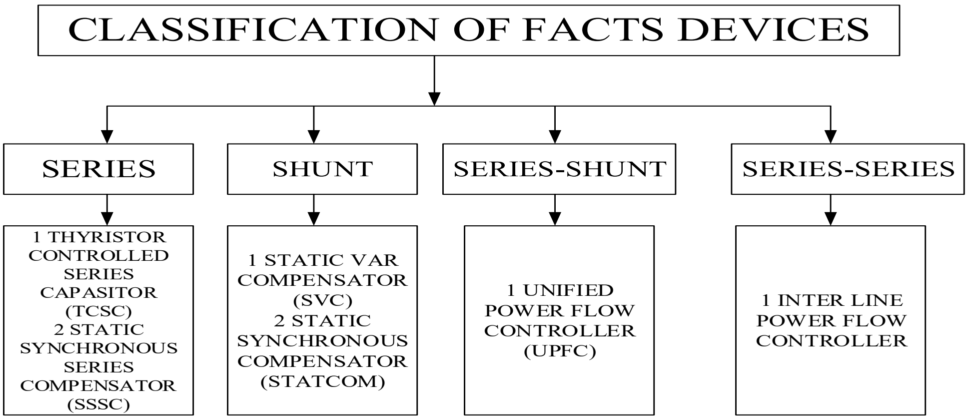

Figure 2. Classes of FACTS Devices

3. MATERIALS AND METHODS

The test networks considered in this study are a 132/33 kV sub-transmission network and a 33/11 kV distribution network located in the municipal area of Kaduna, Nigeria. The sub-transmission station comprises 4 x 60 MVA power transformers and 10 33 kV outgoing feeders. The distribution station consists of 11 15 MVA Power transformers, 7 7.5 MVA power transformers, and 2 2.5 MVA power transformers, located in 10 different 33/11 kV injection substations, with a total of 35 11 kV outgoing feeders. The network has a total radial route length of 297.475km. The one-line diagram of the station is as shown in Figure 3. The relevant network data chosen in this study were obtained from the Kaduna Electricity Distribution Company, Nigeria.

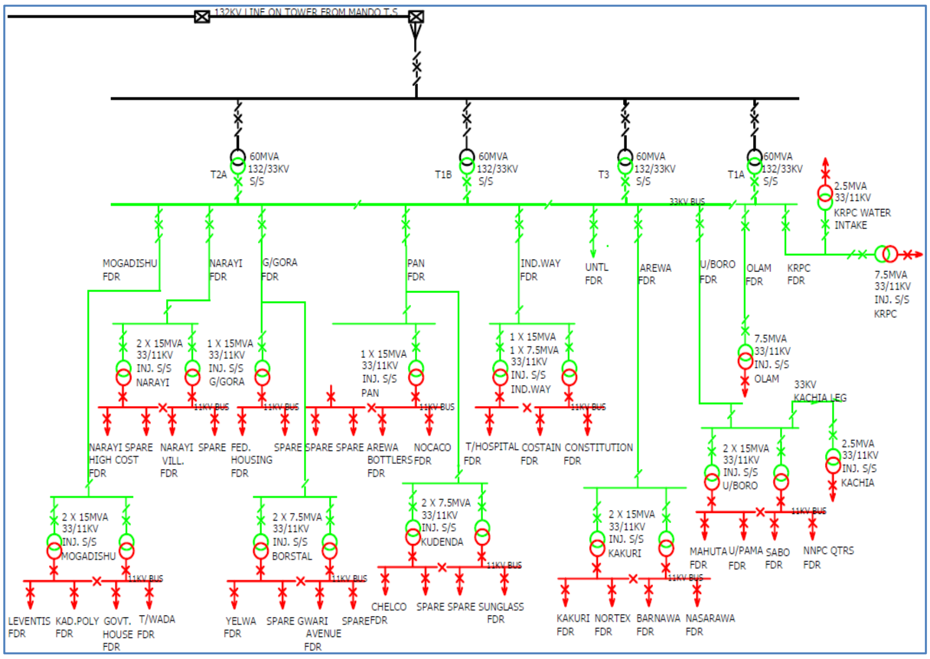

Figure 3. One Line Diagram of 132/33kV Town I power station, Kaduna

3.1 Simulation Environment and Implementation:

The simulations were carried out using ETAP 19.0.1. The town's one power network's grid energy allocation is 115 MW, and the SVC sizing and placement were carried out using 5% of the rated network's megawatt allocation capacity. Load flow analysis was performed for the two scenarios using ETAP's built-in Newton-Raphson iterative load flow techniques, and the results for both scenarios were recorded accordingly. Materials and data used include:

- Line and Bus data of the town's one power network (as provided in Tables IV & V in the appendix below)
- Network Capacity: 115 MW
- Software: ETAP 19.0.1
- SVC size selected: 4 x 5.75 MVAR
- Processor: Intel Core i7, 16GB RAM
- Operating System: Windows 10 Pro

3.2 Load Flow analysis procedure of the Network using Newton-Raphson technique

The network is represented by an equivalent one-line diagram in a balanced distribution system, as shown in Figure 3 above. The shunt capacitance of the line at distribution voltage levels is relatively small and, therefore, can be neglected [34][35]. The procedure for the load flow techniques is given in Figure 4.

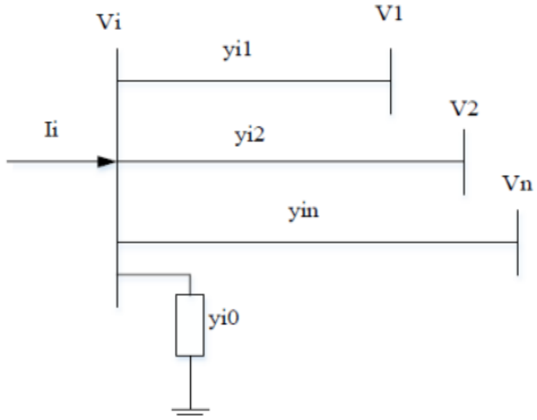

Figure 4. A typical Bus Loading of a power system

About Figure 4 above, the power flow equations in polar form are formulated for an 'n' bus system in the form of a bus admittance matrix Y as;

$$I_i = \sum_{j=1}^{n} y_{ij}\, V_j \tag{1}$$

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| < \theta_{ij} + \delta_j \tag{2}$$

Where *i and j represent the bus's ith* and *jth,* respectively.
The real and reactive power at the bus i is given by:

$$P_i + jQ_i = V_i I_i^* \tag{3}$$

$$\text{or} \quad I_i = \frac{P_i - jQ_i}{V_i^*} \tag{4}$$

Substituting for I_i Equation 4 above gives:

$$P_i - jQ_i = \sum_{j=1}^{n} |V_i||Y_{ij}||V_j| < (\theta_{ij} + \delta_j - \delta_i) \tag{5}$$

The real and imaginary parts is separated as:

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| cos(\theta_{ij} - \delta_i + \delta_j) \tag{6}$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| sin(\theta_{ij} - \delta_i + \delta_j) \tag{7}$$

Expansion of Equations 6 & 7 in Taylor's series and ignoring higher order terms results in:

$$\begin{bmatrix} \frac{\partial P2}{\partial \delta 2} & \cdots & \frac{\partial P2}{\partial \delta n} & \frac{\partial P2}{\partial |V2|} & \cdots & \frac{\partial P2}{\partial |Vn|} \\ \vdots & & \vdots & \vdots & & \vdots \\ \frac{\partial Pn}{\partial \delta 2} & \cdots & \frac{\partial Pn}{\partial \delta n} & \frac{\partial Pn}{\partial |V2|} & \cdots & \frac{\partial P2}{\partial |V2|} \\ \frac{\partial Q2}{\partial \delta 2} & \cdots & \frac{\partial Q2}{\partial \delta n} & \frac{\partial Qi}{\partial |Vi|} & \cdots & \frac{\partial P2}{\partial |Vn|} \\ \vdots & & \vdots & \vdots & & \vdots \\ \frac{\partial Qn}{\partial \delta 2} & \cdots & \frac{\partial Qn}{\partial \delta n} & \frac{\partial Qn}{\partial |V2|} & \cdots & \frac{\partial Qn}{\partial |Vn|} \end{bmatrix} \begin{bmatrix} \Delta\delta 2 \\ \cdot \\ \cdot \\ \Delta\delta n \\ \Delta|V2| \\ \cdot \\ \cdot \\ \Delta|Vn| \end{bmatrix} = \begin{bmatrix} \Delta P2 \\ \cdot \\ \cdot \\ \Delta Pn \\ \Delta Q2 \\ \cdot \\ \cdot \\ \Delta Qn \end{bmatrix} \quad (8)$$

The ΔPi & ΔQi terms in equation (8) are the difference between the preset and calculated values of power given as:

$$\Delta P_i = P_i{}^{sch} - P_i \quad (9)$$

$$\Delta Q_i = Q_i{}^{sch} - Q_i \quad (10)$$

Substituting Equation (8) into Equations (9) and (10), and calculating ΔVi and $\Delta\delta i$ to complete an iteration. The calculated new values are used for the next iteration (k+1).

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \quad (11)$$

$$|V_i|^{(k+1)} = |V_i|^{(k)} + \Delta|V_i|^{(k)} \quad (12)$$

The Newton-Raphson method of iteration can be implemented using the following algorithm:

Step 1: Read the system data, i.e., bus data, line data, etc.

Step 2: Create the bus admittance matrix Y_{bus}

Step 3: Select the initial phase angle and voltage magnitude settings to match the slack bus values. $|V_i| = 1.0\ and\ \delta_i = 0.0$, in a load bus $P_i and\ Q_i$ is specified. $P_i^{sc} and |V_i|$ are definite for generator buses, the phase angle is set at the slack bus angle, $\delta_i = 0.0$

Step 4: Set the Iterative count at $k = 0$ and set the tolerance $\epsilon \leq 0.0001$

Step 5: Use the estimated value of $|V_i| = 1.0\ and\ \delta_i = 0.0$ to determine the applied $P_i^k and\ Q_i^k$ and an equal number of $\Delta Q_i^k and\ \Delta P_i^k$ mismatch.

Step 6: Use the estimated value of $|V_i| = 1.0\ and\ \delta_i = 0.0$ to determine the Jacobian elements of the matrix i.e. $J_1,\ J_2, J_3 and\ J_4$.

Step 7: Solve for $\Delta|V_i| and\ \delta_i$ and update $\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)}, |V_i|^{(k+1)} = |V_i|^{(k)} + \Delta|V_i|^{(k)}$.

Step 8: Check if the residuals ΔQ_i^k and$\Delta P_i^k\ are \leq \epsilon$. Stop the process if YES. If not, go back to step 5 to start the next iteration with the update in step 7, and with the advanced iteration count of $k = k + 1$.

3.3 Static VAR Compensator (SVC) Device Placement

I. SVC Sizing: can be determined based on the reactive power (Q) requirement for voltage support [36][37].

$$Q = V^2/X \quad (13)$$

Equation (13) gives the equation to calculate the reactive power needed

Where;

Q is the reactive power provided by the SVC

V is the voltage at the point of connection

X is the reactance of the line where the SVC is connected

II. SVC Placement: can be determined by minimizing the system's total reactive losses [38][39].

3.4 Research Approach

The modeling and simulation of the Town I power station network in Kaduna were carried out using data obtained from Kaduna Electric on the Electrical Transient Analyzer Program (ETAP software).

1. Simulation without Static Var compensator (SVCs):

Simulation without SVCs was carried out. The one-line diagram network shown in Figure 3 was modeled and simulated in the ETAP software environment. Figure 4 illustrates how a virtual diagrammatic simulator was created using the chosen network data as inputs.

The following steps are used to run the simulation:

Step 1: Selection of components: Power system components like transformers, distribution lines, buses, and loads are selected from the ETAP library.

Step 2: Development of the Network: A single-line diagram was created using various elements from the ETAP library.

Step 3: Mode of analysis: The Newton-Raphson Technique was employed for network modeling and simulation due to its remarkable convergence properties.

Step 4: Simulation Output: The power flow was carried out, and the results were obtained.

2. Simulation with Static Var compensator (SVCs):

Using the same procedures outlined in the preceding section, a simulation with SVCs is conducted. The SVCs are applied to weak buses identified in the network. The chosen network is then subjected to a computer simulation to obtain results based on the data used as inputs [40][41].

4. RESULTS AND DISCUSSIONS

This section presents the results obtained from the simulation in tables and figures, which demonstrate the impact of incorporating a Static Var Compensator (SVC) controller device into Town One's power network in Kaduna. The simulations were carried out using the ETAP software environment.

Table 1. Bus Loading and Voltage Profile of Town One Network Before SVC Placement

Bus No.	Voltage (pu)	Angle (Degree)	Load		Substation		Injected kVAr
			kW	kVAr	kW	kVAr	
1	1.0000	0.0000	0	0	116294	80248	0
2	0.9537	-4.35	35155.9	19078.7	0	0	0
3	0.939	-4.91	39176.2	24972.6	0	0	0
4	0.9546	-3.96	32067.1	19020.4	0	0	0
5	0.9888	-1.15	9624	4986	0	0	0
6	0.8662	-2.52	19669.8	10520.2	0	0	0
7	0.8292	-6.72	8210.5	3700.9	0	0	0
8	0.8175	-8.41	11285.6	4561.6	0	0	0
9	0.949	-4.32	4490.2	2964.1	0	0	0
10	0.9499	-4.42	8558.5	5183.3	0	0	0
11	0.9187	-5.96	4427	2743.6	0	0	0
12	0.908	-7.37	4496.8	2423.9	0	0	0
13	0.9129	-7	3973.3	2141.1	0	0	0
14	0.9330	-4.89	6860.7	4100.3	0	0	0
15	0.9344	-4.89	7367.3	4723.7	0	0	0
16	0.9013	-7.86	6823.2	3612.5	0	0	0
17	0.8956	-7.54	3928.7	2426.2	0	0	0
18	0.9051	-7.17	3358.4	1810.3	0	0	0
19	0.9325	-4.88	12122.1	7705.6	0	0	0
20	0.9105	-6.62	4147.1	2547.8	0	0	0
21	0.8932	-8.29	7889.9	4297	0	0	0
22	0.9345	-4.89	12588.7	8320	0	0	0

Bus No.	Voltage (pu)	Angle (Degree)	Load		Substation		Injected kVAr
			kW	kVAr	kW	kVAr	
23	0.9019	-7.44	6027.3	3717	0	0	0
24	0.8827	-9.58	6463.6	3443.5	0	0	0
25	0.9389	-3.89	14412.7	8822.5	0	0	0
26	0.904	-6.76	7464.6	4310.8	0	0	0
27	0.9083	-6.86	6857.1	3486.1	0	0	0
28	0.9404	-3.9	14398.6	8682.6	0	0	0
29	0.8993	-7.76	8960.5	4463.3	0	0	0
30	0.9152	-6.21	5348.1	3093.2	0	0	0
31	0.9489	-3.98	2764.4	1260.5	0	0	0
32	0.9794	-1.15	2355.6	1219.3	0	0	0
33	0.9887	-1.15	1000.4	513.9	0	0	0
34	0.9639	-2.67	2349.4	1137.8	0	0	0
35	0.972	-2.49	995.1	482	0	0	0
36	0.9888	-1.15	881.6	449.7	0	0	0
37	0.9741	-2.33	877.4	425	0	0	0
38	0.9782	-1.15	5305.5	2761.3	0	0	0
39	0.9623	-2.7	2387.9	1156.5	0	0	0
40	0.9657	-2.28	812.3	346	0	0	0
41	0.9338	-1.08	1999.1	1103.8	0	0	0
42	0.8971	-4.14	1974.5	956.3	0	0	0
43	0.8054	-6.67	4909.2	2377.6	0	0	0
44	0.8182	-6.79	3116.2	1231.6	0	0	0
45	0.793	-8.6	4263.3	1547.4	0	0	0
46	0.7929	-8.51	6693.4	2851.4	0	0	0
47	0.9782	-4.14	2800.5	1735.6	0	0	0
48	0.8938	-7.34	4424.8	2388.3	0	0	0
49	0.8954	-6.96	3895.9	2102.8	0	0	0
50	0.8869	-7.87	4480.3	2169.9	0	0	0
51	0.9001	-7.85	2267.6	1405.3	0	0	0
52	0.8807	-7.45	3859.6	2392	0	0	0
53	0.8909	-7.14	3304.8	1783.7	0	0	0
54	0.8734	-6.4	3968.2	2459.3	0	0	0
55	0.8188	-7.83	2890	1791.1	0	0	0
56	0.8189	-6.57	4262.2	2300.5	0	0	0
57	0.8943	-7.39	3079.5	1908.5	0	0	0
58	0.8669	-7.23	2800.5	1735.6	0	0	0
59	0.7469	-9.27	5453.2	2943.3	0	0	0
60	0.8868	-6.66	4548.5	2818.9	0	0	0
61	0.8952	-6.75	2794.7	1431.8	0	0	0
62	0.9002	-6.82	1543.8	790.9	0	0	0
63	0.8181	-6.61	4763.2	2440.3	0	0	0
64	0.8747	-7.77	4374.3	2118.6	0	0	0
65	0.868	-7.73	4306.6	2206.4	0	0	0
66	0.8786	-5.99	3700.8	2293.5	0	0	0
67	0.9119	-6.21	1478.5	716	0	0	0

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Table 2. Bus Loading and Voltage Profile of Town One Network After Svc Placement

Bus No.	Voltage (pu)	Angle (Degree)	Load		Substation		Injected kVAr
			kW	kVAr	kW	kVAr	
1	1.000	0.000	0	0	111539	232830	0
2	0.9988	-4.2	34398.6	9937.4	0	0	0
3	0.9881	-5.0	40621.1	15806	0	0	0
4	0.9786	4.0	33325.4	10117.1	0	0	0
5	0.9943	-1.2	9729.3	2390.6	0	0	0
6	0.9803	-4.6	20721.4	4518.1	0	0	0
7	0.9705	-8.0	8576.5	3862.1	0	0	0
8	0.998	-9.5	12011.8	5809.7	0	0	0
9	0.9952	-4.2	4543.3	3004	0	0	0
10	0.9928	-4.2	8682.2	5212.1	0	0	0
11	0.9711	-5.9	4517.6	2799.7	0	0	0
12	0.9557	-7.0	4560.2	2459.2	0	0	0
13	0.9603	-6.6	4039.8	2177.2	0	0	0
14	0.9823	-5.0	7025.6	4161.1	0	0	0
15	0.9836	-5.0	7613.5	4852.6	0	0	0
16	0.9754	-7.7	6990.2	3701.9	0	0	0
17	0.993	-7.4	4057.3	2509	0	0	0
18	1.0026	-7.1	3479.3	1875.8	0	0	0
19	0.9823	-5.0	11809.7	6713.8	0	0	0
20	0.9851	-6.6	4220.4	2600.2	0	0	0
21	0.9518	-7.9	7522.2	3436.3	0	0	0
22	0.9848	-5.1	13970.3	6030.8	0	0	0
23	0.977	-7.5	6184.4	3816.3	0	0	0
24	1.0469	-10.2	7639.9	7112.2	0	0	0
25	0.967	-4.5	15558.5	6637.7	0	0	0
26	0.9551	-7.2	7416	4045	0	0	0
27	1.0101	-7.9	8033.8	8245.1	0	0	0
28	0.9647	-4.0	14539.6	8723.8	0	0	0
29	0.9248	-7.7	8976.7	4471.7	0	0	0
30	0.9866	-6.2	5476.8	3169.4	0	0	0
31	0.973	-1.2	2790.6	1272.4	0	0	0
32	0.9849	-1.2	2360.7	1221.2	0	0	0
33	0.9942	-2.7	1002.6	514.7	0	0	0
34	0.9694	-2.5	2354.5	1140.3	0	0	0
35	0.9776	-1.2	997.3	483	0	0	0
36	0.9943	-2.3	883.5	450.4	0	0	0
37	0.9797	-1.4	879.4	425.9	0	0	0
38	0.9857	-2.9	5413	1611	0	0	0
39	0.9699	-2.5	2395	1159.9	0	0	0
40	0.9732	-3.9	814.7	347.1	0	0	0
41	0.963	-7.4	2079.2	1502.1	0	0	0
42	0.9944	-8.1	2050.1	2669.9	0	0	5.75
43	0.9586	-8.1	5194.7	2515.9	0	0	0
44	0.9606	-9.6	3285.3	1298.4	0	0	0
45	0.9767	-10.4	4562.7	1656	0	0	0
46	0.9905	-5.9	7202.8	8953.2	0	0	5.75
47	0.9586	-4.5	2800.5	1735.6	0	0	0

Bus No.	Voltage (pu)	Angle (Degree)	Load		Substation		Injected kVAr
			kW	kVAr	kW	kVAr	
48	0.9462	-6.6	4513.8	2436.3	0	0	0
49	0.9434	-7.7	3967.5	2141.5	0	0	0
50	0.9686	-7.7	4622.1	2238.6	0	0	0
51	0.9743	-7.4	2333.1	1445.9	0	0	0
52	0.9828	-7.1	4013.4	2487.3	0	0	0
53	0.9893	-6.4	3432.3	1852.6	0	0	0
54	0.9578	-8.2	4097.1	2539.1	0	0	0
55	0.9232	-7.9	2926.2	961.8	0	0	0
56	0.9414	-7.4	4458.9	2406.7	0	0	0
57	0.9698	-7.3	3169.8	1964.5	0	0	0
58	0.9439	-20.3	2882.7	1786.5	0	0	0
59	0.9964	-7.1	5973.6	11161.3	0	0	5.75
60	0.9183	-7.2	4602.5	2852.4	0	0	0
61	0.9272	-7.9	2701.5	1137.2	0	0	0
62	1.0025	-16.0	1606.3	822.9	0	0	0
63	0.9878	-7.7	5075.8	11466.2	0	0	5.75
64	0.9092	-7.6	4430.8	2146	0	0	0
65	0.9027	-6.0	4362.4	2234.9	0	0	0
66	0.9518	-6.2	3804.8	2358	0	0	0
67	0.9834	-5.3	1519.9	736.1	0	0	0

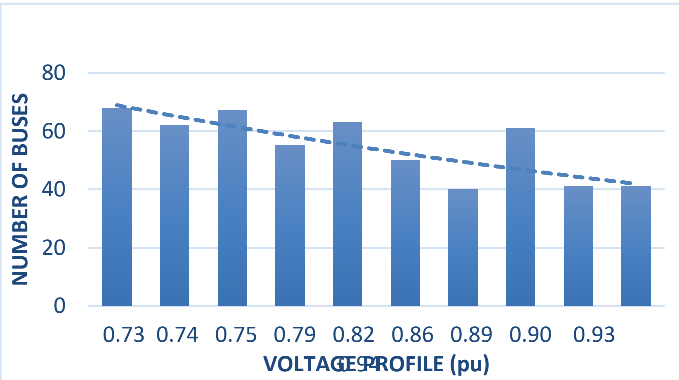

Figure 7a. Chart of Voltage Profile without SVCs

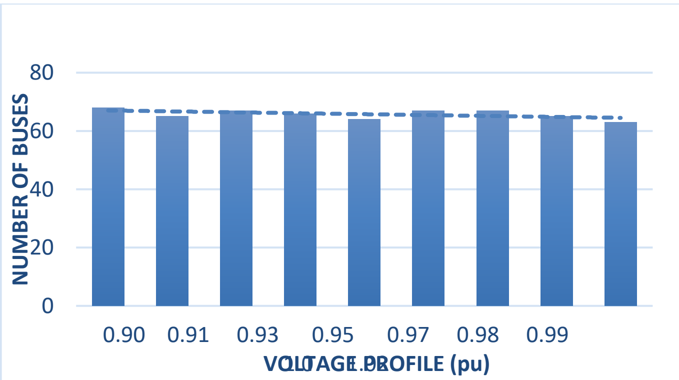

Figure 7b. Chart of Voltage Profile with SVCs

.

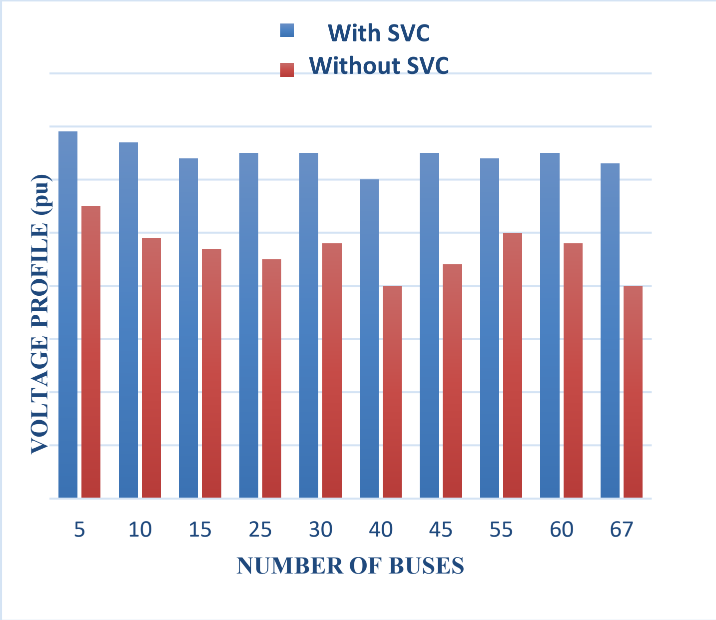

Figure 7c. Chart Voltage Profile

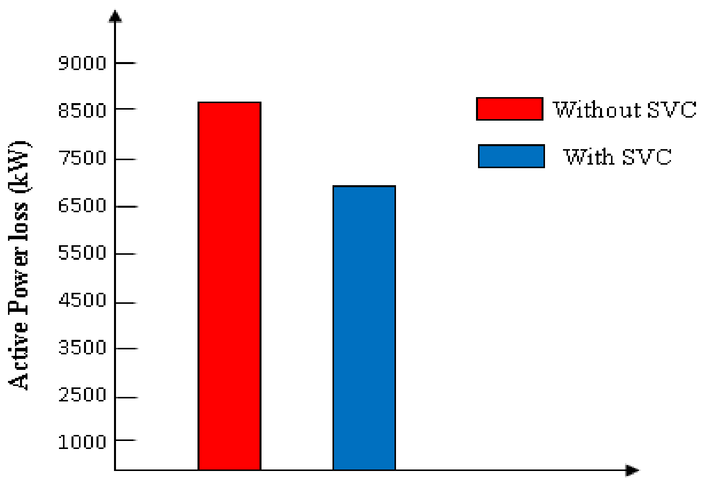

Figure 8. Active power loss for town I network before and after SVCs placement

Table 3. Comparison of results before and after SVC placement

	Before Reconfiguration with SVC	After Reconfiguration with SVC
Tie Switches		42, 46, 59, 63
Power Loss (kW)	8527	6751
Power Loss Reduction (%)	26.30	20.82
Minimum Voltage (pu)	0.743	1.02

4.1 Discussion

The results of the simulations conducted for the Town one 67 – bus network with and without the SVCs are shown in Figure 7, this result represents the voltage magnitude and phase angles of the buses as indicated in Table I and II above. The total active power loss experienced by the network with and without the SVCs is shown in Figure 8. Table III contains the comparison of the results for the two scenario, i.e. with and without the SVCs placement.

4.1.1 Simulation without SVCs

The results of the simulations carried out for the 67 – bus town one network without the SVCs showed that, some of the buses are operating outside the acceptable limit of 0.95 pu to 1.05 pu. The buses operating outside the acceptable limits are bus 7, bus 8, bus 9, and 46 others with the minimum load bus voltage of 0.743 pu. The real and reactive power loss of 8527 kW and 23535 kVAr was experienced by the network.

4.1.2 Simulation with SVCs

The simulations of the network with the SVCs showed a remarkable improvement of voltage profile, as well as significant reduction of power loss as seen Figure 7, 8, and Table 2 and 3. After the placement, the minimum load bus voltage improved from 0.743 pu – 1.02 pu and also the active power loss reduced from 8527 kW – 6751 kW. The weakest buses identified in network are bus 42, 46, 59, and 63. In order to understand the impact of placement of the FACTs device fully, SVCs of 4 x 5.75MVAR rating are placed on the weakest buses in the network.

5. CONCLUSION

The existing 67-bus, 132/33/11 kV, 115 MW Town One Power Network was successfully modeled and analyzed using the ETAP software environment. Simulation results of the existing network indicated that approximately 51 buses operated outside the acceptable voltage range of 0.95 – 1.05 pu. The minimum load bus voltage was found to be 0.743 pu, with total active and reactive power losses of 8527 kW and 23535 kVAr, respectively. To mitigate these losses and enhance network performance, a static VAR compensator (SVC) rated at 4 × 5.75 MVAr was implemented and optimally placed at four of the weakest buses. Load flow analysis incorporating the SVCs demonstrated an improvement in the minimum voltage level from 0.743 pu to 1.02 pu, and a reduction in active power loss from 8527 kW to 6751 kW, representing a 20.82% decrease. As SVC performance is generally influenced by distance, future work may consider the integration of more advanced FACTS devices such as STATCOM or UPFC to achieve improved voltage regulation and overall network efficiency

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APPENDIX A

Table IV. Line Data of Town I Power Station Network

Line No.	From Bus	To Bus	R (ohms)	X(ohms)
1	1	2	0.265	0.131
2	6	7	0.264	0.131
3	1	3	0.494	2.023
4	6	8	0.264	0.4127
5	1	4	0.264	1.247
6	9	47	3.159	0.317
7	1	5	0.265	0.0953
8	10	12	0.211	0.127
9	10	13	0.265	0.125
10	14	16	0.323	0.131
11	15	17	0.264	1.247
12	15	18	3.159	0.317
13	19	20	0.265	0.0953
14	19	21	0.211	0.127
15	22	23	0.265	0.125
16	22	24	0.323	0.131
17	25	26	0.0639	0.0969
18	25	27	0.1361	0.2063
19	28	29	0.1335	0.2024
20	28	30	0.0347	0.0527
21	32	34	0.0172	0.0261
22	33	25	0.1138	0.1724
23	36	37	0.1836	0.2782

Line No.	From Bus	To Bus	R (ohms)	X(ohms)
24	38	39	0.0696	0.1056
25	38	40	0.1432	0.2171
26	41	42	0.1323	0.2006
27	7	43	0.1178	0.1786
28	7	44	0.1826	0.2769
29	8	45	0.0799	0.1211
30	8	46	0.1144	0.1734
31	47	11	0.0582	0.0882
32	12	48	0.0716	0.1085
33	13	49	0.265	0.131
34	16	50	0.264	0.131
35	16	51	0.494	2.023
36	17	52	0.264	0.4127
37	18	53	0.264	1.247
38	20	54	3.159	0.317
39	21	55	0.265	0.0953
40	21	56	0.211	0.127
41	23	57	0.265	0.125
42	23	58	0.323	0.131
43	24	59	0.264	1.247
44	26	60	3.159	0.317
45	26	61	0.0639	0.0969
46	27	62	0.1361	0.2063

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Line No.	From Bus	To Bus	R (ohms)	X(ohms)
47	27	63	0.1335	0.2024
48	29	64	0.0347	0.0527
49	29	65	0.0172	0.0261
50	30	66	0.1138	0.1724
51	30	67	0.1836	0.2782
52	4	25	0.0696	0.1056
53	2	10	0.1432	0.2171
54	2	9	0.1323	0.2006
55	5	36	0.265	0.131
56	3	22	0.264	0.131
57	5	38	0.494	2.023
58	3	15	0.264	0.4127
59	2	6	0.264	1.247
60	3	19	3.159	0.317
61	5	32	0.265	0.0953
62	3	14	0.211	0.127
63	5	33	0.265	0.0953
64	4	28	0.211	0.127
65	4	31	0.265	0.125
66	38	41	0.323	0.131

Table V. Bus Data of Town I Power Station Network

Bus No.	P (kW)	Q (kVAr)
1	115000	42539
2	8617	3876
3	7037	3728
4	7662	4436
5	3389	1641
6	11832	4751
7	4570	2832
8	8667	4678
9	7488	4364
10	8628	2980
11	4435	2750
12	4498	2425
13	3974	2142
14	6861	4100
15	3978	2718
16	6823	3613
17	3929	2426

Bus No.	P (kW)	Q (kVAr)
18	3359	1810
19	4166	2737
20	4147	2548
21	7615	4325
22	6068	4126
23	3107	1922
24	6464	3443
25	7519	4860
26	4642	2865
27	1558	797.5
28	14623	8799
29	8961	4463
30	5348	3093
31	2764	1260
32	2356	1219
33	1000	513.9
34	2349	1138
35	995.1	482
36	881.6	449.7
37	887.4	425
38	5364	2791
39	2388	1157
40	812.3	346
41	1999	1104
42	1975	956.3
43	5031	2437
44	3194	1262
45	4370	1586
46	6861	2923
47	865.4	338
48	4426	2389
49	3897	2103
50	4480	2170
51	2268	1405
52	3860	2392
53	3305	1784
54	3968	2459
55	2890	1791
56	4347	2346
57	3080	1909
58	2801	1736
59	5453	2943
60	4548	2819
61	2795	1432
62	1544	790.9
63	4763	2440
64	4374	2119
65	4307	2206
66	3701	2294
67	1478	716

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