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Analysis of voltage drop using transformer tap changer and placement of capacitor bank with genetic algorithm

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ABSTRACT

The demand for electrical energy is increasing due to high economic growth and population. The impact is that electrical energy operates excessively to meet the required demand. Unbalanced loads, higher power losses on the line, and voltage drops that are higher than allowed are just a few of the issues that may result from this. Adding tap changers and capacitor banks is one method of improving the voltage profile and power losses. To conduct this study, tap changers and capacitor banks were added to the IEEE 33 bus network system. The value, capacity, and location of the tap changers and capacitor banks in the system were ascertained using the genetic algorithm (GA) approach. According to the simulation results, the voltage profile, which initially had 21 buses outside the IEEE standard limits, may be ideal by installing two tap changers and two capacitor banks. Additionally, reactive power losses decreased from 41.8 kVar to 93.3 kVar, and active power losses decreased from 202.7 kW to 130.7 kW, a decrease of 72 kW.

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1. INTRODUCTION

The reliability of the electric power distribution system plays a very important role in the comfort and safety of consumers. The reliability index is a method of evaluating the reliability parameters of electric power distribution equipment against the reliability of the quality of service to customers. One of the problems that occurs in the distribution transmission is voltage drop. Voltage drop is the amount of voltage lost in a conductor [1], [2]. This disturbance occurs because of the length of a conductor in a medium voltage distribution channel, and this is quite interesting to analyze and understand because the impact of this disturbance results in poor service to consumers.

This research has some knowledge gaps, such as numerous studies have also been carried out, including one on the new optimal voltage control strategy in the electric power distribution network using the line drop compensation method based on the adaptive on-load tap changer (OLTC) transformer technique. This method analyses the voltage quality of the electric power distribution network by adjusting the transformation ratio of the step-down power transformer station to determine parameters that characterize the optimal voltage control law [3], [4]. After that, some use the L-index method, which is a numerical method. This method selects the voltage to be optimised; using these voltage values, the L-index can be calculated to identify which buses are vulnerable. With the help of this L-index, the voltage stability margin can be shown, and the voltage safety level can be maintained economically [5]-[7]. Then, there is the problem of voltage drops in the 150 kV transmission, which has been solved by adding capacitors, thereby increasing the voltage in the 7-8 kV range.

If one of the generator conditions is not working, adding capacitors can boost the power transmission between subsystems and raise the voltage to its nominal range. At the very least, adding capacitors to the subsystem can lessen blackouts from low voltage [8]. Based on the research that has been done, by using the adaptive OLTC transformers techniques [9] and and using L-index under various transformers tap changer [5], [10], [11], the results are proven by using the adaptive OLTC and L-index Techniques, which can overcome power losses and voltage drops. Meanwhile, define the problem as framing the voltage drop and power loss as a multi-objective optimization challenge in radial distribution networks.

Our study identified important techniques for enhancing the voltage profile and power losses based on prior research and the previously described problem backdrop. Our novel contribution is adding a tap changer and capacitor bank to the IEEE 33 bus network system [12], [13]. We use the innovative genetic algorithm (GA) [14]-[16] method to determine the value, capacity, and location of the tap changer and capacitor bank. GA can perform optimization problems with complex problems and very large search spaces. This approach allows us to optimize the system for improved performance and reliability. Optimizes both tap changer and capacitor bank placement using a GA, a rare approach in a unified framework.

2. METHOD

This study examined how the IEEE 33 bus distribution network's transformer tap changer and capacitor bank arrangement could reduce voltage loss [17], [18]. Figure 1 shows the IEEE 33 bus network system's single-line diagram, while Tables 1 and 2 display the conductor and load statistics, respectively, with a nominal voltage of 12.66 kV. The data is then modelled using ETAP software to determine the system's power losses and voltage drops, which serve as a starting point for executing the case under study. Then, using MATLAB software, the author creates a GA program to determine the system's optimal network solution. Figure 2 describes the GA.

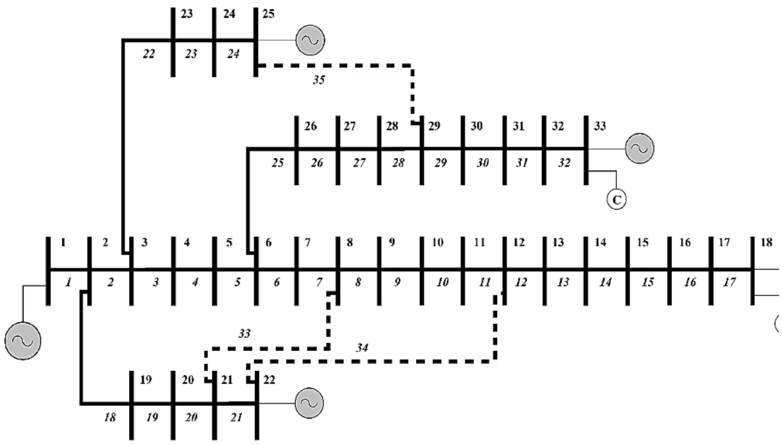

Figure 1. Single line diagram IEEE 33 bus

Generating an initial population (33 buses) with a population size that depends on the problem to be solved and the type of genetic operator to be implemented. Once the population size is determined, the initial population is generated. One method of gene permutation in generating the initial population is the Josephus permutation in combinatorial problems. There are buses from 1 to 33. Permutation of the trajectories can be performed by specifying the starting point and interval. Selection is used to choose which individuals will be selected for crossover and mutation. Selection is used to obtain a good parental perspective by observing the stress profiles that meet IEEE standards. Crossover generates new points in the search space that are ready to be tested. If crossover is not performed, then the parental values will be passed on to the offspring. The principle of crossover is to perform operations (exchange, arithmetic) on the corresponding genes from two parents to produce a new individual. The crossover process is performed on each individual with a specified crossover probability. Gene mutation is the process of replacing a gene with its inverse value, with gene 0 becoming 1 and gene 1 becoming 0. This process is carried out randomly at specific gene positions in individuals selected for mutation. The number of individuals that undergo mutation is determined by the magnitude of the mutation probability, thus achieving the best parental fitness. Meanwhile, the research procedure, as shown in Figure 3 (in Appendix), simulates the power flow calculation without adding a tap changer and a capacitor bank first to observe the voltage profile. If the voltage profile does not meet IEEE standards, then the next step is to add a tap changer and a capacitor bank to achieve optimal performance.

Table 1. Conductor data

Line	From bus	To bus	Resistance (Ω)	Reactance (Ω)	Line	From bus	To bus	Resistance (Ω)	Reactance (Ω)
1	1	2	0.0922	0.047	21	21	22	0.7089	0.9373
2	2	3	0.493	0.2511	22	3	23	0.4512	0.3083
3	3	4	0.366	0.1864	23	23	24	0.898	0.7091
4	4	5	0.3811	0.1941	24	24	25	0.896	0.7011
5	5	6	0.819	0.707	25	6	26	0.203	0.1034
6	6	7	0.1872	0.6188	26	26	27	0.2842	0.1447
7	7	8	0.7114	0.2351	27	27	28	1.059	0.9337
8	8	9	1.03	0.74	28	28	29	0.8042	0.7006
9	9	10	1.044	0.74	29	29	30	0.5075	0.2585
10	10	11	0.1966	0.065	30	30	31	0.9744	0.963
11	11	12	0.3744	0.1238	31	31	32	0.3105	0.3619
12	12	13	1.468	1.155	32	32	33	0.341	0.5302
13	13	14	0.5416	0.7129	33	21	8	2	2
14	14	15	0.591	0.526	34	9	15	2	2
15	15	16	0.7463	0.545	35	12	22	2	2
16	16	17	1.2889	1.721	36	18	33	0.5	0.5
17	16	18	0.732	0.574	37	25	19	0.5	0.5
18	2	19	0.164	0.1565					
19	19	20	1.5042	1.3554					
20	20	21	0.4095	0.4784					

Table 2. Load data

Bus	Active power (kW)	Reactive power (kVar)	Bus	Active power (kW)	Reactive power (kVar)
2	100	60	17	60	20
3	90	40	18	90	40
4	120	80	22	90	40
5	60	30	23	90	50
6	60	20	24	420	200
7	200	100	25	420	200
8	200	100	26	60	25
9	60	20	27	60	25
10	60	20	28	60	20
11	45	30	29	120	70
12	60	35	30	200	600
13	60	35	31	150	70
14	120	80	32	210	100
15	60	10	33	60	40
16	60	20			

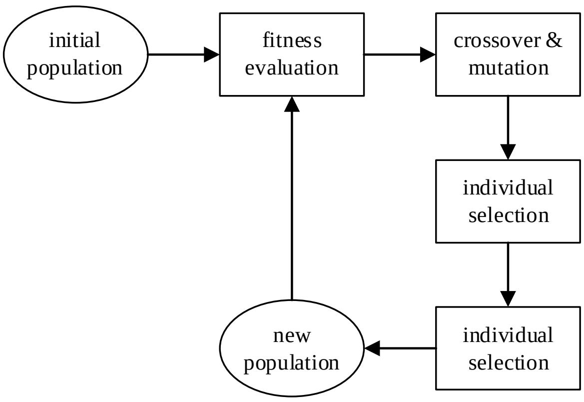

Figure 2. Single line diagram IEEE 33 bus

3. RESULTS AND DISCUSSION

The first scheme is to simulate the power flow without installing a tap changer and capacitor bank to obtain the value of power losses and voltage drops in the IEEE 33 bus network. After discovering abnormal power losses and voltage drops, the IEEE 33 bus network is simulated again, but with the addition of a tap changer to improve the existing voltage drops. After the voltage drops are resolved, the IEEE 33 bus network is simulated again with the addition of capacitor banks in the network system without a tap changer to see whether the voltage profile and power losses can be resolved. Then, after the tap changer and capacitor bank voltage profile data are obtained, they are simulated again. However, the most optimal voltage and power loss profiles are compared with the combination of tap changer and capacitor bank. The tap changer and capacitor bank addition scheme is inseparable from the assistance of the GA method.

3.1. IEEE 33 bus distribution network system power flow (initial condition)

A tap changer and capacitor bank were not added to test the IEEE 33 bus distribution network system. The Newton-Raphson method was used to analyze power flow to ascertain each bus's voltage profiles, power losses, and power flow amount. For further information, see Figure 4. Each bus's voltage profile measurements were acquired following a power flow analysis. Twenty-one buses had voltage profile values that were less than -5% and +5% above IEEE Std 1159-1995. Buses 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 26, 27, 28, 29, 30, 31, 32, and 33 were the ones in question. Bus 18 had the lowest voltage profile, at 91.3089%.

The line impedance is one of the elements that might influence voltage drops and power losses in the system. Bus 18 has the highest overall line impedance value, which travels from the source to the bus, which is why this happens. The overall power flowing through the system is another aspect. The current increases with the amount of power flowing through the system. Before including the tap changer and capacitor bank, the system's total power flow was 3.918 MW, which included the power needed by the load and losses from the voltage drop. Table 3 summarizes the power flow study's findings, which include active and reactive power loss statistics, the system's total power supply, and its total load power. The findings of this investigation are consistent with earlier studies that used IEEE 33 bus data [19], [20].

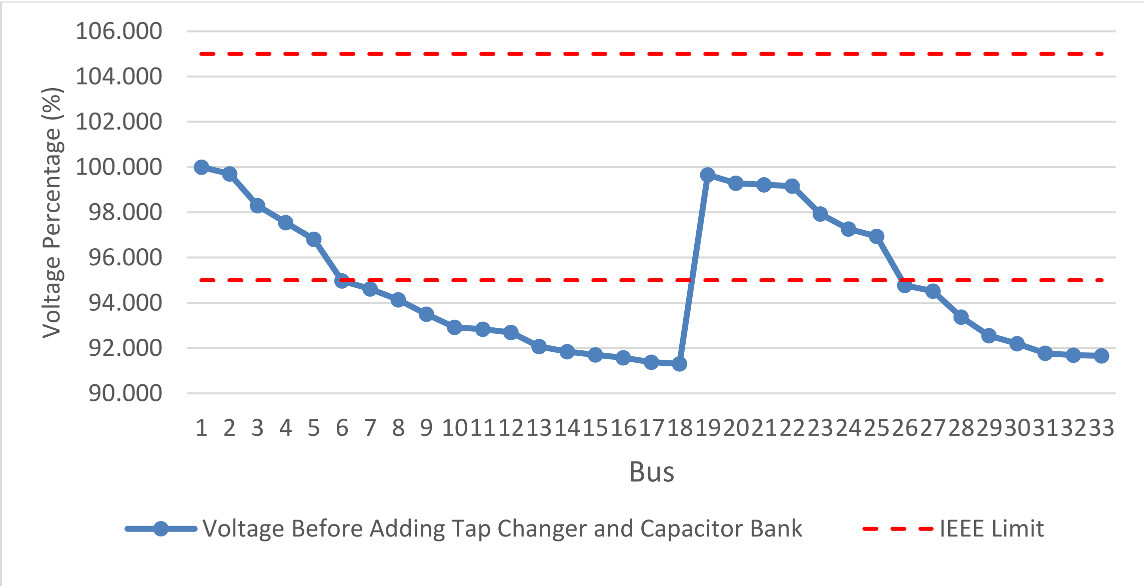

Figure 4. IEEE 33 bus voltage profile before adding tap changer and capacitor bank (initial condition)

Table 3. Power flow results without adding tap changer and capacitor bank (initial condition)

Total power supplied (MW)	Total power supplied (Mvar)	Total load power (MW)	Total load power (Mvar)	Power loss value (kW)	Power loss value (kVar)
3.918	2.435	3.715	2.300	202.7	135.1

3.2. Simulation results with the addition of tap changer

This research adds 2 tap changer units into the IEEE 33 bus single line diagram to reduce the existing voltage drop; the author uses calculations assisted by the GA method to determine the value and location of the tap changer placement. Figure 5 shows the voltage profile after the addition of the tap changer. As depicted in Figure 5, after adding 2 tap changers on bus 5 and 8, the number of voltages drops that were originally on 21 buses is now only 17 with values outside the IEEE 33 bus voltage profile standard. Meanwhile, the results of the power flow study obtained in the form of a summary of active and reactive power loss data, total power supplied, and total load power on the system after the addition of tap changers, as shown in Table 4. The results of this study using tap changer on IEEE 33 data bus are in accordance with previous studies [21]-[23].

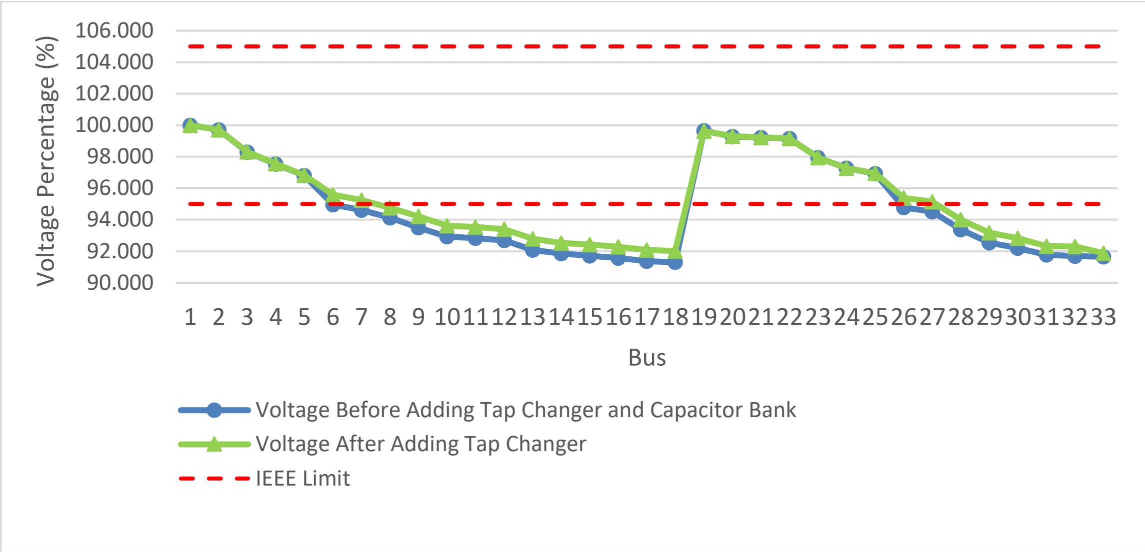

Figure 5. IEEE 33 bus voltage profile after adding tap changer

Table 4. Power flow results with the addition of tap changer

Total power supplied		Total load power		Power loss value	
(MW)	(Mvar)	(MW)	(Mvar)	(kW)	(kVar)
3.987	2.430	3.715	2.300	182.4	130.3

3.3. Simulation results with the addition of capacitor bank

After obtaining the latest voltage profile value when adding the tap changer, the author added 2 capacitor banks into the IEEE 33 bus single-line diagram with a value of 2000 kVar according to the size of the distribution capacitor. Without a tap changer to study voltage drop and power losses, this study uses calculations assisted by the GA method to determine the value and location of the capacitor bank placement. The voltage profile after adding the capacitor bank is shown in Figure 6. As presented in Figure 6, adding 2 capacitor bank units on bus 10 and bus 29, the number of voltages drops that were originally on 21 buses now only has seven buses with voltages below the IEEE 33 bus standard. Meanwhile, the power flow study results were obtained as a summary of active and reactive power loss data, total power supplied, and total load power on the system after adding the capacitor bank, as shown in Table 5. The results of this study using capacitor bank on IEEE 33 data bus are in accordance with previous studies [24]-[26].

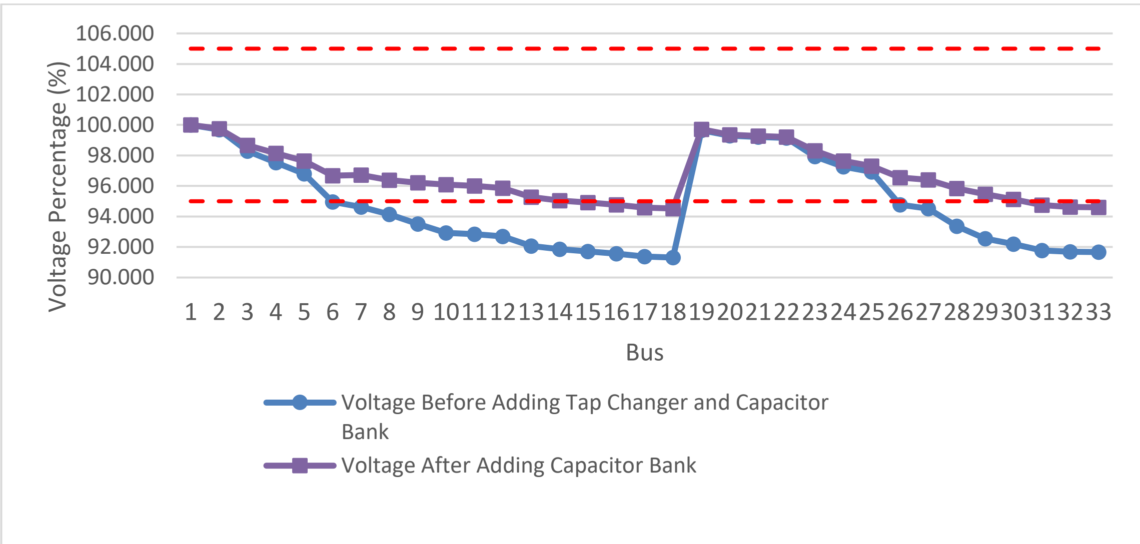

Figure 6. IEEE 33 bus voltage profile after adding capacitor bank

Table 5. Power flow results with the addition of capacitor bank

Total power supplied		Total load power		Power loss value	
(MW)	(Mvar)	(MW)	(Mvar)	(kW)	(kVar)
3.859	0.562	3.715	2.300	143.8	96.0

3.4. Simulation results with the addition of tap changer and capacitor bank

After obtaining the latest voltage profile value when adding the tap changer and capacitor bank, this study combines the voltage profile data of the tap changer and capacitor to examine the optimization of voltage drop and power losses. Figure 7 depicts a simulation result after adding the tap changer and capacitor bank. Figure 7 illustrates the addition of a tap changer and capacitor. The initial condition caused a voltage drop on 21 buses; now, all buses have the standard value of the IEEE 33 bus voltage profile. The voltage profile, enhanced by the combined addition of a tap changer and a capacitor bank, outperforms the improvements achieved by adding either component alone. This enhancement is complemented by a significant reduction in the total power supplied, further validating the efficiency of the changes. Table 6 presents a detailed summary of the power flow results following the addition of the tap changer and capacitor bank.

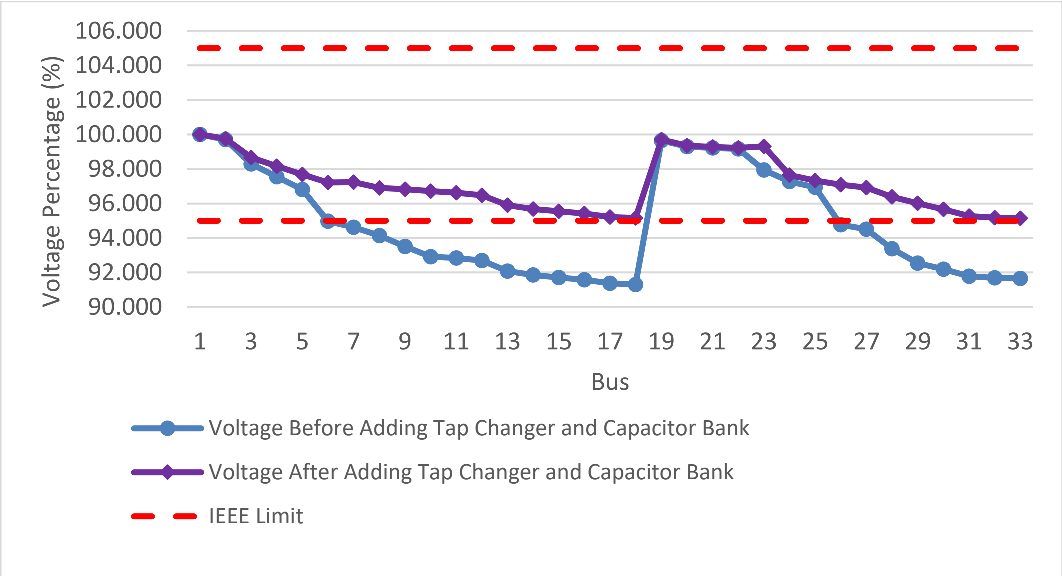

Figure 7. IEEE 33 bus voltage profile after adding capacitor bank

Table 6. Power flow results with the addition of capacitor bank

Total power supplied		Total load power		Power loss value	
(MW)	(Mvar)	(MW)	(Mvar)	(kW)	(kVar)
3.846	0.536	3.715	2.300	130.7	96.3

3.5. Comparison results before addition and after addition of tap changer and capacitor bank

After conducting research and trials of the addition and combination of tap changer and capacitor bank, each case's voltage profile and power losses were obtained. Figure 8 compares all methods. As seen in Figure 8, the addition of a tap changer can only improve 4 buses from voltages below the IEEE 33 bus standard, while the addition of a capacitor bank can improve 14 buses. However, there is a decrease in kW and kVar losses and a decrease in total power from the generator (source). The researcher found a very good voltage profile when the tap changer and capacitor bank were combined. No buses are below the IEEE standard voltage, and the losses are getting smaller, namely 130.7 kW and 93.3 kVar. This proves that the addition of tap changer and capacitor bank can improve the voltage profile, which originally had 21 buses below the voltage, to a normal/standard state, reduce active power losses, which were initially 202.7 kW, and reactive power of 135.1 kVar, to 130.7 kW and 93.3 kVar, and decrease the total supply power from 3.918 MW to 3.846 MW.

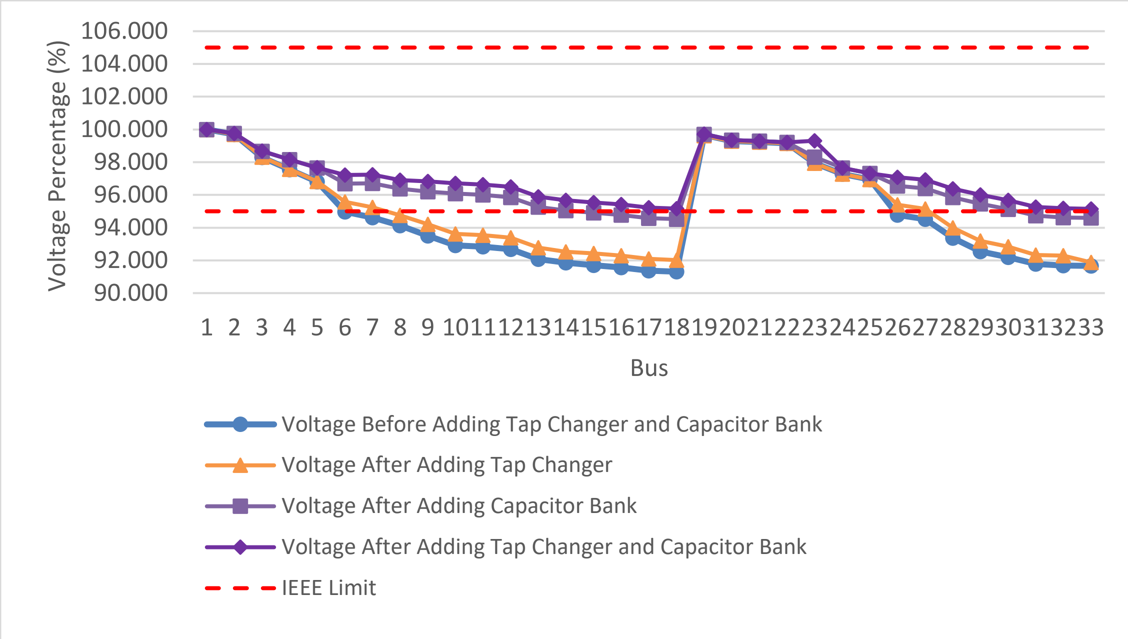

Figure 8. IEEE 33 bus voltage profile after adding capacitor bank

4. CONCLUSION

In the initial condition of the IEEE-33 bus distribution system, the active power losses are 202.7 kW, and the reactive power is 135.1 kVar. This is in line with the minimum voltage profile in the system, which is 91.31% on bus 18 and has 21 buses outside the IEEE standard. Furthermore, the addition of a combination of tap changer and capacitor bank is very suitable to be applied rather than just adding one of them because the addition of this combination can improve 21 buses below the standard voltage and can also reduce the active power losses by 72 kW in the system from the original 202.7 kW to 130.7 kW and reactive power losses by 41.8 kVar from the original 135.1 kVar to 93.3 kVar. This is in line with the minimum voltage profile in the system, which is 91.31% on bus 18, which has now increased to 95.16%. Then, the GA was proven to be able to find/determine the capacity, value, and location of the tap changer and capacitor bank accurately. Future research may look into using Loop networks to test whether Loop networks are better than radial networks.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Yulianta Siregar	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓
Agus Kivander Saragi		✓				✓		✓	✓	✓	✓	✓		
Issarachai Ngamroo	✓		✓	✓			✓			✓	✓		✓	

C	:	**C**onceptualization	I	:	**I**nvestigation	Vi	:	**Vi**sualization
M	:	**M**ethodology	R	:	**R**esources	Su	:	**Su**pervision
So	:	**So**ftware	D	:	**D**ata Curation	P	:	**P**roject administration
Va	:	**Va**lidation	O	:	Writing - **O**riginal Draft	Fu	:	**Fu**nding acquisition
Fo	:	**Fo**rmal analysis	E	:	Writing - Review & **E**diting			

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author [Yulianta Siregar] on request.

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APPENDIX

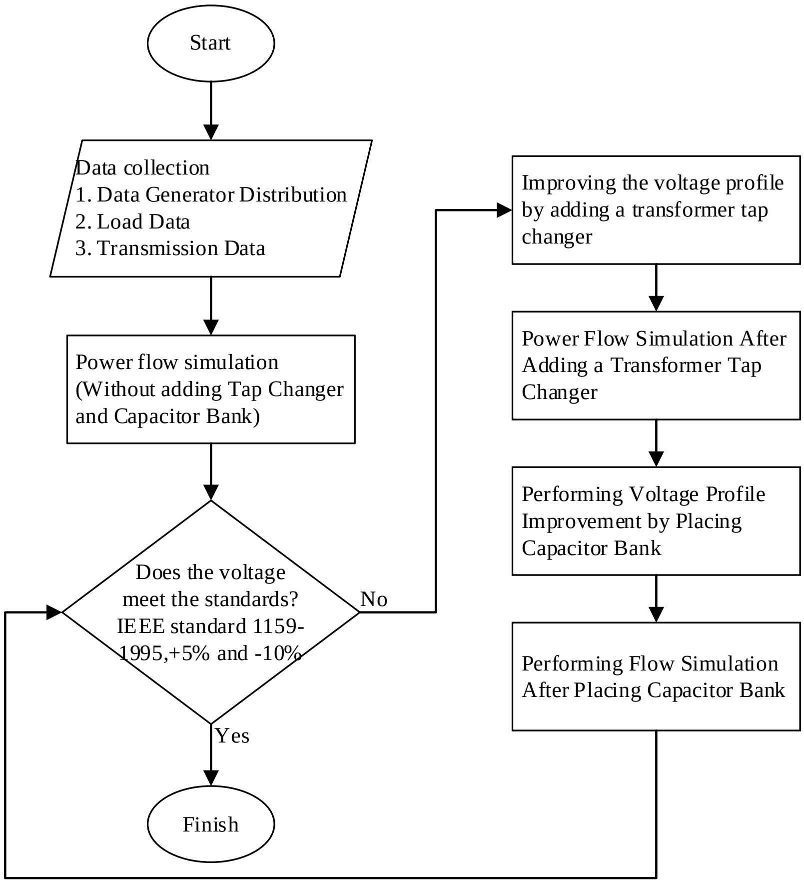

Figure 3. Research flowchart

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