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Voltage Profile Enhancement of Radial Distribution System by Genetic Algorithm in ETAP

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ABSTRACT- Compensation for reactive power is provided, and the use of capacitor banks reduces both active and reactive power losses in distribution systems. In the power system, the capacitor also helps control the voltage and power factor. The genetic algorithm (GA) to the stage finds appropriate OPC. The voltage profiles of the system have improved as a result. The number of capacitors at minimum load has been determined for the candidate buses for optimal capacitor bank placements. To assess the sensitivity of compensating power losses, the calculation of optimal capacitor placement is done at peak load. By using this method, the sag and swelling of the voltage caused by the lead phase of the system are prevented in the increase or decrease of the load within the IEEE standard. Using a ETAP 16.0, a load current analysis of 33-IEEE Simply Radial Test System was made to portray the effect of the method. The Newton-Raphson iteration technique was used for both the original system and the improved system.

Keywords: Radial distribution system (RDS), ETAP, Optimum capacitor placement (OCP), Genetic Algorithm (GA).

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1. INTRODUCTION

One of the biggest difficulties that power engineers face is loss mitigation in power distribution systems. Both transmission and distribution losses could be up to 30% of total power generation. The main reason for these huge power losses is resistance loss because distribution systems operate at much lower voltages than transmission systems [1]. In general, there is a claim that the optimal operation of power distribution networks has devolved into an engineering problem. Radial distribution system (RDS) management through distribution automation, like VAR planning, grid optimization, state estimation, switching, etc., requires the use of an efficient and robust load flow technique. There are many traditional methods to simulate and calculate the load flow, such as Gauss-Seidel, Newton-Raphson, and Fast-Decoupled [2].

Optimum Capacitor Placement (OCP) in the genuine low-voltage distribution grid is computed by a professional software package like MATLAB, Electrical Transient Analyzer Program (ETAP), and Dig Silent Power Factory through environment software programs that worked to the reality of real distribution systems and where annual losses and suitable size for installed capacitors appropriate [3, 4]. The traditional method for solving the voltage profile (sag and swell) or active and reactive power compensation, including power loss, depends on Trial and Error. Therefore, it takes longer to find a solution, and of course, there are better solutions than this [5].

A general optimization-based technique has progressed to find the ideal locations and sizes of capacitor banks in distribution systems while the system is operating in normal conditions or during a fault [6]. To reduce the power losses, the capacitors are placed near the load. This can be executed via an automated technique depending on intelligent customer meters. Meters could track the voltage at consumer locations and transfer the data to the utility, providing the user with the best options. The number of capacitor banks added to the weak buses is suggested using ETAP's best position for the capacitor bank placement module. Also, to enhance steady-state voltage stability in an unstable system, the transformer's appliance on-load tap changers and reactive power correction have been used. Energy is necessary for our country's expansion. To keep the production of electric power at a sufficient level, the power system uses transmission lines to supply power to various types of loads located far from the production facilities [3, 7].

Two-stage approaches are employed for this objective. A dimension reduction distribution load flow algorithm is used in the first step to implement the load flow of the pre-compensated distribution system. The potential locations of compensation are calculated based on this load flow. The GA technique is utilized in the second stage to discover the ideal position and size of the capacitors to enhance low voltage and minimize the cost of energy and power losses. Capacitor cost is kept to a minimum. The network model and analysis were carried out by ETAP [8]. Dimension-reducing distribution load flow was combined with

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the differential evolution algorithm. It was also tested on the IEEE 69-bus system and found to be superior to other methods such as PSO and genetic algorithm. This load flow identifies the position of the capacitors, and the differential algorithm calculates the capacitors' size such that the cost of the capacitor and the energy loss are minimal [9]. In [10-12], the authors addressed a heuristic technique for selecting a distribution grid power flow least loss configuration based on real power loss sensitivities concerning the impedances of the candidate branches. Especially considering the majority of power losses occur in the distribution system, which accounts for 13% of total power generated. Based on fault analysis studies, a transient stability analysis of interconnected multi-machine power systems has been proposed and observed. The study has included an analysis of an IEEE 42-bus system. This was accomplished by employing several contingency scenarios and configurations. The ETAP program was used to perform load flow analysis, best power flow analysis, and transient stability analysis. It was found that the nearest to the fault location had a greater power divergence [4].

Many topologies have been proposed about the optimal load flow for reducing losses in distribution systems, but more accurate and exact topologies are currently being developed. ETAP was created under a quality affirmation strategy and is utilized as high-sway programming all around the world. ETAP program allows users to optimize the Genetic Algorithm. Also, other programs like MATLAB allow many ways to use modern algorithms like (PSO, Genetic algorithms, etc.) [13]. But most of the optimization is worked offline. The genetic algorithm in ETAP is working online. This is considered an advantage when compared with MATLAB [14-15].

The contribution of this work, using all the modern capabilities in the ETAP 19 program to compensate for the losses in the active and reactive power, to improve the voltage profile in the applied system using the genetic algorithm for an IEEE 33 bus radial distribution system by choosing optimal locations and sizes of capacitors are found. The load flow has been done before and after placing the capacitor, and the transient stability analysis has been implemented to show the state of the system before and after placing the capacitor banks. In addition, the maximum potential of this program (ETAP) was taken advantage of, so that it gives researchers an indication of future research that will be applied to this program.

The organization of the current work is as follows:
First, the problem is prepared using the necessary equations, followed by the optimal capacitor's location (OCP) principles for the stage to understand the most important analysis components. Then a genetic algorithm is used to determine optimal capacitor spaces. Finally, the results are presented in five parts based on load current analysis, which aims to identify the weak points of the system and select the best locations for capacitor placement.

2. PROBLEM FORMULATION

This work aims to find the ideal capacitor size and optimal location in a radial distribution system, as well as reduce the cost of power loss and capacitors. The distribution feeder's conductor losses and load requirements must be met by the substation. The current flow in the branch (*i, k*) connecting buses (*i*) and (*k*) is represented by the relationship concerning the division of real power and reactive power demands about voltage. Mathematically, the following basic formulas can be driven [14, 16]:

$$V_i = I_{ik} \frac{P_{ik} - jQ_{ik}}{V_i} \quad (1)$$

Where:
I_{ik} : Current flowing through a branch (*i, k*)
P_ik : Total real power flow within the branch (*i, k*)
Q_{ik}: Total reactive power flow within the branch (*i, k*)
V_i: Voltage at bus (*i*)

The above equation represents the total power loss (TPL) in a power system. It is calculated by abbreviation to the actual loss of current in each line of the system. This loss is proportional to the class of power flowing through each line ($|I_{ik}|^2$) multiplied by the line's resistance (R_{ik}). The total power loss (TPL) in a feeder can be expressed as follows:

$$TPL = \sum_{ik-1}^{n} |I_{ik}|^2 R_{ik} \quad (2)$$

Where:
n: Current flowing through *ba* ranch (*i,k*)
R_{ik} : Resistance of branch (*i, k*)

The first equation defines the total power loss (TPL) as a product of active power loss ($TPLa$) and reactive power loss ($TPLr$), which appears to be a typo. Secondly, the more accurate equation shows that the total power loss is in all lines in the system due to active electrical loss (active power, (I_{ik}^a) and reactive power, due to reactive power, in I_{ik}^r). TPL can alternatively be expressed in terms of active power and reactive power components, as follows:

$$TPL = TPL_a TPL_r \quad (3)$$

$$TPL = \sum_{ik-1}^{n} |I_{ik}^a|^2 R_{ik} + \sum_{ik-1}^{n} |I_{ik}^r|^2 R_{ik} \quad (4)$$

Where:
I_{ik}^a: Active current through a branch (*i, k*).
I_{ik}^r : Reactive current through a branch (*i, k*).

For a given source spiral network, it is not possible to reduce the loss TPL in conjunction with the active branch current component since the source at the root bus is the only source of real power. It is possible to reduce the subscript base cap *T*, cap *P*, cap *L*, end base, and sub r loss associated with the passive branch current components, though provided a portion of the neighborhood active-power load. The capacitor modifies just the reactive part of the branch set's α current when it pulls a passive current I_c in a spiral network. The capacitor does not affect the current flowing via other branches. Consequently, the (*i, k*) the branch's new passive current is provided by *equation (5)*.

$$I_{rik}{}^{new} = I_{ik}^r + D_{ik} I_{ik}^c \quad (5)$$

Where: $\begin{cases} D_{ik} = 1, if\ branch\ (i,k) \in \alpha \\ D_{ik=0,otherwise} \end{cases}$

Here I_{ik}^{r} is the branch's passive current of the system created by the load flow analysis. The Power losses TPL_{r}^{com} connected with the passive element of limb current of the system after the above -mentioned tax compensation calculates the reactive strength loss ($\mathrm{TPL}_{\mathrm{r}}^{\mathrm{com}}$). This indicates that the disadvantage is a yoga in all lines, and this compensation is proportional to the square with reactive current ($I_{ik}^{r} + D_{ik}I_{c}$), which is the original reactive current and compensates the current injection injected by the capacitor. placement of capacitor as follows:

$$\mathrm{TPL}_{\mathrm{r}}^{\mathrm{com}} = \sum_{ik-1}^{n}(I_{ik}^{r} + D_{ik}I_{c})^{2}R_{ik} \quad (6)$$

The difference between *equations (5)* and *(6)* is the total loss saving $\mathrm{T_{LS}}$, which is provided by *equations (7-10).*

$$\mathrm{T_{LS}} = \mathrm{TPL_{r}} - \mathrm{TPL_{rcom}} \quad (7)$$

$$\mathrm{T_{LS}} = \sum_{\mathrm{ik-1}}^{\mathrm{n}}(\mathrm{I_{ik}^{r}})^{2}\mathrm{R_{ik}} - \sum_{\mathrm{ik-1}}^{\mathrm{n}}(\mathrm{I_{ik}^{r}} + \mathrm{D_{ik}I_{ik}^{c}})^{2}\mathrm{R_{ik}} \quad (8)$$

$$the\ \sum_{ik-1}^{n}\left(2D_{ik}I_{ik}^{r} + D_{ik}{I_{c}}^{2}\right)R_{ik} \quad (9)$$

$$\sum_{ik-1}^{n}(D_{ik}I_{ik}^{r} + D_{ik}I_{c})R_{ik} \quad (10)$$

One can get the capacitor current I_c that minimizes loss by using the formula $ds/dI_c = 0$.

The *equation (11)* calculates the optimal value for the compensation current (in *c*) injected by a capacitor. This indicates that it is determined by the ratio of power -coordinated reactive current and resistance for all lines for total resistance, indicating how the current is necessary to offset the reactive strength. the current form loss saving of the capacitor is offered by *equation (11).*

$$I_{c} = \frac{-\sum_{ik\in\alpha}(I_{ik}^{r})R_{ik}}{\sum_{ik\in\alpha}R_{ik}} \quad (11)$$

The suggested technique can also be frequently employed to further optimize saving of energy cost by selecting a series of buses that have recompensed for much loss reduction through the best possible capacitor placement. The reactive power constraints of the system must be satisfied when deciding the size of the capacitors; for this reason, the size of the pertinent bus capacitor may be represented below *equation (12)*;

$$Q_{c} = V_{m}I_{c} \quad (12)$$

The injected reactive power by the capacitor can be constrained by equation (13);

$$\text{the } \mathrm{Q_{cj}}^{\min} \leq \mathrm{Q_{cj}} \leq \mathrm{Q_{cj}}^{\max} \quad (13)$$

The load's reactive power must be higher than the reactive power that is being supplied by *equation (14).*

$$the\ Q_{c}^{\ Total} \leq Q_{L}^{\ Total} \quad (14)$$

On the radial distribution feeder, optimal capacitor placement (OCP) specified the size, type, and location of three-phase capacitor banks in which annual savings from a reduction in power losses, and peak power, were maximized, and for which capital and installation costs were reduced and related capacitors and apparatus. OCP determines the power loss reduction, power factor enhancement, and system voltage profile enhancement.

3. ETAP'S OPTIMAL CAPACITOR PLACEMENT PRINCIPLES

Considering the expansion of nonlinear load, selecting the appropriate location of discrete-size capacitors with the least investment is a critical issue for minimizing the influence on a harmonic distortion of the voltage, as well as concerns connected to series and parallel resonances. Furthermore, improper allocation will result in massive system losses. The system power factor often decreases as the demand for a rural power distribution system increases. Increased load and as a result in [17, 18]:

(1) Increased losses of the system.
(2) Voltage regulation issues.
(3) Fines for power components in wholesale electricity contracts.
(4) Miniature capacity of the system.

Because of inductive loads and delivery apparatus, most of the power systems have a lagging power factor (transformers and lines). Naturally, the Power systems are inductive, requiring further reactive power flow from the electrical system. On the other hand, high reactive power requirements result in minimized system capacity, increased losses, reduced voltage, and increased operational costs. It is known as the relationship between real power (kW) and total power (kVA), further improving the system power factor. Power factor is a measure of how well a given load matches pure resistance. A capacitor bank of sufficient rating can supply the reactive power demand in a system at the distribution system reactive load centre. It is intended to be linked at the inductive load center, or well ahead of or beyond it [19, 20].

4. JUSTIFICATION FOR USING GA FOR OCP

GA is a research algorithm that is based on the mechanics of natural selection. A GA produces a populace that grows over time through mutation and replication. The real parameters of the problem should be represented in the genetic algorithm technique before the genetic algorithm operations. It is intended that the size and position of the capacitors used be encoded as a chromosome. This application's representation choice is a chromosome divided into two halves. The first portion indicates the position of the capacitors [21-23]. The size of the capacitors used is indicated in the second section. During the reproduction procedure, a pair of chromosomes with identical structures is chosen at random. Then, each chromosome is processed independently, first for the binary section and then for the binary section. If two parents share a quantity (value) for a certain location, the chromosome created by regeneration will save it.

During the genetic cycle, new solutions are obtained within this population by applying mutation and crossover operators. GA employs a "Chromosomal" model, which necessitates that the solution is coded as a finite-length string, as shown in Figure 1 which displays a flow diagram of an ideal GA used in this simulation [24].

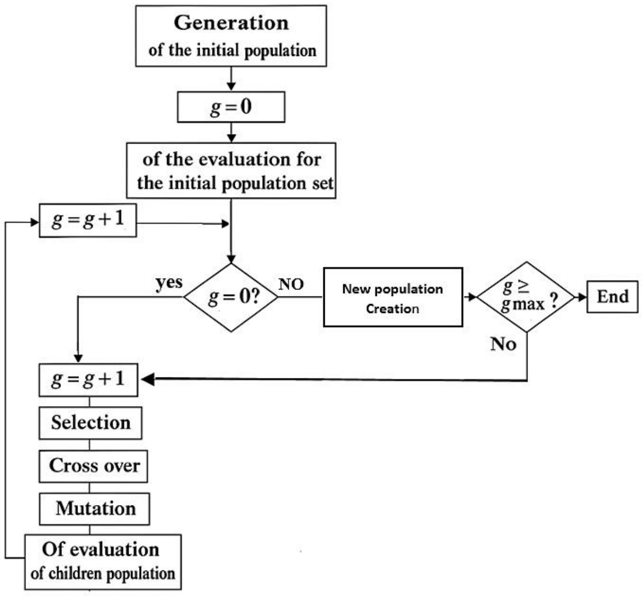


Figure 1. Flow Diagram of a Genetic Algorithm

4.1. Pseudo Code of the Genetic Algorithm

Logical current of genetic algorithm for optimal capacitor placement Genetic algorithm (GA) is used on a structured sequence to find the best places and sizes for capacitors in the power system. Here is described how it works, phase speed steps:

Step 1: Problem coding
Each possible solution is represented as "chromosome".

The chromosome is divided into two parts:
i. Part 1 (Status): Specifies where the capacitor is located (*eg.* which is coded as buses - binary or integer value).
ii. Part 2 (size): Specifies how large each capacitor is (*eg.* remaining rankings - a coded as real or integer value).

Step 2: Form -like population
A random set of chromosomes (solutions) is formed - it is called early population. Each chromosome represents another combination of capacitor spaces and sizes.

Step 3: Evaluate fitness
For each chromosome:
Use the capacitor configuration on the power system (eg, use ENAP or Load Flow Analysis). Calculate fitness value, which measures the quality of the solution.
i. Examples: Fitness = voltage profile improvement + reduction in electricity loss.
ii. High fitness = better solution.

Step 4: Choice
Choose the best chromosome (parents) from the population based on their suitability.
There is a high probability of being chosen in highness solutions (such as "existence of qualification").

Step 5: Crossover
Randomly selected parents.
Exchange of parts of their chromosomes to create new "children" solutions.
Example: Replace the "position" section of a parent with the other part with the "position" section - equal to "shape".

Step 6: Mutation
Some children replace small parts of chromosomes randomly.
It introduces diversity and helps avoid being stuck in weak solutions.
Example: Turn slightly into the position section, or change the capacitor shape slightly.

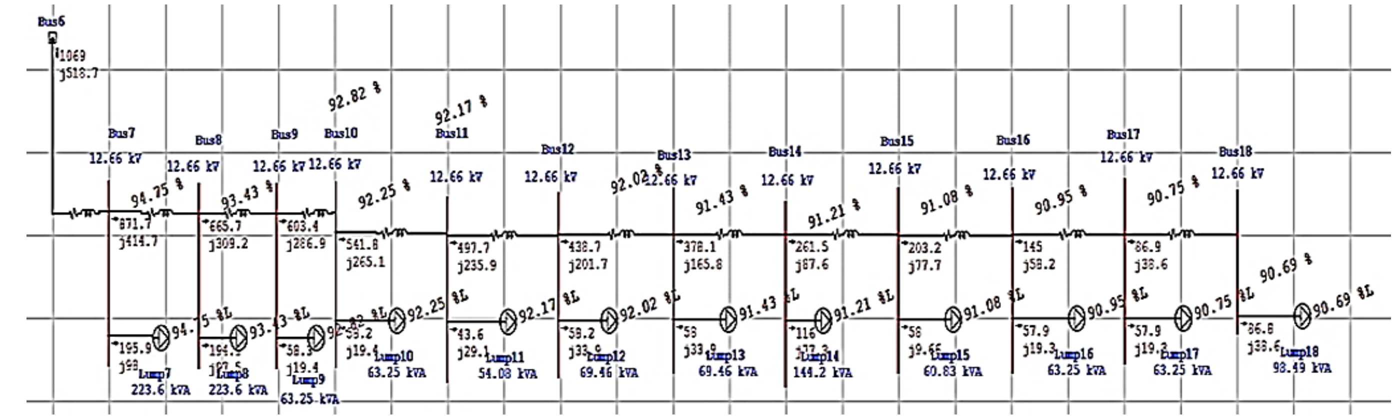
Step 7: Make new generation
Mix parents and children, and then hold only the best N solutions to create the next generation.

Step 8: Repeat up to convergence
Repeat steps 3–7 for a certain number of generations (eg 100), or until the solution is significantly improved.

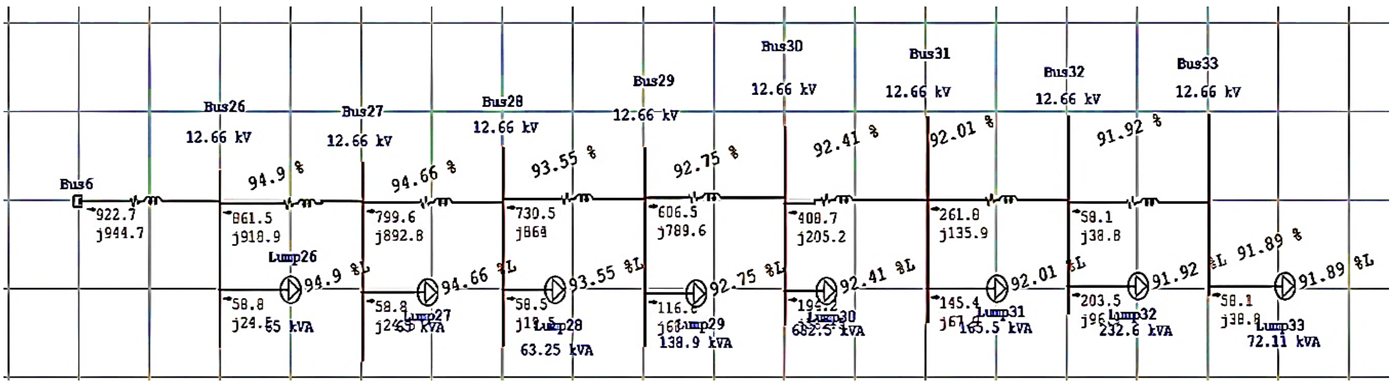
Step 9: Output Best Solution
Finally, the chromosome with the highest fitness is chosen as the optimal solution.
This tells you the best place and form of capacitors.
Then you can confirm the improvement in voltage profiles and electricity losses.

4. SIMULATION RESULTS

Analysis of load flow and optimal capacitor placement (OCP) are implemented for an IEEE-33 bus radial system by using ETAP 19. Load flow analysis was completed in which the Newton-Raphson method was used as shown in *figure 2(a)* and *figure 2(b)* respectively. A capacitor bank placement, size, and cost considerations can weigh all of these elements and consider load levels. Furthermore, they are critical challenges that must be addressed during the design phase. This system should also be capable of placing capacitors for power factor correction and voltage support while reducing total capital and operation costs. Using ETAP 19.0's ideal capacitor placement, the location of the capacitor bank can be easily established, and loss reduction (reactive power compensation), voltage support, and total cost minimization are seen. *Figure 2(a)* shows the original voltage profile of the 33-bus system before the capacitor installation, where a significant voltage drop is seen on the downstream sheds (94.99 kV bus33). *Figure 2(b)* presents a better voltage profile after optimal capacitor placement using a genetic algorithm. Capacitors were installed on Bus10 and Bus23, resulting in increasing voltage levels and reducing electrical damage, demonstrating the efficiency of the proposed method.



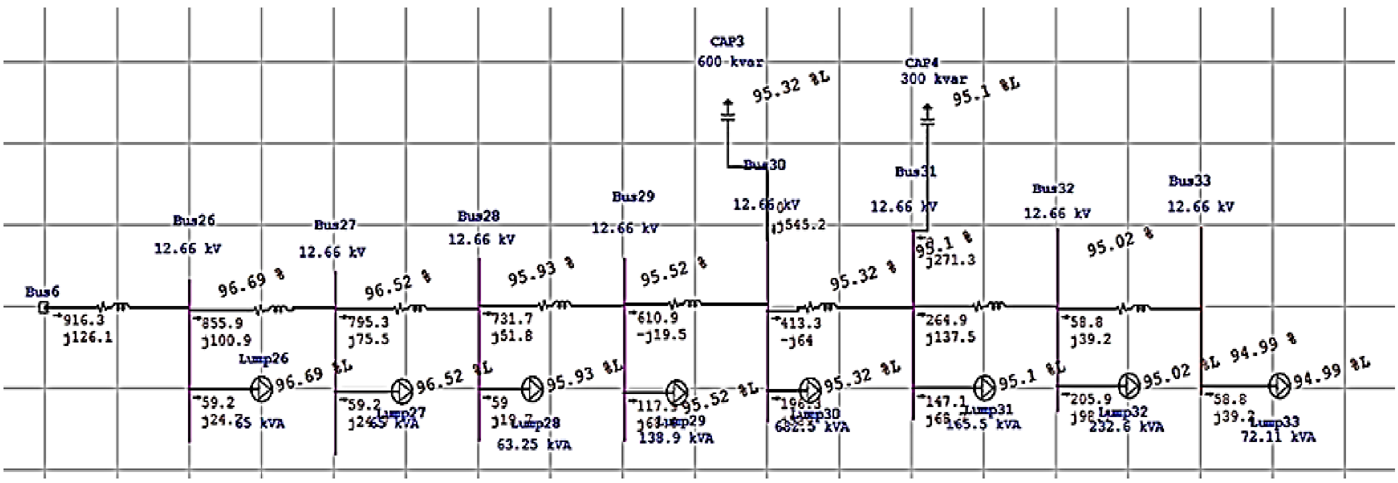
(a)



(b)

Figure 2. (a) Load Flow Analysis before OCP, (b) Load Flow Analysis before OCP

Figures 3(a) showed in voltage profile before the capacitor placement performed significant drops on the downstream buses (*eg.*, only 33 at 94.99 kv). After implementing GA-based optimal capacitor placement, the capacitors were installed on Bus10 (600 remaining) and Bus23 (500 remaining), resulting in noticeable improvement in voltage levels. The minimum voltage increased from 94.99kv to approximately 95.5kv, indicating the performance of the system and the low power loss. *Figure 3(b)* have been improved the total voltage profile, with the minimum voltage 94.99kv that grew from 95.47kV. This improvement not only increases system voltage stability, but also reduces actively power loss. After the aftermath, the level of subsequent voltage was high, with most buses-maintained values above 95.4kv, compared to the pre-perfect landscape where many buses fell below 95kv. This shows the efficiency of GA-based capacitor placement to support food voltage and improve the general system performance.



(a)

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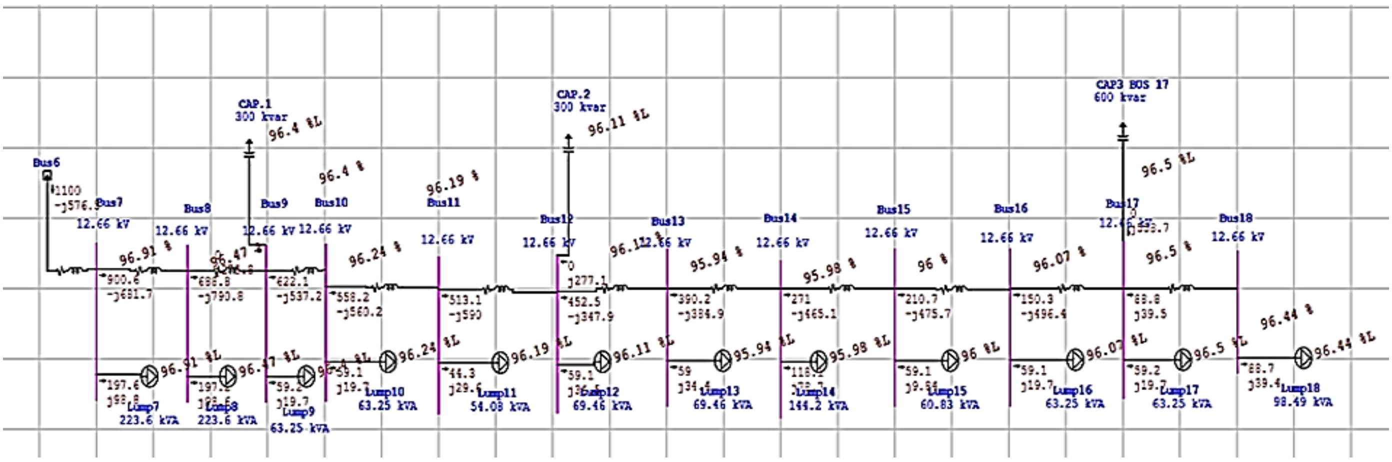

Figure 3. (a) Load Flow Analysis after OCP, (b) Load Flow Analysis after OCP

The optimization using the genetic algorithm in EATP provides the best possible location in the form of bus numbers 10, and 12,17,30,31 and optimal sizes 300,300,600,600,300kvar, respectively. The buses with kvar/Bank and a number of banks should have the capacitor placed on them. These results are shown in *table 1*.

Table 1. OCP Result

ID	Kvar /Bank	# Of Bank
Bus 10	300	**1**
Bus 12	300	**1**
Bus 17	300	**2**
Bus 30	300	**2**
Bus 31	300	**1**
All	2100	**7**

Table 2 shows the power losses (P) and reactive power losses (Q) within the system before and after connected capacitors. From the table, it is evident that the real and reactive power losses are reduced after compensation. The P-losses and Q-losses are reduced by 43kW and 25 kVar, respectively.

Table 2. P& Q Losses

Losses	Before OCP	After OCP
P-Losses (kW)	202.66	129.2
Q-Losses (kVar)	134.8	109

Figure 4 shows the relation between power losses and iteration of GA for current work. It shows that the loss of electricity begins with a high early value and then decreases as the number of repetition increases. Early price: On the relaxation of 0, the power losses are about 175 kW. This is the first point of the adaptation process. Final value: When GA moves, the loss of electricity drops significantly and then becomes stable. About 50, the loss of electricity has been final, with a low price of about 135 kW. Headed: The total reduction in power loss is about 175 kW - 135 kW. This reflects the effectiveness of the genetic algorithm to find a customized solution that reduces the loss of current from significant amount and then converts to the best possible value.

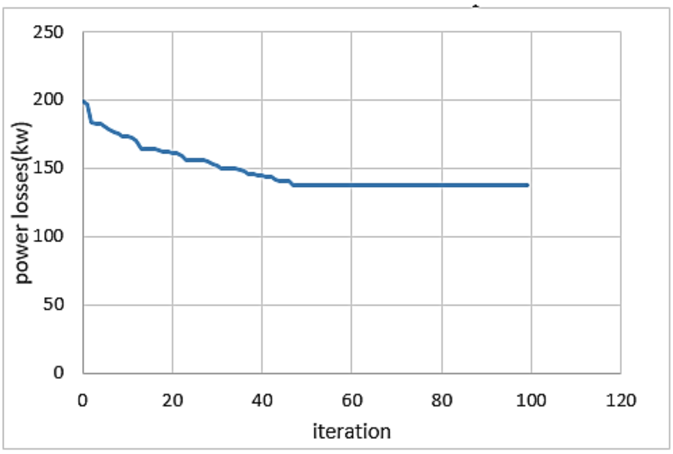

Figure 4. The Relation between Power Losses and Iteration GA

Figure 5 below depicts the system's voltage profile both before and after compensation. From the figure, we obtained that the voltage of the buses is improved after compensation, which means that the capacitors play a good role in enhancing the voltage and reducing the voltage drop. It observed the voltage profile has been weak busses between 17-19 improved from 90 and after OCP equals 94.67%, and also other points.

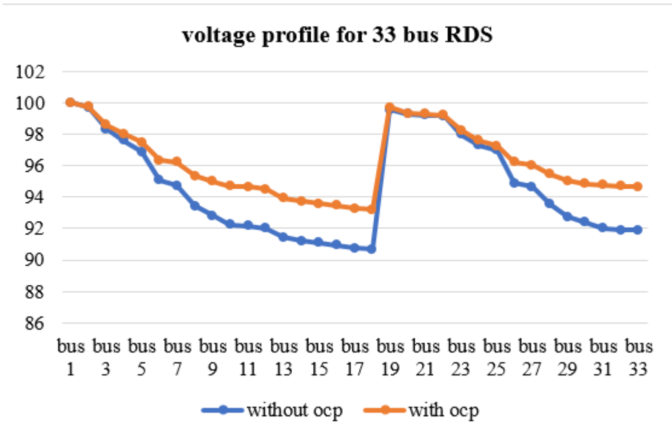

Figure 5. Voltage Profile for 33 Bus RDS

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Also, the transient stability analysis is applied to check the stability of the system to see how the capacitors affect the stability of the distribution system. Before applying the ideal capacitor location, the system's condition is unstable, as depicted in Figure 6. Disruptions: A major event, such as short -circuit or sudden major load changes, occurs in about 2 seconds. You can see it as a point where the excitement for all buses suddenly falls. System response: After the first fall, the underlying properties and control actions of the system swing the voltage and then recover. For about 5 seconds, the voltage has stabilized and has returned to a close price for the East Gentle level. This plot indicates that the system is temporarily stable even before the optimal capacitor placement (OCP), as it successfully rides through disruptions and returns to a stable operating position. However, alternative and tension saw highlights the dynamic behavior of the system and shows the need for reforms such as OCP.

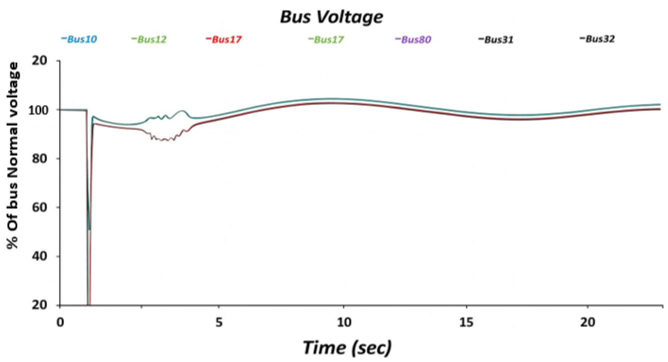

Figure 6. Transient Stability of System before OCP

Figure 7 shows the state of the system after compensation by 900 kVar capacitance. In the figure, the stability of the system shows that it has improved but is still not stable enough. Also shows the transient stability of an electrical system after adding capacitor with a capacity of 900 left. Also, the electrical voltage changes in different buses over time after a sudden disturbance. Disorders: In about 2 seconds, the system caused a major disruption (for example, short -circuit), causing a sharp decline in the voltage in all buses. Stability: After this fall, the tension returns to its normal level over time, with some smaller fluctuations. This rapid recovery indicates that the system is stable, and in addition to the 900-remaining capacitor, the system was successfully riding through disturbances.

In short, the graph proves that the system has a good ability to stabilize errors and to overcome errors for additional capacitor capacity.

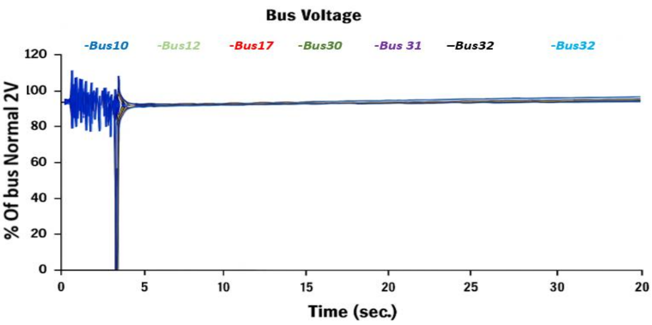

Figure 7. Transient Stability of System with 900 kVar Capacity

Figure 8 shows that the stability becomes more stable when 2100 kvar capacity is connected to the system. This means that when all the capacitors suggested by OCP are connected to the system, the system will become more and more stable, and voltage will be enhanced. Disorders: An error occurs in about 2 seconds, causing a sudden and sharp tension to fall in all buses. This is the immediate response to the system to release volatility. Recovery: After the first fall, the system is quickly hardened and the voltage returns to the stable level before destination. In this case, the tension is even more than normal. This rapid and strong recovery is the direct result of the larger capacitor of 2100 left. Compared to a system with low or without compensation, it shows that a large capacitor capacity leads to a very strong and fast recovery with minimal fluctuations and more stable voltage profiles. The system is very constant.

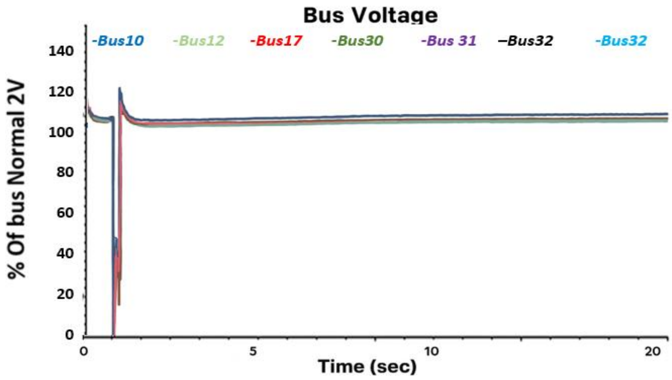

Figure 8. Transient Stability of System with 2100 kvar Capacity

Table 3 compared two identical power functions. It focuses on function and power loss before and after OCP, including the percentage of loss reduction. The table shows that our method achieves better results in reducing losses compared to other functions.

Table 3. Comparison between relative works and current work

References	Methodology use	Power loss before improvement (KW)	Power loss after improvement (KW)	The percentage of reduction loss (%)
2019 [25]	Etap system 33 bus	210.91	150.7	28.54 %
2024 [26]	PSO 33bus	202.66	135.4	33.188%
Present work	G.A 33bus	202.66	129.22	36.23 %

5. CONCLUSIONS

The optimal capacitor placement has been done for 33-IEEE bus radial distribution systems. The load flow was analysed for the original system to specify which buses are under voltage. It was found that many buses are under voltage. After that, the optimal capacitor placement has been implemented to get the optimal place and capacitance of the capacitor. The ETAP provided a table of capacitors, which are one bank of 300 Kvar/bank at bus 10, two banks of 300 Kvar/bank at bus 12, one bank of 300 Kvar/bank at bus 17, one bank of 300 Kvar/bank at bus 30, and two banks of 300 Kvar/bank at bus 31. It is clear from the results that all buses that were under voltage were improved after placement of suggested capacitors, and they are in range. From this study, we realised how ETAP can define the best way to improve the power system performance easily.

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