Voltage stability index improvement system by optimal placement of STATCOM in distributed systems

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Abstract

To provide the needed load, an interlinked radial distribution network includes a high amount of nodes and branchings. In the context of Pakistan, increased electrical demand places excessive stress on the radial distribution network, affecting the overall network's performance and potentially leading to voltage collapse; hence, it is desirable to keep the voltage at each bus within allowed limits. To tackle voltage stability indices concerns, several technologies such as STATCOM and other downstream linked devices are used, however proper sizing and location is also a key obstacle in the network. This study provides a Particle Swarm Optimization approach that finds the optimum position and configuration of STATCOM to be deployed on the real-time distributor by identifying the voltage regulation for the lowest bus in the network. The installation of STATCOM in the right area increased the voltage stability index (VSI), effectively reduced energy loss, and boosted the voltage stability, according to the results.

Keywords – STATCOM, VSI, optimal placement, distribution system

1. Introduction to distribution systems

Electricity is delivered to end-users via a distribution network in an electrical network. There are three kinds of distribution systems in general. The radial distribution design is commonly utilised. Because of its significant advances, the distributed parameter system is employed all over the world [1]. The distribution system is typically imbalanced and has good resistance to the resistive ratio, resulting in significant power losses and compromising the power system's stability. It is related to over thirteen per cent (13%) of all losses [2]. Power loss is obtained due to the induction character of the loads since the majority of domestic and commercial loads are responsive.

As a result, it is critical to include appropriate counterbalancing equipment in the distributing system to reduce power loss and enhance voltage profiles all across boards and enhance the voltage regulation of particular buses and the entire network [3]. STATCOM devices are put in distributed parameter solutions in the current evaluating and analysing the voltage stability, reducing real and reactive inefficiencies, and improving voltage regulation. STATCOM was created to preserve the voltage stability by delivering reactive power support and managing the voltage level in transmission networks; research was performed to implement the same approach for distribution networks [4].

STATCOM is used in distribution systems to improve voltage stability, decrease losses, and improve voltage stability. The STATCOM is a voltage regulation device that is linked in shunt to a particular circuit with an electrical distribution network [5]. STATCOM is a quick compensating device that introduces opposing electricity into the grid to enhance the voltage stability and remove energy loss. To get the most out of the system, it's advised that STATCOM sensors be placed in the best possible position with the best possible scale. Incorrect alignment of STATCOM devices might cause the equipment to fail and potentially affect its operational aspects [6].

With traditional methodologies, enough study is done to successfully refine the issues of placement and scale of STATCOM. The enhancement of the voltage stability in transmission lines utilising STATCOM was the focus of the most recent study [7]. As a result, this research is focused on the best STATCOM size and location, as well as an installation within a real-time zonal distribution line. The goal of this research is to provide a rapid and non-traditional method for calculating the best optimum optimal location and size of STATCOM for improving voltage stability, reducing power losses, and improving voltage profile [8].

Particle Swarm Optimizing (PSO) could be used to identify the ideal size for STATCOM. The primary difference in this work is that it uses a combined load flow analysis (LFA) and VSI method with PSO to evaluate the best optimal location and size for STATCOM in order to improve VSI, reduce power wastage, and increase voltage profile. It was used on the Real-Time Feeding.

The remainder of the paper is organized as follows: section 2 indicates the background of the distribution systems. The proposed PSO model with the combined VSI model is discussed and explained in section 3. The software outcome analysis of the proposed method is shown in section 4. Section 5 illustrates the conclusion and future scope of the system.

2. Background to the distribution systems

Several articles have been published in recent times describing the optimum utilization of capacitor banks in electrical systems to avoid the voltage instability issue and improve the voltage profile while exposed to the optimizing issue's primary goal function.

The optimization strategies employed in the capacitance assignment problem can be broken down into three categories suggested by Gupta et al. [9]. The analytical technique is the first method; it is a simple technique that relies on the quantitative problem definition and its assumptions to fix issues. Numerical systems are the second method, in which a mathematical issue is employed to address mathematical operation.

These approaches are based on iterative strategies that leverage quick computation capabilities and huge memory availability to maximise or reduce an optimal solution, and they are basic methods [10]. The third technique is the metaheuristic optimizing method, which seems to be the easiest method in optimizing that tries all feasible solutions from a present set, although it is inefficient in terms of processing time and storage. There are smart-based optimizing approaches like (genetic algorithm, PSO, plant growth, hybrid, and fuzzy).

The measurement of voltage stability has long been regarded as the most difficult aspect of power network monitoring [11]. The highest power system load capability limitation before power failure has received a lot of attention.

Voltage breakdown is defined as a sudden decline in the voltage level of an electricity system. A voltage breakdown could result in an unanticipated power deficit. France, Japan, Sweden, and Germany were among the countries that contested the voltage collapse issue suggested by Nafeh et al. [12]. As a result, voltage stability indexes (VSIs) have been developed to determine the bus in the network that is most susceptible to voltage volatility.

Many methodologies have been investigated and presented to address voltage fluctuations and voltage breakdown issues. The integration of dispersed generators (DGs) into the power grid, on the other hand, improves power quality and reliability while lowering power losses [13]. As a result, the optimal option has been mentioned in the literature, which would be to use the amount of reactive power of a DG linked at a suitable site to operate devices with maximum economical and reliability, as well as to improve the capacity of the power network [14]. As a result, precise indices are necessary for power distribution utilities to determine the likelihood of voltage collapse, after which the utilities typically utilise a compensating device including a DG.

Numerous research papers have been published recently to determine the best way to distribute DGs in the electricity system Chi et al. [15]. To improve the benefits of DGs, a variety of optimization strategies have been applied with various objective functions, including power loss reduction, voltage regulation, and voltage regulation. Optimization-based DG allocation problems can be categorised into a variety of groups based on empirical functions, restrictions, and algorithm types.

3. Proposed particle swarm optimization model of STATCOM

The study's major aim is to strengthen the system's VSI to prevent voltage instability and to identify and enhance the bus with the lowest stability index. Aside from VSI, the study's major two objectives, which are the most significant in enhancing voltage stability, have been addressed. In every distribution system, the load voltage and total electrical failure are more important. The goal of this research is to optimize the general voltage profile while lowering real and reactive energy inefficiencies.

3.1 Voltage stability index

The operator can use the Voltage Stability Indicator to see how near the network is to collapse. VSI determines the system's poorest node, which is the most vulnerable to voltage collapse. Since growing loading, extraction, and enhanced power optimization techniques, the issue of voltage control and voltage instability has worsened. The voltage stability is used to determine which circuit is most vulnerable to voltage instability.

3.2 Power loss reduction

Many study studies have analysed and proven that the distribution network has many losses, accounting for around 13% of total losses, which impair the overall power study's validity, especially the major distribution network. The inclusion of other gadgets may have an impact on the power network and raise power losses, but this research is designed in such a manner that these damages are taken into account as well, reducing the previously computed loss. In this investigation, power loss was improved with the inclusion of VSI.

3.3 Voltage profile improvement

Consumers are inextricably linked to the distribution system. Customers come in many shapes and sizes, and their loads range from capacitive to inductive. As a result, when a load is exploratory, a variety of challenges develop, ranging from under-voltage to overcharge.

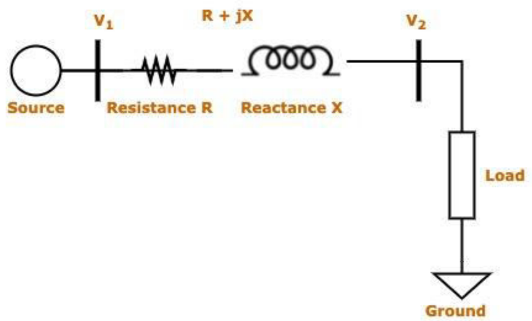

Fig. 1. Standard distribution system

The standard distribution system is shown in Fig. 1. The system has the source, resistance, reactance in the transmission lines, and load which is connected to the ground. This bus voltage was also considered into account in the assessment, because when VSI is enhanced, the voltage magnitude of any bus is not damaged, and there are no voltage sags or other voltage concerns. The bus voltages of the process presented have also been modified, which will aid in preserving the power network's functionality (system).

3.4 PSO Algorithm

This research collaborated on a PSO algorithm that relied on a population-based randomized algorithm. Every object moves in an N-dimensional solution space through an irrational produced velocity in this method, which has a collection of swarms which are randomised triggered. The two dominant values for every component are maintained throughout all Particle Swarm Optimization systems. The first is considered the most promising (fitness) method, has been obtained to date and has already been maintained. The pbest value is used to represent such a result. The second most frequent option is the global optimal, or gbest, which is assessed by the PSO compilers by watching the pbest readings and then setting both of the quantities. The particle's velocity is changed using Equation (1).

$$Vl_{x,y}^{new} = Vl_{x,y}^{old} - \propto \left(random\ (k)\right) + \beta\left(Pr_{x,y}^{gbest} - Pr_{x,y}^{old}\right) \quad (1)$$

The old and new voltage are expressed as $Vl_{x,y}^{new}\ and\ Vl_{x,y}^{old}$. The global best and old power value are denoted as $Pr_{x,y}^{gbest}\ and\ Pr_{x,y}^{old}$. Here, random is a randomised variable with a value of 0 to 1, and $\propto$ and β are acceleration coefficients. If the desired quantities are not discovered, Equation (2) updates the position.

$$Pr_{x,y}^{new} = Pr_{x,y}^{old} + Vl_{x,y}^{new} \quad (2)$$

The old and new power are denoted as $Pr_{x,y}^{old}\ and\ Pr_{x,y}^{new}$. The new and updated voltage is denoted as $Vl_{x,y}^{new}$. When x= 1,2, 3..., N and y = 1, 2, 3..., N are varied. More repetitions are required to reduce the inaccuracy to the point where the location can be determined in a single phase. The updated power is denoted in Equation (3).

$$Pr_{x,y}^{new} = (1-\propto)Pr_{x,y}^{old} + \propto Pr_{x,y}^{gbest} - \beta(random\ (k)) \quad (3)$$

$\propto$ and β are acceleration coefficients, and the global best power is denoted $Pr_{x,y}^{gbest}$. The old and new power are expressed as $Pr_{x,y}^{old}\ and\ Pr_{x,y}^{new}$. $\propto$ runs between 0.1 and 0.5, and β between 0.1 and 0.7.

3.5 Load flow analysis

In this investigation, the Forward/Backward Sweeping Power-flow procedures were applied. The required impedance and resistor of the transmission lines used in the branches construction are used to calculate the resistivity of the feeding branch. The

Forward/Backward Sweeping Power-flow method has two steps: backwards sweeping and forwards sweeping.

Backward sweeps: Every node of a distributing network's grid voltage is determined in this stage.

Following the backward sweeping, this phase is used to calculate the power at every node of a supply chain.

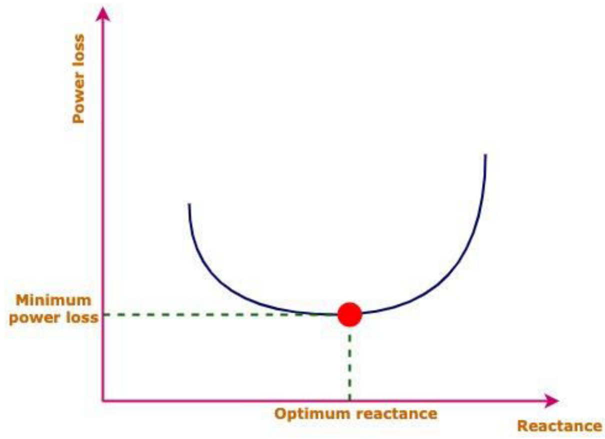

Fig. 2. Relationship between reactance and power loss

The relationship between reactance and power loss is expressed in Fig 2. The power is maximum at a minimum and maximum reactance. The lower power loss is attained at medium reactance values.

3.6 Description of the feeder

For the study, a real-time feeder was employed. Line and load statistics are derived from the feeder's standard. There are 51 buses on the feeder, carrying a load of 4 kWatts.

The steps in the technique are as follows:

Step 1: In MATLAB, data is entered and the system is simulated.

Step 2: Using the MATLAB program, load flow data were analyzed using the Backward/Forward sweeping method.

Step 3: The PSO method is utilised to determine the fault type for STATCOM deployment.

Step 4: Using the PSO algorithm, a particular bus for the deployment of STATCOM is determined.

Step 5: The VSI of the poorest bus is calculated using the values acquired in step 4.

Step 6: After the STATCOM has been installed, the findings are achieved.

3.7 VSI with DG allocation

Fig. 3 shows the overall flowchart of the proposed system. Fig. 3(a) shows the end-to-end voltage stability workflow and Fig. 3(b) shows the optimization model.

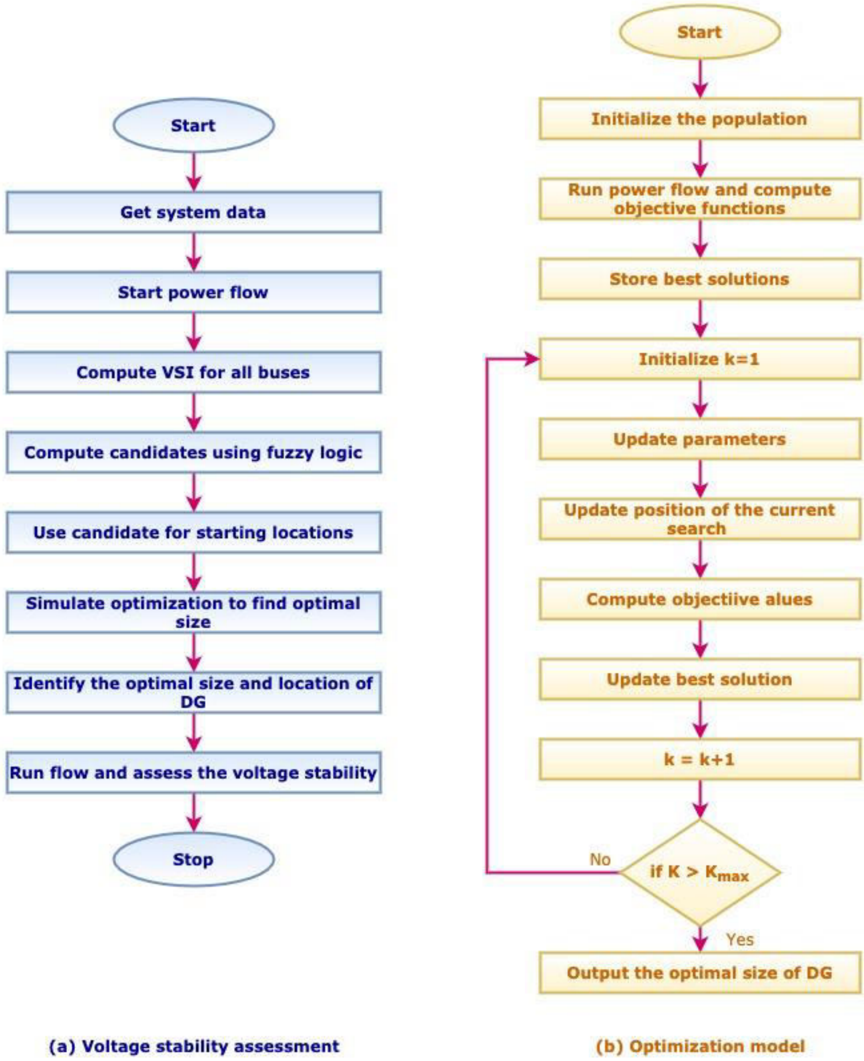

Fig. 3(a). Voltage stability assessment and 3(b). Optimization model

The flowchart shows how to analyse the power reliability of the system while allocating the DG optimally. The total procedure is completed in the steps that follow:

- Define the optimal solution by reading the system information (line and load information).
- Obtain the reference voltage and direction for all buses by running the energy flow.
- Compute the LFA after calculating the VSI for every node. To organize the alternative buses, just use a fuzzy controller.

- Create a set of searching whales with the different buses, WOA variables, and the maximum number of generations K_{max} at random.
- Run current flowing and compute the optimal solution for every search whale, then save the best result.
- Modify the variables for every searching whale.
- Compute every search agent's optimal solution. Update the most effective solution.
- If $k < K_{max}$, go back to the previous step.
- Return the best answer you've found so far.
- As the DG's optimum size and location, choose the best option.
- By following the curve and running the continuing power flow, it assesses the electric grid voltage reliability.

The proposed PSO method is designed with LFA and VSI to analyse the voltage stability in distribution systems and position optimization of STATCOM. The software outcomes of the system are analysed in the next section.

4. Simulation analysis and outcomes

The implementation of the developed combination VSI and LFA method is evaluated utilising radial distribution networks 10, 32, 68, and 84 in this section. In comparison to other well-known optimizing strategies, the practicality and effectiveness of composite VSI and LFA for optimally allocating DG in radial distributing networks are demonstrated. MATLAB M-files were used to run all of the simulations. The amount of agents is set to 100, and the number of repetitions is set to 50.

Table 1. Voltage stability analysis

Bus No	Base	STATCOM
1	100	100
2	95	97
3	93	95
4	89	93
5	86	91
6	83	89
7	76	85
8	71	98
9	96	95
10	93	92
11	91	89

12	87	85
13	85	95
14	83	92
15	81	90

The voltage stability analysis is tabulated in Table 1. The analysis is done by varying the buses from minimum to a maximum level and the respective outcomes of the base and STATCOM are analysed. The outcome shows the effectiveness of the proposed system using the LSA and VSI method. As the bus size increases, the respective voltage stability of the system is decreased. The STATCOM mode has higher. Voltage stability than the base model in all the conditions.

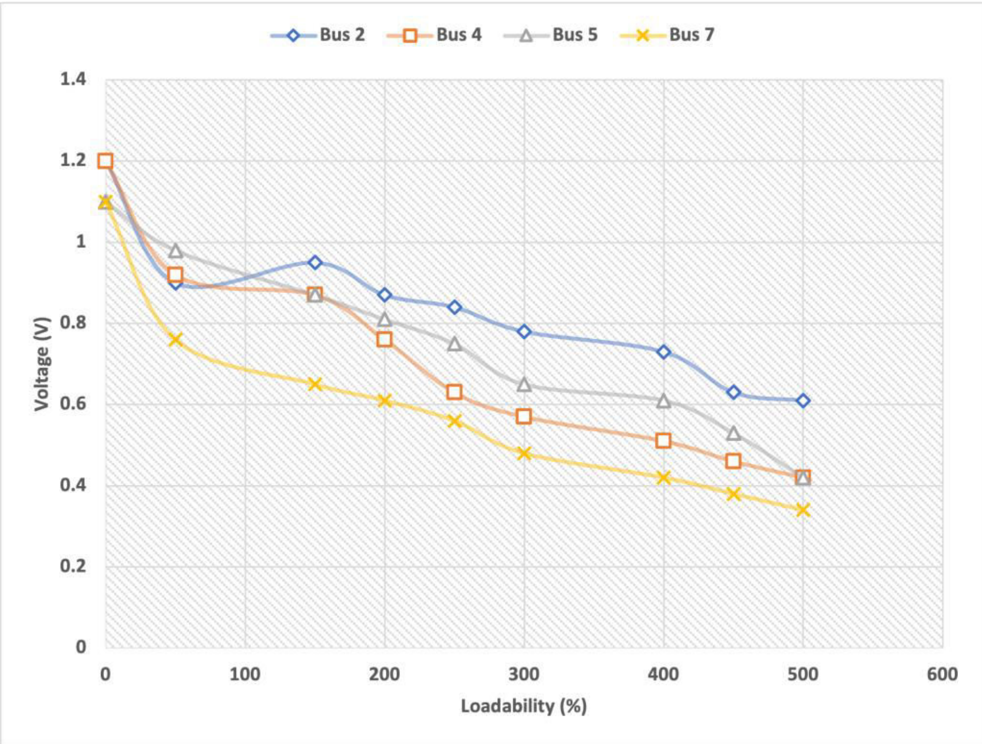

Fig. 4. Loadability analysis

The loadability analysis of the system is shown in Fig. 4. The voltage of the STATCOM is varied from minimum to maximum and the loadability is also increased. The simulation outcomes of the proposed system show the higher loadability with lower voltage at the DG. The buses are varied from 1 to 4 and the outcomes are monitored continuously. The proposed system with PSO and LFA and VSI methods exhibits higher outcomes than the existing models.

Fig. 5 indicates the voltage stability analysis of the proposed system. The buses for the simulation analysis are varied from minimum to maximum level and the outcomes are plotted. The voltage stability outcomes of the base and STATCOM are computed and the outcomes show the higher impact of the proposed system. As the bus count increases, the respective voltage stability of the system also increases. The higher voltage stability leads to higher accuracy.

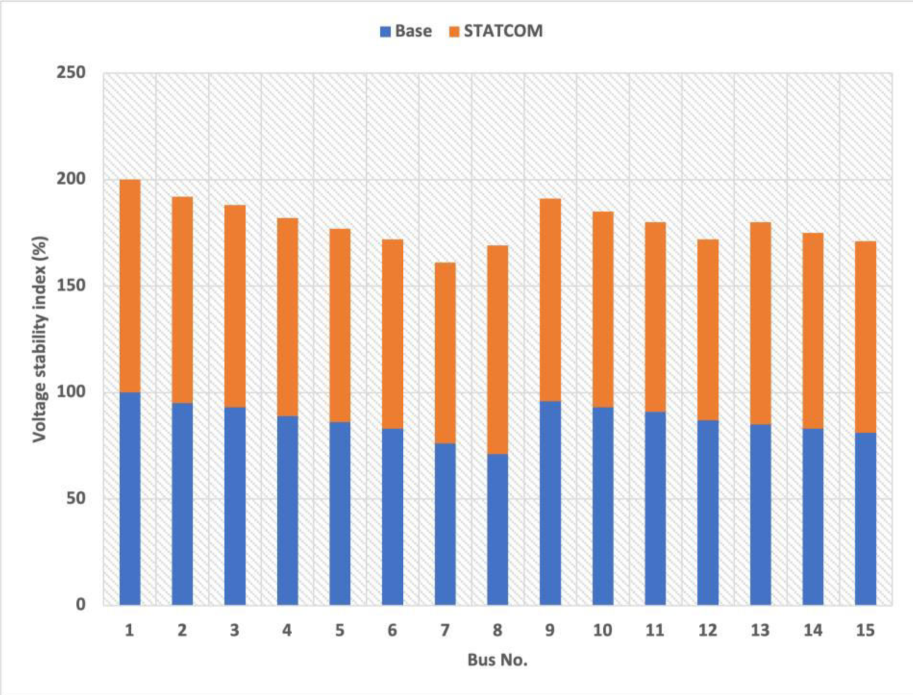

Fig. 5. Voltage stability analysis of the proposed PSO system

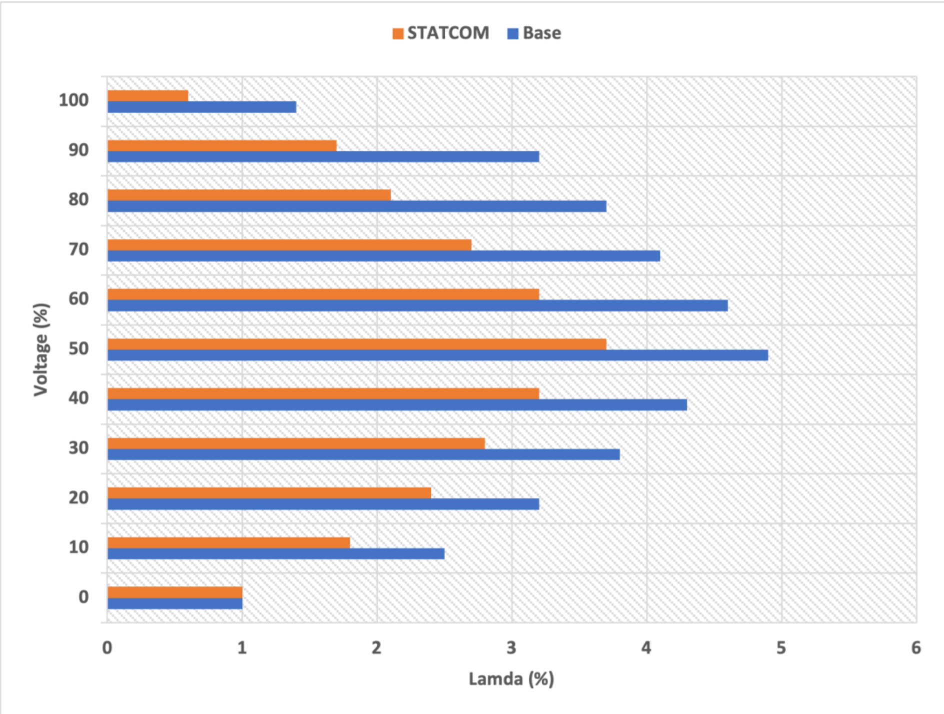

Fig. 6. The voltage analysis of the distribution systems

The voltage analysis of the distribution system is shown in Fig. 6. The voltage of the DG is varied from 0% to 100% with an incremental size of 10%. The impact of the lamda at the DG using LFA and VSI is analysed and plotted. The results show the impact of the STATCOM model on the base distribution systems. The optimized placement produces better results in all the simulation conditions.

The simulation outcomes of the proposed system with PSO with LFA and VSI are analysed and plotted. The outcomes show the impact of the optimized position model under different evaluation conditions.

5. Conclusion and future scope

This research demonstrated a current technique for increasing voltage stability index, reducing power losses, and enhancing the power quality of a real-time distribution network. The Particle Swarm Optimizing Technique was used to determine the best size and position of STATCOM to be allotted in the system. It is an efficient and highly attentive method. The main goal of this research was to improve the voltage regulation of the poor bus in order to prevent the system from collapsing and affecting the performance of all consumers linked to the feeders. The assignment of STATCOM on the network enhanced not just System Reliability, but also the grid voltage and decreased the system's energy loss, according to the results. Aside from that, simulation findings show that the technique has a high degree of convergence. However, the results show that this strategy is successful in increasing VSI, improving voltage profiles, and lowering complete power losses.

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