A hybrid system for voltage stability and placement optimization of STATCOM in distribution systems

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Abstract

A methodology is provided in this paper for determining the optimal assignment (i.e., sizing and position) of Distributed Generators (DGs) and static compensators (STATCOM) in a radial distribution system (RDS). The voltage stability index (VSI) is used to locate the best STATCOM position, and the fast voltage stability index (FVSI), and phase voltage stability index (PVSI) are used to locate the best-distributed energy location. The suggested work is presented as a non-linear optimal solution with a hybrid power stability optimization (HPSO), which is solved utilising a meta-heuristic/evolutionary-based approach in this paper. The Bat method is used to determine the ideal dimensions of STATCOM in RDSs. Two basic IEEE 34 and 85 bus RDSs are investigated in this study to assess the correctness, feasibility, and applicability of the suggested optimal allocating method. In the RDSs, the experiments demonstrate a reduction in energy losses and an increase in bus voltages.

Keywords – STATCOM, voltage stability, optimization, optimal placement

1. Introduction to STATCOM and optimization

Renewable energy has gotten a lot of attention in the last few years for a myriad of purposes. Increased knowledge of sustainable and renewable sources like wind and sunlight has sparked a movement toward energy-efficient gadgets and preservation strategies to reduce energy consumption and save money [1]. The distribution channels in the overall power system suffer higher losses (about 13%), and the voltage quality problems of the radial distribution system (RDS) must be addressed immediately.

For parallel volt-ampere reactionary design, series capacitor preparing, transfer capacity research, reactive exchange studies, and loss optimization research, the optimal operation of the distribution network is used [2]. Customers benefit from dispersed generation (DG) from a variety of sources since it is a cost-effective and dependable source of power. Because of its advantages, the optimal incorporation of dispersed generation into a current power network is critical [3]. The tricky problem of optimal DG distribution (i.e., placement and sizing) is to increase system performance by lowering power losses and enhancing voltage safety and stability. STATCOM can be used for dynamic power balancing, which helps to reduce voltage fall and power wastage caused by increased demand [4]. After calculating multiple power flowing solutions according to a particular set of consumer requests, the optimum solution is found.

The modification of dependent variables in the optimum requires an effective optimization technique. Due to the constraints of traditional optimization methods, evolutionary methods are being used as an optimization procedure in this study [5]. Convolutional neural networks are used in the planning, management, and analysis of power systems. Demand forecasts, optimum power flow, production planning, state prediction, static and complex security evaluation, damage detection, fault placement, and voltage profile stability evaluation are some of the uses.

Fuzzy systems are used in the planning, management, and control of energy systems. Transmission expansion design, reliability test, daily load prediction, voltages and reactive current management, state estimate, vulnerability assessments, fault detection, converters control, and varied controller design are just a few of the uses available [6]. The bat algorithm (BA) is utilised in this study to find the best location and size for STATCOMs and DGs in RDSs. The voltage stability index (VSI) is used to determine the best placement for STATCOM, and the fast voltage stability index (FVSI), and phase voltage stability index (PVSI) are used to determine the best site for DG.

The rest of the article is enumerated as follows: section 2 indicates the literature survey of the STATCOM and distribution systems. The proposed hybrid position optimization system is designed and analysed in section 3. Section 4 shares the software analysis and performance comparison. The conclusion and future scope of the system are listed in section 5.

2. Background to the STATCOM and distribution systems

With the evolution of energy systems, one of an electricity utility's key commercial operations has been controlling the network infrastructure effectively and reliably. One of the most important concerns is the amount of energy delivered by the entire network as the customer load changes; also, the system is not fixed [7]. Long design studies are conducted several years in advance to assess the current networks' resiliency in various scenarios. To design the building or refurbishment of a facility for further growth, engineering analysis tools, especially simulation models, are used. However a planning analysis may identify the appropriate running configuration for a projected loading condition, the system circumstances on that day may differ.

Abd-Elazim et al. employed a well-known meta-heuristic, the controlling system (CS) method, to create the best STATCOM architecture in multimachine environments [8]. They've shown how to use curves to get the best STATCOM site. They also transformed the parameters tuning problem into an optimization challenge that the CS method solved. Ultimately, the fresh strategy was compared to traditional approaches, demonstrating the work's effectiveness.

Bhattacharyya et al. devised a method for determining the appropriate position for the STATCOM in meshes distribution channels [9]. The most important task was determining the best position for the STATCOM, as well as its size. Finally, the suggested methodology was compared to established methods for determining STATCOM size and location. Finally, the authors calculated the impact of optimal STATCOM position on power losses, cost of electricity, and other factors.

Inkollu et al. proposed a new framework for optimising devices with the goal of maintaining voltage regulation in energy systems [10]. As a result, the position static optimization (PSO) method was created in order to improve voltage regulation. The PSO method was used in this approach to get the best possible allocation and size of devices. The proper arrangement and configuration of units were successfully verified using the suggested approach.

Kavitha et al. reported the use of a cathode ray oscillator (CRO) to determine the best location for STATCOM to minimise transmission loss, increase voltage regulation, and optimise grid voltage in the electricity system [11]. The efficiency analysis was carried out using the IEEE 30 and 58 transit systems. The simulation results validated the suggested work's results in terms of settling time and power failure.

Abd-Elazim et al. proposed a technique to optimise the number, that plays the most critical role in improving system efficiency at a low cost [12]. The intended purpose was to achieve advances linked to optimum utilisation by considering voltage and cost differences. The created technique was also tested in terms of safety and reliability.

Gupta et al. developed an Imperialistic Competitive Algorithm (ICA) for handling allocation challenges [13]. This strategy reduced overloads, and voltage changes were discovered as a result of demand expansion and power loss crises. The results obtained by using ICA for assignments have shown that ICA is superior to other traditional techniques.

Yuvaraj et al. employed a new approach called ICA to determine the best STATCOM architecture in a multimachine setting, which was inspired by socio-political phenomena [14]. They demonstrated the photovoltaic (PV) for determining STATCOM's ideal position. The STATCOM variable was identified as an optimization problem that ICA was able to handle. In terms of diverse disruptions and limitations, the STATCOM performed better than the open-loop STATCOM. The planned work was shown to be better in terms of improved power quality.

Nonlinear computing, on the other hand, better voltage profile, decreased power loss and lowered the cost of responsive support, but the method is harder to maintain and operate, requiring more memory [15]. The PSO method improves stability and reduces power loss, however it must be evaluated using the most recent optimization technique. In addition, the CRO algorithm produced good resolution and ideal communication loss reduction, even though it was a lengthy procedure that required verifying the viability of each option. The method can improve security while also reducing load deviations. It did necessitate a cost estimation of devices. Furthermore, the imperialist competition algorithm boosted the system's total voltage profiles and specifications. However, it is necessary to estimate the entire power, and a longer settling time was required to reduce system oscillation. As a result, an intelligent method must be introduced as a competition to the classical algorithms described above.

3. Proposed hybrid position optimization system

The creation of a more robust and speedier optimal assignment method is the main focus of the effort. The power flow analysis solution includes a load flow answer, which is the proportionality constraint of the optimum assignment problem. The most basic numerical method for analysing a distribution system is energy flow. The factors that most affect the cost reduction objective are power flow generations of generators and the generator reference voltage.

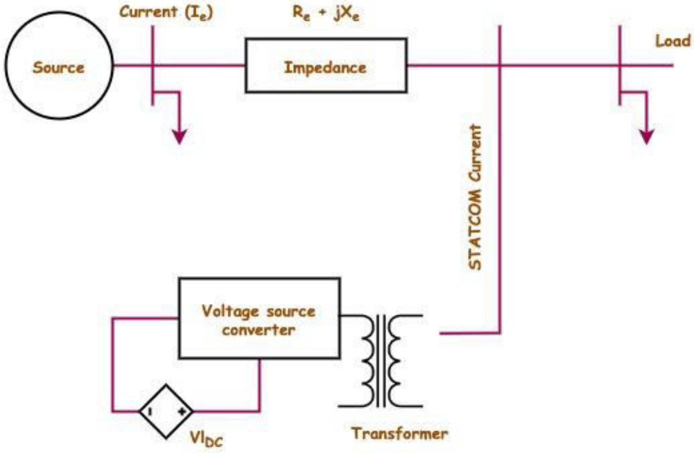

Fig. 1. Distributed system model

The distributed system model is shown in Fig. 1. The system has a source, and impedance and voltage source converters are used to connect the load. The real power production is practically at peak value for the fault detection aim. Generator voltages, transformer tapping, and shunts all have an impact on loss. In RDSs, this goal function is quite important. This objective can be defined in Equation (1):

$$\min J_1 = \min(Pr_{TL}) \quad (1)$$

The total load power is denoted Pr_{TL}.

- **Equality constraints**

The balance of power between total energy production from DS, DG, and STATCOM, and devices and gadgets plus losses is represented by this restriction. This limitation can be defined in Equation (2)

$$\sum_{x=0}^{N} Pr_x + Pr_{TL} = Pr_{DG} + Pr_{STATCOM} + Pr_{DS} \quad (2)$$

The power of the system is denoted Pr_x, and the total load power is denoted Pr_{TL}. The DG power is denoted Pr_{DG}, STATCOM power is denoted $Pr_{STATCOM}$, and the DS power is denoted as Pr_{DS}.

- **Inequality constraints**

These control factors' limitations are carefully chosen to be within acceptable bounds. The penalty technique is then used to analyse the functional boundary condition, where the optimization problem is reinforced by a punishment term for every broken functional restriction. The method's drawback is the modelling of converter taps.

1) Bus voltage amplitudes are limited

The magnitude of voltage on each bus is limited and it is expressed in Equation (3).

$$Vl_x^{min} \leq |Vl_x| \leq Vl_x^{max} \quad (3)$$

The minimum voltage, and maximum voltage are denoted Vl_x^{min} *and* Vl_x^{max}. The current-voltage is denoted as Vl_x.

2) Reactive Power Compensation (RPS) constraints

The STATCOM injects reactive power ($Q_{STATCOM}$) at the ith alternative bus is restricted using Equation (4).

$$Q_{SATCOM,x}^{min} \leq |Q_{STATCOM}| \leq Q_{STATCOM,x}^{max} \quad (4)$$

The reactive power minimum and maximum value are shown as $Q_{SATCOM,x}^{min}$ and $Q_{SATCOM,x}^{max}$. The STATCOM reactive power is denoted as $Q_{STATCOM}$.

3) Active power limitation

The amount of real power that DG can inject into the bus is restricted using Equation (5).

$$Pr_{DG,x}^{min} \leq \left|Pr_{DG,x}\right| \leq Pr_{DG,x}^{max} \qquad (5)$$

The minimum and maximum power of the DG are shown as $Pr_{DG,x}^{min}$ and $Pr_{DG,x}^{max}$. The power of the DG is represented as $Pr_{DG,x}$.

3.1 Proposed hybrid algorithm

This study offers a new hybrid method that affects the behaviour of bats by optimizing with the voltage stability method, resulting in a higher convergence speed since the method uses the best approach of both methods. The adjustments in this method were performed to the method's position updating; that really is, if the actual value of N is much less than 1, the location refresh of the bat at the primary search agent occurs, but the remainder of the method remains unchanged. Because the algorithm is so impressive in terms of key updating concepts, it effectively improves the accuracy of the best solution.

3.2 Solution encoding

The correlating position low optimization (LO) and dimensions (that what size: remuneration value of Q power flow) must be recognised for locating the STATCOM, and the relevant solution provided as input to the suggested method for obtaining the optimum solutions. There are four different sorts of experiments, which are detailed in the Simulated Settings section. It's for the 'if 1 STATCOM' requirement. Likewise, two places LO and two dimensions (replacement value of Q) are determined in the second study (if 2 DSTSTCOM is utilised). Three LO and trio sizing (replacement value of Q) are discovered in three trials (if 3 STATCOM is being used), and four LO are obtained in final step 4 (if 4 STATCOM would be used).

3.3 Objective function of the proposed model

Requirement meet, VSI, Price of SATCOM, FVSI and PVSI are some of the restraints listed here. The total amount of electrical energy used at any particular time is known as electric demand. Depending on the rate tariff, this metric is in kilowatt-hours and kilovolt amps. The voltage stability magnitude (VSM) is denoted and used for optimum position placements. The related demand should match the established load model, and if it doesn't, a penalty must be applied. The voltage quality index must then range between 0.91 and 1.2. Equation (6) shows the optimum bank in the voltage stability .

$$OB = minimum \begin{Bmatrix} Required\,power & VSI\ need \\ Price\ of\ STATCOM & VSM \end{Bmatrix} \qquad (6)$$

The required power, VSI, VSM and other STATCOM parameters are used to compute the final position optimization results.

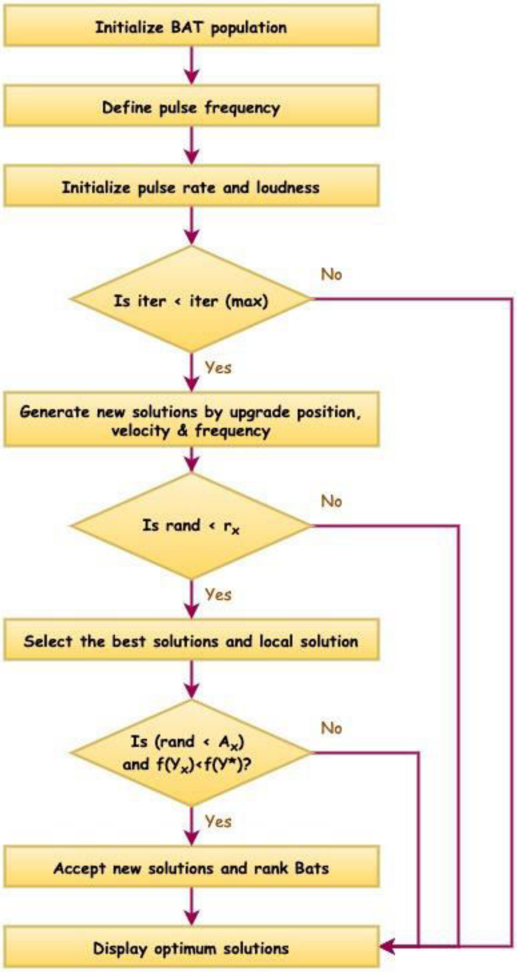

Figure 2. The workflow of the system

The workflow of the system is denoted in Figure 2. The implementation of the proposed methodology is described below:

Step 1: Enter the bus information, distributed system (DS) load flow, and Bat method data.

Step 2: Calculate voltage levels, complete power losses, incremental loss coefficients, and system voltage indices for the best-estimated state (i.e., without DG and STATCOM).

Step 3: Using the hybrid method and VSI, find the best areas for DG placement.

Step 4: For the quantity of kW and kVA to be supplied within their lowest and maximum limitations, initialise the randomized Bat method.

Step 5: Using equations, create a new answer by altering the wavelengths.

Step 6: For each Bat position, calculate the fitness function using the optimal solution.

Step 7: Using the rand method, randomly generate an integer. If rand>pulse frequencies, use the equation to get a local solution close to the optimal answer. If not, proceed to Step 10.

Step 8: If (rand < amplitude (A_x)) is true, accept innovative solutions, lower A_x, raise reactance r_x, and then edit the existing best solution. If not, the optimal option should be marked as the fittest solution.

Step 9: Review the criteria for stopping. Go over to Step 5 if ($iter < iter(n)$), otherwise stop the process.

Step 10: Print the best option.

In this way, the hybrid bat optimization method is designed for voltage stability and STATCOM systems. The hybrid power stability optimization is used to position optimization and the outcomes of the systems are analysed in the upcoming sections.

4. Simulation and outcome analysis

MATLAB 2015a was used to implement a comprehensive model. The suggested method's approach was tested using standard IEEE 34 and 85 bus Nigerian distributing networks derived. The direct load circulation method is used to examine the inefficiencies and voltage magnitude for all of the systems. The suggested optimization technique HPSO is used to find the best position and size for DG and STATCOM.

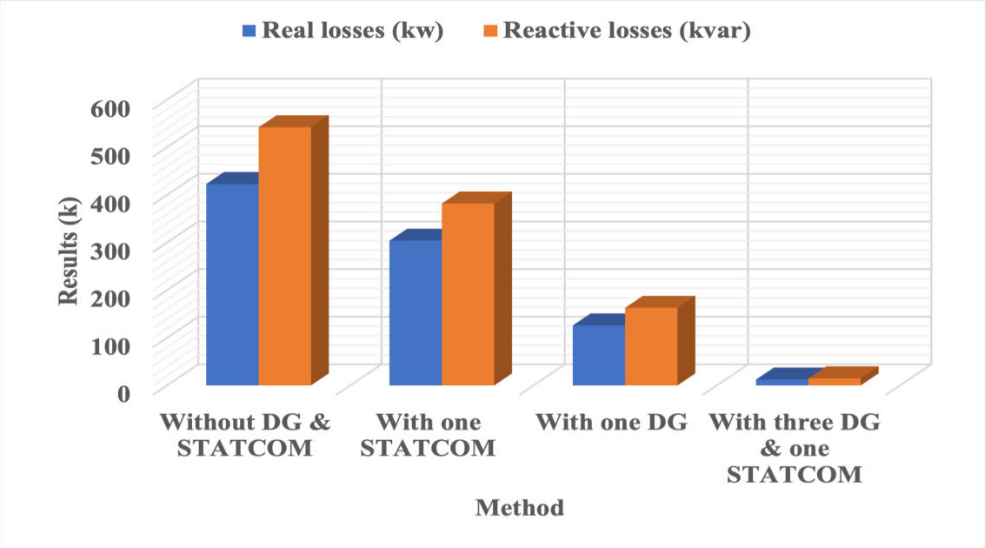

Figure 3. The loss analysis of the system

The loss analysis of the system is depicted in Figure 3. The system is analysed under different conditions like without DC & STATCOM, with one STATCOM, with one DG and with three DG & one STATCOM. The different conditions are analysed and the outcomes of the real losses and reactive losses are computed and plotted. As the number of DG and STATCOM increases, the losses in the system decrease.

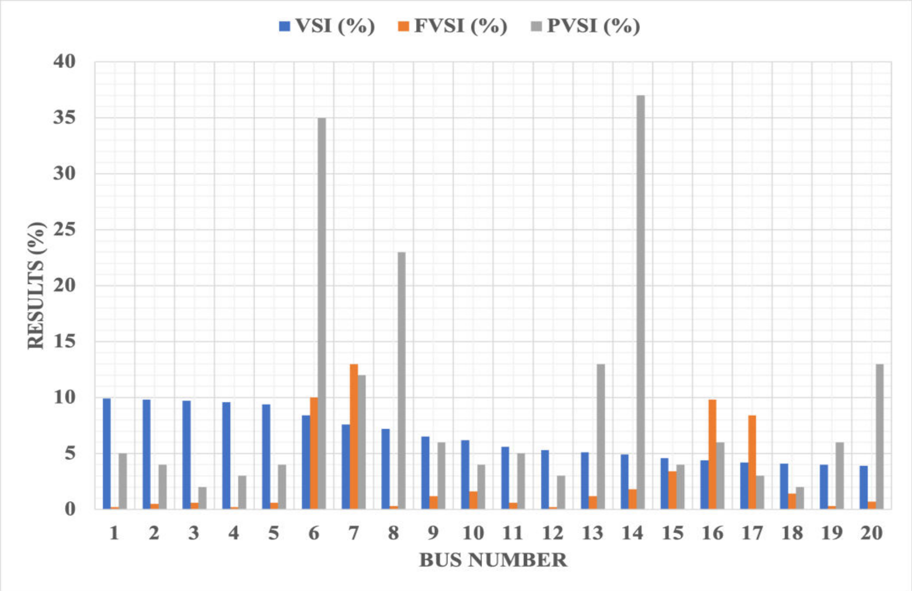

Figure 4. The Voltage stability analysis

The voltage stability analysis of the system is shown in Figure 4. The analysis is done by varying the bus number from 1 to 20 and the respective VSI, FVSI and PVSI are monitored. The results are analysed and computed over different time periods and different bus numbers. The proposed HPSO system is analysed and used for voltage stability and position optimization models. The higher system ability and effectiveness are achieved by hybrid bat position optimization and voltage stability method.

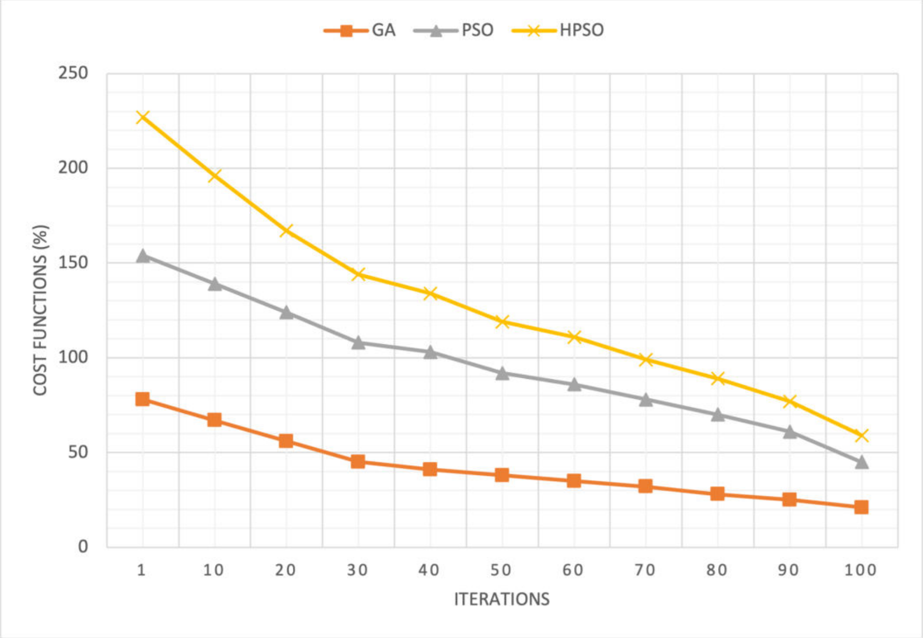

Figure 5. Cost function analysis

The cost function analysis of the HPSO system is shown in Figure 5. The iterations are varied from 1 to 100 with a step size of 10 iterations. The cost function is analysed over the different systems like a genetic algorithm (GA), phase stability optimization (PSO) and HPSO system. As the iteration increases, the respective cost function of the system decreases. The proposed HPSO system produces higher results than the existing GA and PSO systems.

The suggested HPSO system with the hybrid bat position optimization and voltage stability method produces better results in DG, STATCOMs and etc.

5. Conclusion and findings

This study solves the optimal assignment problem, which is the design and placement of STATCOM and DG to reduce system inefficiencies and voltage profile improvement of radial distribution systems (RDSs). The HPSO approach is used to discover a suitable site for the DG, and the voltage stability index (VSI) is used to locate an appropriate area for the STATCOM in this study. The hybrid bat algorithm is used to determine the best DG and STATCOM sizes in RDSs. On IEEE 34 and 85 bus RDSs, the feasibility of the suggested optimization process is tested. In RDSs, allocating DGs and STATCOMs at the same time decreases power losses and improves the voltage profile. The study might be expanded in the future to discover the best places for electric vehicle recharging stations.

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