Optimal Placement and Sizing of DSTATCOM in Radial Distribution System Using Gravitational Search Algorithm

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ABSTRACT

In order to reduce power losses and improve the voltage profile of the Radial Distribution network, a Gravitational Search Algorithm (GSA) is described in this work. A backward forward load flow algorithm is taken as a base case and Loss Sensitivity Factors (LSF) are used for identifying the candidate buses for D-STATCOM placement whereas the optical allocation and sizing of D-STATCOM is done by using GSA. The proposed work has been evaluated using the industry-standard IEEE 33-Bus Radial Distribution Test network. The acquired results have been compared with the results obtained in Base Case, Genetic Approach (GA), Immune Algorithm (IA), Harmony Search Algorithm (HSA), Power Loss Index (PLI) technique, and Differential Evaluation Algorithm in order to verify the usefulness of the proposed algorithm (DEA). MATLAB software was used to run the simulation.

Keywords: Distribution STATIC Compensator (D-STATCOM), Gravitational Search Algorithm (GSA), Loss Sensitivity Factors, Optimal Allocation, Optimal Size, Power Loss Minimization, Radial Distribution System.

1. NOMENCLATURE

P_i, Q_i	Real and Reactive Powers at i^{th} bus
P_{Li}, Q_{Li}	Real and Reactive Load Powers at i^{th} bus
P_{Li+1}, Q_{Li+1}	Real and Reactive Load Powers at $(i+1)^{th}$ bus
P_{i+1}, Q_{i+1}	Real and Reactive Powers flow beyond $(i+1)^{th}$ bus
Z_j, Z_j'	Impedances of j^{th}branch/line before and after placing D-STATCOM
r_j, r_j'	Resistances of j^{th}branch/line before and after placing D-STATCOM
x_j, x_j'	Reactance of j^{th}branch/line before and after placing D-STATCOM
I_j	Current flow in j^{th}branch/line
V_i, V_{i+1}	Voltage magnitudes at the buses $i, i+1$ before placing D-STATCOM
V_i', V_{i+1}'	Voltage magnitudes at the buses $i, i+1$ after D-STATCOM Placement
θ_j	Phase angle of the current flow in j^{th}branch/line
δ_i, δ_{i+1}	Phase angles at the buses $i, i+1$ before placing D-STATCOM
δ_i', δ_{i+1}'	Phase angles at the buses $i, i+1$ after D-STATCOM Placement
$P_{T,Loss}$	Total Real Power Losses before placing D-STATCOM
$P_{T,Loss}^{with\ D-STAT}$ or $P_{D-STAT,TLoss}$	Total Active Power Losses after D-STATCOM installation.
$Q_{T,Loss}$	Total Reactive Power Losses before placing D-STATCOM
$Q_{loss(j)}$	Reactive power loss in j^{th}branch/line
$LSF_{(j)}$	Loss Sensitivity Factor (w.r.to. Reactive power) of j^{th}branch/line for D-STATCOM placement
I_{D-STAT}	D-STATCOM current

$\frac{\pi}{2}+\delta'_{i+1}$	Phase angle of D-STATCOM current
V_{min}, V_{max}	Minimum and maximum voltage constraints for all buses
Q_{D-STAT}	Reactive power injected by D-STATCOM

2. INTRODUCTION

Now a day, a noteworthy ruin is faced by the distribution power system. When buses are moved far from the substation in distribution systems, the voltage at the buses decreases and there are significant losses. The lack of reactive power across the distribution network is the cause of the voltage reduction and excessive losses. The requirement of sufficient reactive power support to the appropriate locations is the most well-known method for improving power factor, voltage profile, and reducing line losses in distribution power systems. Increasing network losses and poor voltage regulation are caused by the expanding and complicated nature of electric distribution systems. According to studies, I^2R losses at the distribution level account for roughly 10 to 13% of the total power generated [1]. Deregulation worsens issues with the Radial Distribution System's power quality, including voltage swings, distortion, imbalance, sag, and insecurity (RDS). The aforementioned power quality issues prompt increment in power losses, response time is additionally decreased and furthermore influence power flow limits are reduced. Therefore, power system engineers should provide consumers with high-quality energy that has fewer power losses [2]. Shunt capacitors and series voltage regulators are the two common techniques for maintaining the distribution system's voltages within acceptable bounds. In any case, due to their step-by-step functioning, conventional series voltage regulators have a few disadvantages, including the inability to provide reactive power and relatively moderate reaction times [3-5]. When employed in a similar circuit with inductive components, shunt capacitors have the tendency to oscillate and are limited in their ability to create reactive power that is continually changing [6].

Several controllers have been used for effective series and shunt compensation. As a result of enhancements in the voltage and current handling capabilities of power electronic equipment that has taken into account the development of Flexible AC Transmission Systems (FACTS). It should be noted that FACTS devices respond quickly to changes in the state of the network. FACTS devices were first developed for transmission systems, but a similar concept known as D-FACTS devices or Custom Power Devices (CPDs) has started to be used in distribution systems [7-8]. Unbalanced loads, voltage sag, voltage swings, and voltage imbalance are some examples of power quality issues that can be resolved with a converter for shunt-linked voltage supplies called D-STATCOM. Over traditional reactive energy compensation devices, D-STATCOM offers a number of benefits, including low power losses, reduced harmonic output, high levels of regulatory functionality, low cost, and small size [9–14].

3. LITERATURE SURVEY

Few scholars, who have concentrated on the study of D-STATCOM placement and sizing in RDS, have created and deployed a number of algorithms for power loss mitigation and voltage augmentation in the distribution system. Authors *Mehdi Hosseini et.al.* proposed an analytical method for finding best location of DVR and D-STATCOM and concluded that D-STATCOM performance is superior than DVR in view of enhancing the voltage profile and power loss reduction but its size is comparatively high [7]. *Joseph Sanam et. al.* proposed an Exhaustive Search Method to minimize the power loss in IEEE 30-bus system by placing D-

STATCOM at 5th bus [15]. Researchers *Seyed Abbas Taher and Seyed Ahmadreza Afsari* was developed Immune Algorithm (IA) and concluded that the IA is more effective than Genetic Algorithm (GA) [16]. Authors *Yuvaraj.T et.al.* presented Bat Algorithm (BA) for D-STATCOMs allocation and sizing in RDS and said that BA converges quickly than IA [2]. Differential Evaluation Algorithm (DEA) was devised by Joseph Sanam et al. to reduce installation costs and energy loss costs while also improving voltage magnitudes [17]. Power Loss Index (PLI) Method was introduced by Atma Ram Gupta et al. to determine the ideal position for UPQC and DSTATCOM in RDS [8]. An analytical method for determining the ideal location and size of DSTATCOM was proposed by authors S M Suhail Hussain et al. They discovered that the method is efficient and simple to use [18]. Researchers Joseph Sanam et al. created a mathematical model of DSTATCOM and integrated it into backward forward load flow to account for reactive power [15]. The best location and size of D-STATCOM can be found by calculating the voltage stability index in RDS under various load scenarios, claim authors Abhinav Jain et al [19]. *T. Yuvaraj et. al.* proposed Harmony Search Algorithm under light load condition and Bat Algorithms for DSTATCOM allocation and sizing in RDS by considering light load, medium load and peak load conditions [20,21]. *K Subbarami Reddy et. al.* proposed Penguins Search Optimization Algorithm for optimal placement and sizing of DSTATCOM [22].

This paper organized as the Section I discuss the Nomenclature, introduction in section II and Literature Survey given in section III, section IV depicts problem formulation and Mathematical modelling of D-STATCOM is presented in Section V. While section VII discusses the simulation findings of the proposed work, section VI provides specifics about the gravitational search algorithm. Finally, section VIII has the conclusion.

4. PROBLEM FORMULATION

A. Power Flow Analysis [25]

The simple 2-bus Radial Distribution System (RDS) is shown in Figure 1.

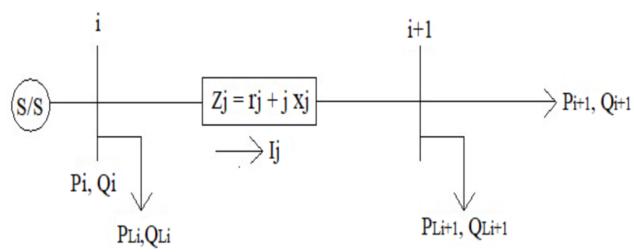

Figure 1: Single line diagram of a simple 2-Bus Radial Distribution System

The active (*Pi*) and reactive (*Qi*) powers that flows through branch 'j' are given as,

$$P_i = P_{i+1}^1 + r_j \frac{({P_{i+1}^1}^2 + {Q_{i+1}^1}^2)}{V_{i+1}^2} \quad (1)$$

$$Q_i = Q_{i+1}^1 + x_j \frac{({P_{i+1}^1}^2 + {Q_{i+1}^1}^2)}{V_{i+1}^2} \quad (2)$$

Where, $P_{i+1}^1 = P_{i+1} + P_{Li+1}$ and $Q_{i+1}^1 = Q_{i+1} + Q_{Li+1}$

The current measured within the branch "j" is represented as

$$\mathrm{I_j} = \frac{\mathrm{V_i}\llcorner\delta_i - \mathrm{V_{i+1}}\llcorner\delta_{i+1}}{r_j + jX_j} \qquad \text{Also } \mathrm{I_j} = \frac{\mathrm{P_i} - j\,\mathrm{Q_i}}{\mathrm{V_i}\llcorner -\delta_i} \quad (3)$$

From Equation (3) the voltage magnitude at bus i and i+1 can be derived as

$$V_i = \left[V_{i+1}^2 + 2\left(\mathrm{P_i r_j} + \mathrm{Q_i x_j}\right) - \left(r_i^2 + Q_i^2\right) \frac{\left(P_i^2 + Q_i^2\right)}{V_i^2}\right]^{1/2} \quad (4)$$

$$V_{i+1} = \left[V_i^2 - 2\left(\mathrm{P_i r_j} + \mathrm{Q_i x_j}\right) + \left(r_i^2 + Q_i^2\right) \frac{\left(P_i^2 + Q_i^2\right)}{V_i^2}\right]^{1/2} \quad (5)$$

The phase angle at bus I and i+1 can be calculated similarly as

$$\delta_\mathrm{i} = \delta_\mathrm{i+1} - \tan^{-1}\left[\frac{\left(\mathrm{Q_i r_j} - \mathrm{P_i x_j}\right)}{V_i^2 - \left(\mathrm{P_i r_j} + \mathrm{Q_i x_j}\right)}\right] \quad (6)$$

$$\delta_\mathrm{i+1} = \delta_\mathrm{i} + \tan^{-1}\left[\frac{\left(\mathrm{Q_i r_j} - \mathrm{P_i x_j}\right)}{V_i^2 - \left(\mathrm{P_i r_j} + \mathrm{Q_i x_j}\right)}\right] \quad (7)$$

Calculated are line "j's" active and reactive power losses. using the formula

$$P_{loss(j)} = r_j \left[\frac{\left(P_i^2 + Q_i^2\right)}{V_i^2}\right] \quad (8)$$

$$\mathrm{Q_{loss(j)}} = \mathrm{x_j} \left[\frac{\left(\mathrm{P_i^2} + \mathrm{Q_i^2}\right)}{\mathrm{V_i^2}}\right] \quad (9)$$

The total active and reactive power losses in the radial distribution system can be calculated using the following calculations (TAPL & TRPL)

TAPL

$$P_{T,Loss} = \sum_{j=1}^{Nb} r_j I_j^2 = \sum_{j=1}^{Nb} P_{loss(j)} = \sum_{j=1}^{Nb} P_{loss}(i, i+1) \quad (10)$$

TRPL

$$\mathrm{Q_{T,Loss}} = \sum_{j=1}^{Nb} x_j I_j^2 = \sum_{j=1}^{Nb} Q_{loss(j)} = \sum_{j=1}^{Nb} Q_{loss}(i, i+1) \quad (11)$$

Where, Nb represents the quantity of the branches.

B. Power Loss Calculation using D-STATCOM (D-STAT)

Following the installation of D-STATCOM in the distribution system, it is possible to calculate the active power losses through line 'j' in Fig. 1.

$$P_{D-STAT,loss(j)} = r_j \left[\frac{\left(P_{D-STAT}{}_{(i)}^2 + Q_{D-STAT}{}_{(i)}^2\right)}{V_i^2}\right] \quad (12)$$

The radial distribution system's total active power losses (TAPL) can be computed as

$$P_{D-STAT,\ TLoss} = \sum_{j=1}^{Nb} P_{D-STAT,loss(j)} = \sum_{j=1}^{Nb} P_{D-STAT,loss}\,(i, i+1) \quad (13)$$

C. Loss Sensitivity Factors (LSFs)

By taking into account the first derivative of Q loss(j) in equation (9), which is related to the reactive power load Q (i, i+1), it is possible to determine the candidate bus for D-STATCOM deployment.

$$LSF_{(j)} = \frac{\partial Q_{loss(j)}}{\partial Q_{i,i+1}} \Rightarrow \frac{\partial Q_{loss(j)}}{\partial Q_j} = x_j \frac{2Q_i}{V_i^2} \quad (14)$$

The LSFs are obtained from the load flow in the base scenario (before compensation).

D. Objective Function

The suggested work's Objective Function (F) is provided by

$$Minimize\ (F) = min\ (P_{D-STAT,TLoss}) \quad (15)$$

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The limitations on equality and inequality taken into account in this work include voltage constraints

$$V_{min} \leq |V_i| \leq V_{max} \quad \text{i.e., } 0.95 \leq V_i \leq 1.05 \tag{16}$$

Reactive Power Constraint

$$Q_{D-STAT}^{min} \leq Q_{D-STAT} \leq Q_{D-STAT}^{max}$$

i.e.,
$$1kVAr \leq Q_{D-STAT} \leq 2 \text{ MVAr} \tag{17}$$

5. Mathematical Modeling of D-Statcom

The D-STATCOM is a shunt connected voltage source converter that corrects power quality concerns like an unbalanced load, voltage sag, voltage volatility, and voltage unbalance. Figure 1 depicts the schematic diagram of a straightforward 2-bus RDS. Figure 2 displays the phasor diagram that corresponds to Figure 1. The voltage and current relationship from Fig. 1 can be shown in equation (20)

$$V_{i+1}\llcorner\delta_{i+1} = V_i\llcorner\delta_i - Z_j I_j \llcorner\theta_j \tag{18}$$

$V_i\llcorner\delta_i$ and $I_j \llcorner\theta_j$ can be derived from load flow equations.

In this study, D-STATCOM, which can only increase reactive power to the system, is utilised to control voltage under steady-state settings. The system's voltage $V_i\llcorner\delta_i$ must therefore be kept in quadrature with ID-STAT (i). D-STATCOM integration into the distribution system causes all bus voltages, particularly those of the buses close, to be in the D position.

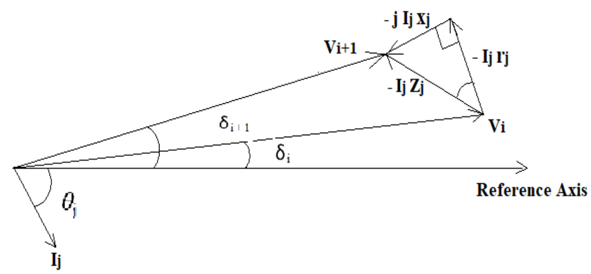

Figure 2: Phasor diagram of 2-bus Radial Distribution System shown in fig.1.

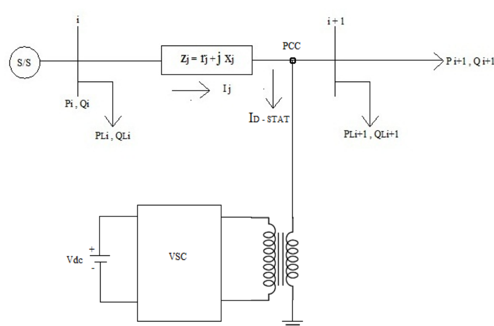

Figure 3: Schematic diagram of 2-bus RDS with D-STATCOM placement at $(i+1)^{th}$ bus.

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STATCOM's and the network's branch currents vary in a steady state. Figure 3 shows the schematic for a 2-bus basic RDS where D-STATCOM is positioned on the (i+1)th bus to regulate voltage. STATCOM's and the network's branch currents vary in a steady state. Figure 3 shows the schematic for a 2-bus basic RDS where D-STATCOM is positioned on the (i+1) th bus to regulate voltage. The phasor diagram under this condition is shown in Figure 4. When D-STATCOM is connected, the voltage at the (i+1)th bus shifts from V (i+1) to V (i+1)'. In the phasor diagram shown in figure 4, the phase angle of the ith bus voltage V i, i.e., I is considered to be zero for ease of comprehension.

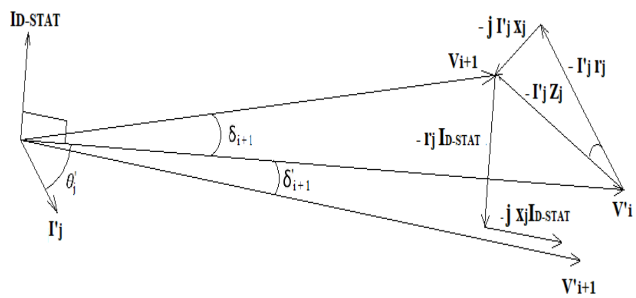

Figure 4: Phasor diagram of 2-bus RDS with D-STATCOM placement at (i+1)th Bus.

Therefore,

$$\llcorner I_{D\text{-}STAT}=\frac{\pi}{2}+\delta'_{i+1},\ \delta'_{i+1}<0 \tag{19}$$

and voltage at (i+1)th bus after D-STATCOM placement is given by

$$V'_{i+1}\llcorner\delta'_{i+1} = V'_i\llcorner\delta'_i-(r_j+jx_j)I'_j\llcorner\theta'_j$$
$$-(r_j+jx_j)I_{D-STAT}\llcorner\frac{\pi}{2}+\delta'_{i+1} \tag{20}$$

The voltage $V'_i\llcorner\delta'_i$ and current $I'_j\llcorner\theta'_j$ are obtained from the load flow calculations.

Therefore,

LHS of equation (22) can be written as

$$V'_{i+1}\llcorner\delta'_{i+1} = V'_{i+1}(cos\delta'_{i+1}+jsin\delta'_{i+1})$$
$$=V'_{i+1}cos\delta'_{i+1}+j\ V'_{i+1}sin\delta'_{i+1} \tag{21}$$

Similarly, RHS of equation (21) can be written as

$$V'_i\llcorner\delta'_i-(r_j+jx_j)I'_j\llcorner\theta'_j\ -(r_j+jx_j)I_{D-STAT}\llcorner\frac{\pi}{2}+\delta'_{i+1} \tag{22}$$

Having divided and equated the Real and Imaginary components on both sides of the equations. (23) & (24) then

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Real Part ($V'_{i+1} cos\delta'_{i+1}$) is equal to

$$V'_i cos\delta'_i - r_j I'_j cos\theta'_j + r_j I_{D-STAT} sin\delta'_{i+1} + x_j I_{D-STAT}\, cos\delta'_{i+1} \quad (23)$$

The imaginary Part ($V'_{i+1} sin\delta'_{i+1}$) is equal to

$$V'_i sin\delta'_i - r_j I'_j \sin\theta'_j - x_j I'_j cos\theta'_j - r_j I_{D-STAT} cos\delta'_{i+1} + x_j I_{D-STAT} sin\, \delta'_{i+1} \quad (24)$$

Now, by taking some assumptions given below

$$y_1 = V'_i cos\delta'_i - r_j I'_j cos\theta'_j \quad (25)$$

$$y_2 = V'_i sin\, \delta'_i - r_j I'_j sin\theta'_j - x_j I'_j cos\theta'_j \quad (26)$$

$$y_3 = -r_j \quad (27)$$

$$y_4 = -x_j \quad (28)$$

$$m = V'_{i+1} \quad (29)$$

$$g_1 = I_{D-STAT} \quad (30)$$

$$g_2 = \delta'_{i+1} \quad (31)$$

Then the Real Part becomes as

$$mCos\, g_2 = y_1 - y_3 g_1 Sin\, g_2 - y_4 g_1 Cos\, g_2 \quad (32)$$

Therefore, $$g_1 = \frac{mCos g_2 - y_1}{-y_3 Sin g_2 - y_4 Cos g_2} \quad (33)$$

And the Imaginary Part becomes as

$$mSin\, g_2 = y_2 + y_3 g_1 Cos\, g_2 - y_4 g_1 Sin\, g_2 \quad (34)$$

Therefore, $$g_1 = \frac{mSin g_2 - y_2}{-y_3 Cos g_2 - y_4 Sin g_2} \quad (35)$$

But the equations (35) & (36) both are equal.

Then

$$\frac{mCos g_2 - y_1}{-y_3 Sin g_2 - y_4 Cos g_2} = \frac{mSin g_2 - y_2}{-y_3 Cos g_2 - y_4 Sin g_2} \quad (36)$$

After solving the above equation, we get

$$my_3 - Cos g_2(y_1 y_3 + y_2 y_4) + Sin g_2(y_1 y_4 - y_2 y_3) = 0 \quad (37)$$

Again, taking some more assumptions given below

$$G_1 = y_1 y_4 - y_2 y_3 \quad (38)$$

$$G_2 = y_1 y_3 + y_2 y_4 \quad (39)$$

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$$g = Sing_2 \tag{40}$$

Squaring on both sides of equation,

Then, $g^2 = Sin^2 g_2$ and $Cos^2 g_2 = \sqrt{(1-g^2)}$ (41)

Then equation (43) becomes as

$$my_3 - G_2\sqrt{1-g^2} + G_1 g = 0 \tag{42}$$

$$my_3 + G_1 g = G_2\sqrt{1-g^2} \tag{43}$$

Squaring on both sides and after simplifying,

Then, $(G_1^2 + G_2^2)g^2 + 2G_1 my_3 g + (m^2y_3^2 - G_2^2) = 0$ (44)

This is a quadratic equation with unknown parameter $'g'$ and it is obtained by solving using equation below.

$$g = \frac{-b\pm\sqrt{b^2-4ac}}{2a} \tag{45}$$

Where,

$$a = G_1^2 + G_2^2 = (y_1y_4 - y_2y_3) + (y_1y_3 + y_2y_4) \tag{46}$$

$$b = 2G_1my_3 = 2(y_1y_4 - y_2y_3)(V'_{i+1})(y_3) \tag{47}$$

$$c = m^2y_3^2 - G_2^2 = [{V'_{i+1}}^2 * (-r_j)]^2 - (y_1y_3 + y_2y_4)^2 \tag{48}$$

There are currently two origins for "g." We look at the following boundary criteria to get the correct root value.

$$V'_{i+1} = V_{i+1} \text{ when } I_{D-STAT} = 0 \text{ and } \delta_{i+1} = \delta'_{i+1} \tag{49}$$

Then, the results shows that eqn. (45) is the correct root of $'g'$ which is given by

$$g = \frac{-b+\sqrt{b^2-4ac}}{2a} \tag{50}$$

The phase angle of the $(i+1)^{th}$ bus voltage is $g = Sing_2$

$$g_2 = Sin^{-1}(g) = Sin^{-1}\left[\frac{-b+\sqrt{b^2-4ac}}{2a}\right] \tag{51}$$

The amount of current that D-STATCOM injected is indicated as

$$|I_{D-STAT}| = g_1 = \frac{mCosg_2 - y_1}{-y_3Sing_2 - y_4Cosg_2}$$

$$= \frac{V'_{i+1}Cos(\delta'_{i+1}) - y_1}{-y_3Sin(\delta'_{i+1}) - y_4Cos(\delta'_{i+1})} \tag{52}$$

In a similar manner, D-injected STATCOM's current's phase angle is given as

$$\angle I_{D-STAT} = \frac{\pi}{2} + \delta'_{i+1} = Sin^{-1}(g) \tag{53}$$

δFinally, The D-STATCOM injects reactive power that is provided by

$$jQ_{D-STAT} = (V'_{i+1} \llcorner \delta'_{i+1}) \cdot \left(I_{D-STAT} \llcorner \frac{\pi}{2} + \delta'_{i+1}\right)^{*} \quad (54)$$

Where, '*' represents the complex conjugate.

6. Gravitational Search Algorithm

The Gravitational Search Algorithm (GSA) was first developed by Esmat Rashedi and associates in 2009. Based on Newton's equations of motion and gravity, it is a brand-new meta-heuristic optimization method [26]. The steps listed below can be used to describe the GSA [27, 28].

The location of N masses (agents) is indicated as

$$U_j = \left(U_j^1, \dots, U_j^c, \dots, U_j^n\right) \text{ for i=1,2,3,......,N}$$

Where, U_j^d represents the position of j[th] mass in c[th] dimension.

The Gravitational Constant $G(t)$ at time (t) is given as

$$G(t) = G_0 e^{\left(\frac{-\delta t}{T}\right)}$$

G_0 and δ are initialised at the beginning and will be lowered to manage the search accuracy where T is the total number of iterations. Calculations are made of the internal masses (agents) and gravitational

$$mass_j(t) = \frac{Fit_j(t) - Worst(t)}{Best(t) - Worst(t)} \quad (55)$$

$$Mass_j(t) = \frac{mass_j(t)}{\sum_{k=1}^{N} mass_k(t)} \quad (56)$$

Where 〖Fit)] _j (t) is the fitness value of the jth mass at time (t), "Best" (t) and "Worst" (t) are the minimum and maximum fitness, respectively, and 〖Mass〗 _j(t)is the mass of the jth agent at time (t) h_{Best} is updated by

$$h_{Best} = H_{Best\_Final} + \left[\frac{T-t}{T} X(100 - H_{Best\_Final})\right]$$

H Best is the set of the first H masses (agents) with the best fitness value, while H (Best Final) is the set of the final H masses (agents) with the largest mass and the most recent fitness value.

F is the overall force.

$$F_{jk}^c = G \times \frac{M_j M_k}{R_{jk} + \tau} \times (U_k^c - U_j^c)$$

Where $R_{jk} = \left\|U_j, U_k\right\|_2 = \sqrt{\sum_{c=1}^{D} (U_k^c - U_j^c)^2}$

Where τ is small coefficient

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On mass (agent) j in dimension c, the sum of the forces generated by the cth components of the forces from other agents will act.

$$F_j^c(t) = \sum_{k \in H_{Best}, k \neq j}^{N} rand_k F_{jk}^c(t)$$

A random number between 0 and 1 is called rand k.

Given by are the accelera$tion\ factor, velocity\ v, and\ location\ U.$

$$\alpha_j^c = \frac{F_j^c}{Mass_j}$$

$$v_j^c(t+1) = rand_j \times\ v_j^c(t) + a_j^c(t)$$

$$U_j^c(t+1) = U_j^c(t) + v_j^c(t+1)$$

$rand_j$ is random variable in interval (0,1)

7. Simulation Results

The simulation was run in MATLAB (R2017a) version 9.2.0 on an Intel (R) core (TM), i5 processor-powered personal computer with 4GB of RAM. Throughout the simulation, some assumptions were made, including the initial gravitational constant "G0" being assumed to be 100, the population size, and the maximum number of iterations being assumed to be 50 and 100, respectively.

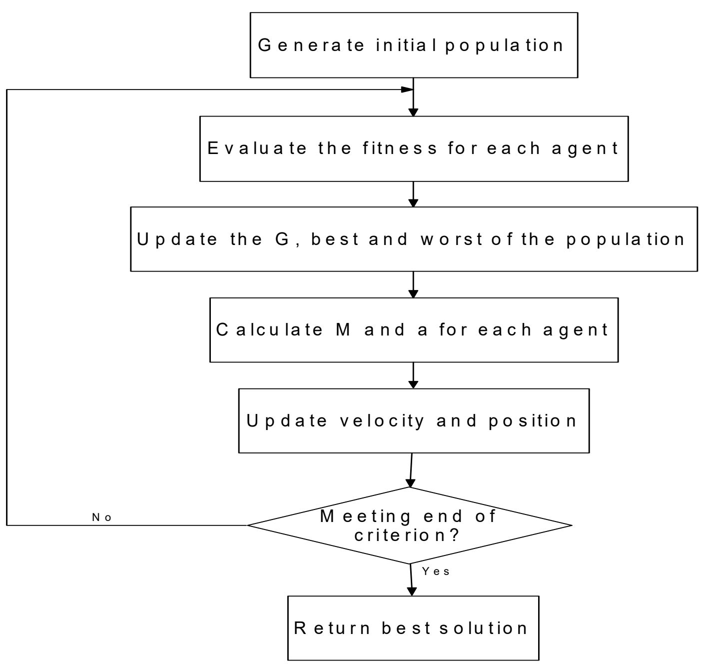

Figure 5: Basic Gravitational Search Algorithm Principles (GSA)

33-BUS RADIAL DISTRIBUTION TEST SYSTEM

Figure 6 shows the single line diagram of an IEEE 33-bus test system with 33 buses and 32 branches. The test system's buses and branches data were collected from [24]. 100 MVA and 12.66 kV are regarded as the basis voltage and base VA, respectively. The network's total active and reactive load powers are estimated to be 3.715 MW and 2.300 MVAr, respectively. The Total Active Power Losses (TAPL) and Total Reactive Power Losses (TRPL) calculated after running backward forward load flow in MATLAB as a base case are 210.98 kW and 143.13 kVAr, respectively. The bus with the lowest voltage magnitude is bus 18, which has a voltage of 0.9133 p.u. Voltage Sensitivity Factors (VSF) and Loss Sensitivity Factors (LSF) are employed to establish the best position.

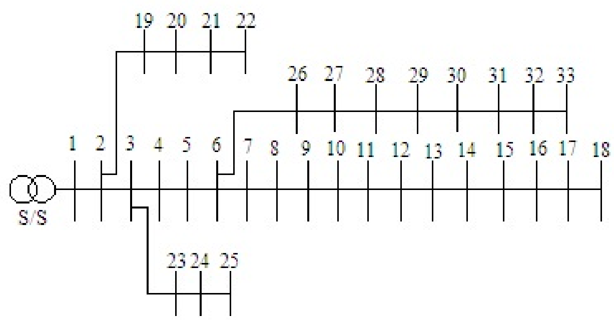

Figure 6: Standard IEEE 33-Bus Test System

for positioning D-STATCOM. The buses with the highest LSF and lowest VSF (VSF1.01) are selected as the candidate buses for allocation of D-STATCOM in RDS. The LSFs are determined using equation (19) from the base case load flow. If the buses have VSF values higher than 1.01, no compensation is necessary. The 29th bus is chosen as a candidate bus for D-STATCOM allocation in this paper.

Table 1: Voltage magnitudes at all buses without and with D-STATCOM placement

Bus No.	Voltage Magnitude (p.u.)		Bus No.	Voltage Magnitude (p.u.)	
	Without D-STATCOM	With D-STATCOM		Without D-STATCOM	With D-STATCOM
1	1	1	**18**	**0.9133**	**0.9259**
2	0.997	0.9975	19	0.9965	0.997
3	0.9829	0.9856	20	0.993	0.9934
4	0.9755	0.9797	21	0.9923	0.9927
5	0.9681	0.9741	22	0.9916	0.992
6	0.9497	0.9618	23	0.9794	0.982
7	0.9462	0.9583	24	0.9727	0.9754
8	0.9413	0.9535	25	0.9694	0.972
9	0.9351	0.9474	26	0.9477	0.9607
10	0.9294	0.9418	27	0.9452	0.9594
11	0.9286	0.9409	28	0.9337	0.956
12	0.9271	0.9395	29	0.9255	0.9538

Contd…

Bus No.	Voltage Magnitude (p.u.)		Bus No.	Voltage Magnitude (p.u.)	
	Without D-STATCOM	With D-STATCOM		Without D-STATCOM	With D-STATCOM
13	0.921	0.9334	30	0.9219	0.9525
14	0.9187	0.9312	31	0.9178	0.9484
15	0.9173	0.9298	32	0.9169	0.9476
16	0.9159	0.9285	33	0.9166	0.9473
17	0.9139	0.9265	-	-	-

Cost of D-STATCOM [20]

The following equation can be used to determine the annual cost of D-STATCOM (57)

$$Cost_{D-STAT_{year}} = C_{D-STAT} * \left[\frac{(1+B^{\wedge})^{n_{D-STAT}} * B^{\wedge}}{(1+B^{\wedge})^{n_{D-STAT}} - 1}\right] \quad (57)$$

Where, $Cost_{D-STAT_{year}}$ is the annual cost of D-STATCOM

C_{D-STAT} is the D-STATCOM cost and it is 50 \$/kVAr

B^ is the asset rate of return and it is taken as 0.1

n_{D-STAT} is the durability of D-STATCOM which is taken as 30.

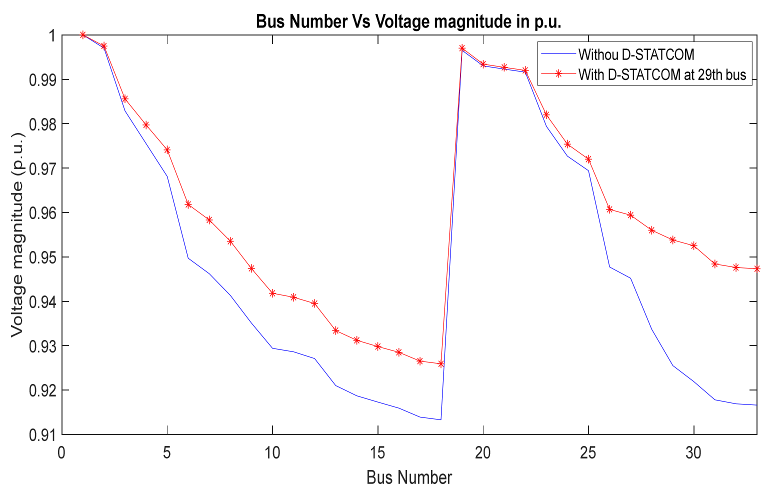

Figure 7: Voltage profile of the 33-bus RDS under the cases of without and with D-STATCOM placement at 29th bus

Total Cost Saving (TCS) [20]

The TCS is calculated by using the equation (70)

$$TCS = K_p(T \times P_{T,Loss}) - K_p(T \times P_{T,Loss}^{with\ D-STAT}) - (K_c \times Cost_{D-STAT_{year}}) \quad (58)$$

Table 2: Performance analysis of the proposed algorithm after installation of D-STATCOM in 33-bus RDS

		Base Case	IA [16]	BA [2]	HSA [20]	DEA [17]	Proposed (GSA)
Optimal Size(kVAr)		-	962.49	1250	1150	1252.7	1259.9
Location		-	12	30	30	30	29
TAPL (kW)		210.98	171.79	143.38	143.97	143.50	143.31
Reduction in APL	**kW**	-	39.19	67.6	67.01	67.48	67.67
	%	-	18.57	32.04	31.76	31.98	32.07
TRPL (kVAr)		143.13	115.26	96.17	96.47	-	96.35
Reduction in TRPL	**kW**	-	27.87	46.96	46.66	-	46.78
	%	-	19.47	32.80	32.59	-	32.68
Minimum Voltage (Bus Number)		0.9133	0.9258	0.9260	0.9236	0.9256	0.9259
Total Cost Saving ($)		-	11,130	24,545	24,264	27,211	31,194

Where K p, K (c), and T stand for the cost of energy losses, the time duration proportion, and the number of hours in a year, respectively, and their corresponding values are set to 0.06 $/kWh, 1 year, and 8760 hours, respectively.

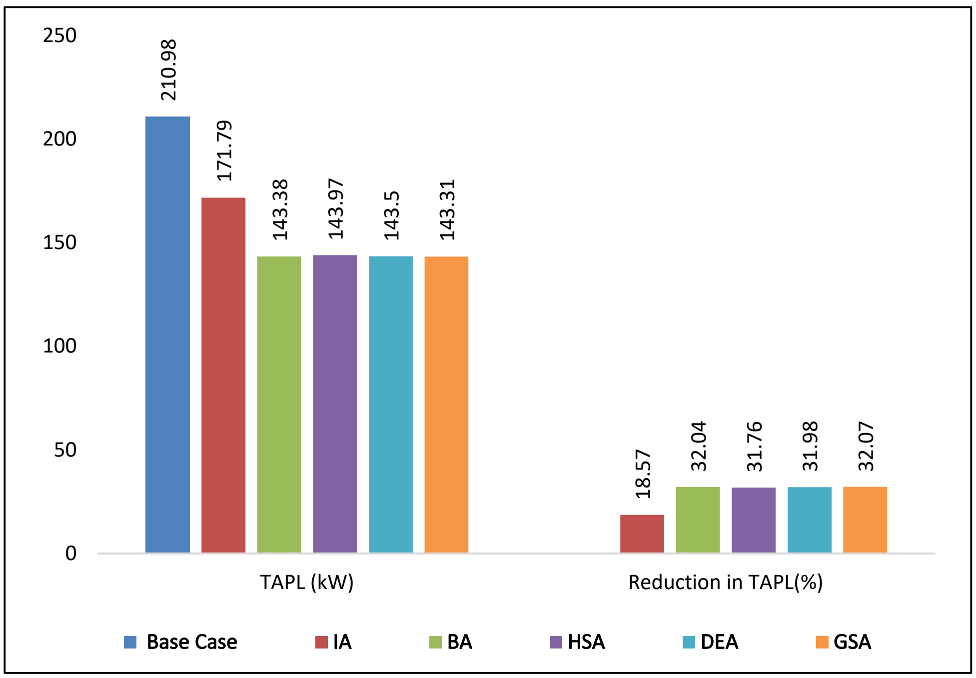

Figure 8: Comparison of GSA with other heuristic algorithms in view of Total Active Power Losses (TAPL) and % Reduction in TAPL

Voltage magnitudes at all buses without and with D-STATCOM placement bus are given in Table I. The voltage profile of the network without and with D-STATCOM allocation at 29^{th} bus is plotted and shown in Figure 7. Comparison of GSA with other heuristic algorithms in view of Total Active Power Losses (TAPL) and % Reduction in TAPL shown in Figure 8 whereas Figure 9 shows the Performance comparison of TCS in GSA with other heuristic algorithms.

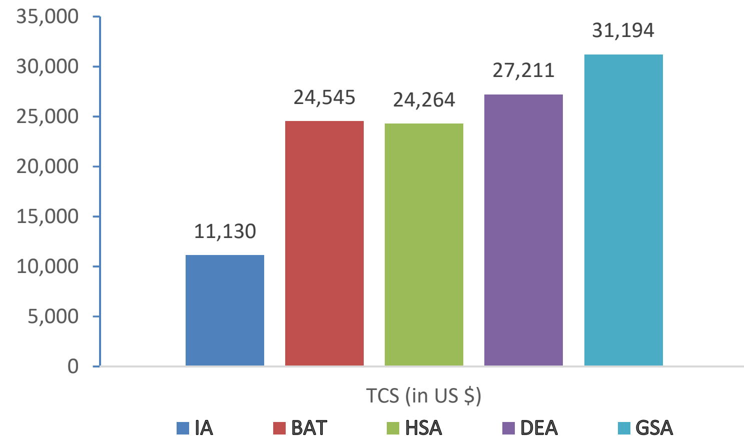

Figure 9: Performance comparison of TCS in GSA with other heuristic algorithms.

Table II contrasts existing and proposed algorithms for active and reactive power losses, ideal size and position, decrease in active and reactive power losses, and total annual cost savings (TCS). The D-STATCOM is located on the 12th bus, and Immune Algorithm [16] experiences more losses, per Table II. The losses in the Bat Algorithm are negligible even if the D-STATCOM is placed on the 30th bus in comparison to other existing algorithms [2]. The total active and reactive power losses in the suggested algorithm are 143.31 kW and 96.35 kVAr, respectively. Active and reactive power losses were reduced by 32.07% and 32.68% respectively, while the system's minimum voltage was raised to 0.9259 p.u. Particularly, the system's Total Yearly Cost Saving (TCS) of US$31,194 is the highest of any existing systems' total annual cost savings. This shows that the Gravitational Search Algorithm (GSA) under consideration outperformed all other algorithms. Particularly, the system's Total Yearly Cost Saving (TCS) of US$31,194 is the highest of any existing systems' total annual cost savings. This shows that the Gravitational Search Algorithm (GSA) under consideration outperformed all other algorithms.

8. Conclusion

In order to determine the ideal location and size for DSTATCOM in the RDS, the Gravitational Search Tool (GSA), a Newtonian Gravity-based optimization algorithm, has been demonstrated in this study. To reduce system power losses and increase bus voltage, the right location for DSTATCOM allocation is even more crucial. The best position of DSTATCOM is determined in this work using the LSF and VSF concept. LSF and VSF provide a better placement in terms of least power losses, most extreme TCS, and large bus extents in the RDS as compared to other dependability files. Results from the suggested technique are tested on a 33-bus RDS, and they are verified by additional heuristic algorithms. The DSTATCOM can be used to lower the overall power losses of the RDS, according to the study's findings. As a result, it is feasible to claim that the proposed algorithm considerably increases the operational suitability of the RDS and that it is a useful strategy to apply across all RDS in order to gain better execution.

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