Efficient Capacitor Location in Radial Distribution Networks via Reptile Search Approach

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Abstract: - A vigorous technique known as the Reptile Search Approach (RSA) is invested in this article, for optimum post and amplitude of parallel capacitance devices for two Radial Distribution Networks (RDN). Primarily, the ultimate appointee nodes for fixing capacitance devices are introduced via Loss Sensitivity Factors (LSF). Subsequently, the developed RSA is exploited to derive the capacity of capacitors and their sites from the gathered nodes. The cost function is launched to diminish the gross losses, and thereafter, grow the gross savings yearly. The found results through the suggested approach are contrasted with others to emphasize their merits. Also, the outcomes are presented to confirm the influence of the introduced approach to minify the losses, and gross charge and promote the net saving and voltage levels.

Key-Words: - Reptile Search Approach, Cost Function, Loss Sensitivity Factors, Radial Distribution Networks, Optimal Capacitor Positions, Power System.

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1 Introduction

Distribution and transmission grid losses are observed as significant consuming in any electrical framework. As a result of the expansion in the demand, and ecological constraints, the transmission, and RDN are being functioned under overburdened scenarios, and resistive losses in the RDN have been the major issue. To achieve economical merits, the basic situations to fetch reasonable power quality and improved leverage have created a favorable medium for the issue of loss diminution techniques and utilizing modern functional procedures. Power loss attenuation is the single substitute to promote the qualification of the RDN. Thus, it has appeared that in the final several years, distinct authors have intensified RDN loss attenuation and voltage consistency. There are distinct advantageous approaches in the published papers for the attenuation of losses in RDN. Nevertheless, the extremely utilized techniques as (a) capacitor placement, (b) grid reconfiguration (c) DG placement, (d) DSTATCOM placement and its uneven editions to recognize top potential concerns are (e) synchronic reconfiguration and capacitor placement, (f) synchronic reconfiguration and DG placement, (g) synchronic DSTATCOM and DG siting, and (h) synchronic restructure, capacitor, and DG placement are displayed in [1]. Traditionally, loss attenuation has concentrated majorly on optimizing grid restructuring or capacitor placement for imaginary power guidelines. For the reason that fixing capacitors is the most famous and the simplest resolution, they are securing the significant elements of the RDN, [1].

Pending final years, distinct approaches are addressed to get the appropriate positions and optimum capacities of parallel capacitors. Simulated Annealing [2], Tabu Search [3], Genetic Approach [4], Mixed Integer Nonlinear Programming Approach [5], Direct Search Approach (DSA) [6], Teaching Learning Based Optimization [7], Plant Growth Simulation Approach (PGSA) [8], Heuristic Approach [9], Cuckoo Search Approach [10], Particle Swarm Optimization (PSO) [11], Fuzzy Genetic Approach (FGA) [12], Differential Evolution (DE) [13], Flower Pollination Approach (FPA) [14], [15], Improved Harmony Search [16], Mine Blast Approach [17], Combined Fuzzy-HPSO [18] and Bat Approach [19] are addressed to handle the capacitor sitting assignment. Yet, these approaches can take place to ingest the lowest charge. To vanquish these damages, the RSA is appointed here to deem the operation of the most effective capacitor location.

The current work inspects a novel method identified as the Reptile Search Approach (RSA). The prime stimulus for this event comes from the coordinated action displayed by crocodiles at the time of predation, [20], [21], [22], [23] and [24]. A significant distinction between RSA and alternative approaches lies in its unique approach to updating the standings of search entities, which incorporates four innovative methods.

For instance, the attitude of the encircling target is modeled by incorporating two separate movement strategies: high-walking and belly-walking. Moreover, crocodiles communicate and collaborate to efficiently implement tracking tactics. The RSA strives to create powerful exploration methods that produce premium results and offer novel solutions for complex practical challenges, [24] and [25]. RSA is developed to diminish the gross real resistive losses, and the net charge and to support the profile of voltages for RDN. The facilities of the parallel capacitors process are initially achieved by assessing the nodes following LSF. Thereafter RSA is delivered to lay the most effective placement and scaling of shunt capacitors from certain points. The verification of the developed approach in advancing the level of voltage and diminishing real losses is given for two RDNs. The outcomes of the RSA are contrasted with distinct approaches to affirm its supremacy, [25].

2 Loss Sensitivity Factors

In this section, LSFs can be appointed to allocate the elected points to configure capacitors, [26]. Figure 1, displays a transmission bar 'l' joined among 'i' and 'k' points.

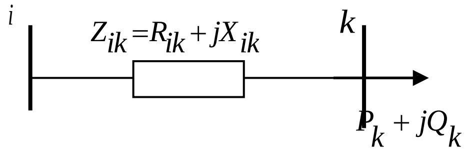

Fig. 1: Identical network for radial distribution grid

The actual real loss is realized by $I_l^2 R_{ik}$ that can be computed by:

$$P_{ik-loss} = \frac{(P_k^2 + Q_k^2)R_{ik}}{(V_k)^2} \tag{1}$$

The LSFs may be formed by the next arrangement:

$$\frac{\partial P_{ik-loss}}{\partial Q_k} = \frac{2Q_k * R_{ik}}{(V_k)^2} \tag{2}$$

The normal voltages are assigned by finding the ratio between the primary voltages and .95. If the normal potentials are weaker than 1.01 they may be presented as elected points for capacitor construction. It is intelligible to register that the amount of LSFs appraise the series in which points can be organized to deploy shunt capacitor banks, [27].

3 Cost Function

The cost equation for the most efficient capacitor site process is to lessen the gross charge, defined as the next equalization:

$$\text{Charge function} = K_P . P_{Loss} . T + D \times \left(K_I \times CB + K_C \times \sum_{i}^{CB} Q_{Ci} \right) + K_o \times CB \tag{3}$$

where the elements are seized from [15].

K_P : The price for each kilo Watt Hours and equalizes to 0.06 $/ kilo Watt Hours ,

T : 8760 hours for year,

P_{Loss} : The gross losses post compensation,

D : The depreciation agent equalizes to 0.2,

CB: The size of installing capacitors,

K_C : The charge for each kilo Var and equates to 25 $/kVar,

K_I : The charge per composition equates to 1600$,

Q_{Ci} : The amount of composed not active power in kilo Var,

K_o: The working charge equates to 300 $ per year per position.

The previous relationship is narrowed since achieving the next boundaries.

3.1 Equality Boundary

- ***Power Flow Boundary***

Classic tools cannot be exploited in the RDN because of ill status. The forward sweep technique has been discussed in [27] to handle the power transfer operation of RDN. The balance threshold is formed by the next equalization:

$$P_{Slack} = \sum_{b=1}^{L} P_{Lineloss}(b) + \sum_{i=1}^{N} Pd(i) \tag{4}$$

$$Q_{Slack} + \sum_{q=1}^{CB} Q_C(q) = \sum_{b=1}^{L} Q_{Lineloss}(b) + \sum_{i=1}^{N} Qd(i) \tag{5}$$

where

P_{Slack}	:	The real power of the slack point,
Q_{Slack}	:	The imaginary power of the slack point,
L	:	The scale of the transfer system in the grid,
$Pd(i)$	:	The need of real demand at point i,
$Qd(i)$	:	The need of imaginary demand at point i,
N	:	The scale of full points.

3.2 Inequality Boundaries

- ***Potential Threshold***

The amount of the potential at any point ought to be narrowed by the next threshold:

$$0.90 \le V \le 1.05 \tag{6}$$

- ***Power Factor Restriction***

Power Factor (PF) might override the lower size and lower than the peak size as discussed by the next threshold.

$$PF_{\min} \le PF \le PF_{\max} \tag{7}$$

- ***Capacitor Rating Boundary***

The supplied kVAr from the integrated capacitor is revealed as an interrupted amount by increments of 50 kVAr and defined within the scope below:

$$Q_{C\min} \le Q_C \le Q_{C\max} \tag{8}$$

4 Reptile Search Approach

The RSA, such as other approaches, consists of two sides: exploration and exploitation. Exploration denotes comprehensive investigation and exploitation denotes localized inspection. The public attitude, tracking, and enclosing tactics of crocodiles in the wilderness are the stimulus for the developed approach. In order to derive the optimization process and the inspection reptile approach, the methods of encircling and tracking victims used by crocodiles are modeled, [20]. The developed approach can clarify both soft and complex optimization procedures.

4.1 Demeanor and Biology of Crocodile

Crocodiles are semi-aquatic reptiles that float effortlessly within water. Known for their powerful teeth and jaws, they are regarded as formidable trackers. Additionally, their physical features reflect their predatory nature. Crocodiles can lift their legs to the sides in the process of swimming, allowing them to move swiftly through the water. Moreover, they can make sudden movements while swimming. Listed here are the key details of crocodiles, [20], [21].

Eyesight: Crocodiles' exceptional night vision enables them to hunt in the dark, while other animals struggle with poor visibility during the night.

Diet and hunting: Crocodiles attack a diverse range of animals, including reptiles, mammals, amphibians, mollusks, fish, crustaceans, and birds. Moreover, they prey on smaller crocodiles. Young crocodiles typically target small fish and invertebrates. Crocodiles can endure long periods without food and hunt with patience. Even massive and powerful organisms, including deer, sharks, and impaired elephants, may become prey to crocodiles, [21], [22].

Motion: When a crocodile holds its legs straight beneath its body, it can move quickly over short distances, both on land and in water.

Recognition: Crocodiles can recognize their prey's behavioral patterns and use this knowledge to enhance their hunting strategies.

Hunting: Crocodiles have developed advanced hunting techniques, often engaging in cooperative strategies. One such complex approach is coordinated hunting, where they work together in organized efforts to capture prey. Similar to lions acting as ambushers during a hunt, crocodiles sometimes exhibit lion-like behavior, running swiftly to secure their prey, [22], [23].

***Cooperation and coordination*:** Crocodiles demonstrate remarkable intelligence and complexity by performing various tasks and coordinating effectively within groups during hunts. They typically track in near-shore waters and at night. For instance, when tracking fish, a group of crocodiles will maneuver to guide the fish into a ball-like formation. They then take turns feeding, eventually targeting the center of the clustered fish. In group hunting, large crocodiles often take on the task of guiding fish from the deeper parts of the lagoon toward shallower areas, where smaller crocodiles prevent their escape. Typically, crocodiles work together to frighten the prey, and in response to the prey's movements, one crocodile breaks away from the group to launch an attack. This hunting strategy is commonly observed among crocodiles. After feeding, they rest for a while before resuming the hunt with a different group. [23], [24].

To introduce a novel optimization algorithm capable of addressing optimization problems across various disciplines and overcoming existing limitations, the attitude of crocodiles while encircling and tracking has been imitated. The optimization process in RSA is explained in the following sections, and the analytical framework of the approach is ultimately presented, [24].

4.2 Initialization Stage

The optimization procedure commences with a set of candidate resolutions produced randomly, as represented by the following equation. The best solution obtained at each step is considered a near-optimal result, [25].

$$X = \begin{bmatrix} x_{1,1} & \cdots & x_{1,j} & x_{1,n-1} & x_{1,n} \\ x_{2,1} & \cdots & x_{2,j} & \cdots & x_{2,n} \\ \cdots & \cdots & x_{i,j} & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{N-1,1} & \cdots & x_{N-1,j} & \cdots & x_{N-1,n} \\ x_{N,1} & \cdots & x_{N,j} & x_{N,n-1} & x_{N,n} \end{bmatrix} \tag{9}$$

A collection of candidate resolutions is represented by X, where the position of the j^{th} place of the i^{th} solution is indicated by $x_{i,j}$. The total number of potential responses and the suggested challenge's dimension volume are indicated by N and n.

$$x_{i,j} = rand \times (UB - LB) + LB, \qquad j = 1,2,..n \tag{10}$$

where $rand$ is a arbitrary quantity, UB and LB establish the upper and lower bounds of the suggested issue.

4.3 Encirclement Phase

In the encirclement stage, crocodiles surround their prey by both lifting their legs and shifting in a belly-crawling manner. This activity slows down their ability to quickly close in on the prey. Consequently, a global exploration search takes place, allowing for a broader search of the space.

RSA may shift among exploration (encircling) and exploitation (tracking) seeking phases, this shift among diverse behaviors is completed based on four situations; the entire number of resolutions is split into four segments. The exploration tools of RSA assess the seeking areas and process to identify an optimal resolution based on two primary seeking methods: the high walking technique and the abdomen walking technique.

The technique of high walking motion is defined by $t \leq 0.25T$, and $t \leq 2\frac{T}{4}$ and $t > \frac{T}{4}$ characterized the technique of abdomen walking movement.

The two styles mentioned above are used for exploration seeking. Similarly, an arbitrary multiplier factor is applied to the component in order to generate diverse results and explore different fields. The most basic rule has been employed to imitate the crocodiles' encircling attitude. In equation (11), the location-updating equations for the exploration stage are presented.

$$x_{(i,j)}(t+1) = \begin{cases} rand \times \eta_{(i,j)}(t) \times Best_j(t) \times \beta - R_{(i,j)}(t). & t \leq 0.25T \\ rand \times Best_j(t) \times x_{(r_1,j)} \times ES(t), t \leq \frac{T}{2} \; and \; t > 0.25T \end{cases} \tag{11}$$

where $Best_j(t)$ denoting the j^{th} location of the best outcome attained so far, $rand$ represents an arbitrary number in the range [0,1], t denotes the current iteration number. T represents the utmost number of repetitions. The predator entity for the j^{th} position in the i^{th} resolution is determined by $\eta_{(i,j)}$, which is determined using the following formula. β specifies a sensitive parameter, governs the exploration precision during the surrounding stage across the course of iterations (β = 0.1). $R_{(i,j)}$ is a simplified function utilized to narrow the seeking space, and ascertained as follows. r_1 denotes an arbitrary number within the span of 1 and N, $x_{(r_1,j)}$ represents an arbitrary position of the i^{th} solution, $ES(t)$ represents an evolutionary framework, which is a Ratio of probabilities randomly picked from [-2, 2] throughout each round and calculated as follows:

$$\eta_{(i,j)} = Best_j(t) \times P_{(i,j)}, \tag{12}$$

$$R_{(i,j)} = \frac{Best_j(t) - x_{(r2,j)}}{Best_j(t) + \varepsilon}, \tag{13}$$

$$ES(t) = 2 \times r_3 \times \left(1 - \frac{1}{T}\right) \tag{14}$$

where, ε is a small amount and r_2 represents an arbitrary value within the range 1 and$N$, r_3 defines an arbitrary integer value within the range -1 and 1, $P_{(i,j)}$ indicates the percentage of diversity at the interval corresponding to the j^{th} status of the best achieved outcome. The j^{th} status of the ongoing outcome, is ascertained as outlined below:

$$P_{(i,j)} = \alpha + \frac{x_{(i,j)} - M(x_i)}{Best_j(t) \times (UB_{(j)} - LB_{(j)} + \epsilon}, \tag{15}$$

where the average status of the i^{th} resolution is symbolized by $M(x_i)$, the superior and inferior boundaries of the j^{th} site are expressed by $UB_{(j)}$ and $LB_{(j)}$. α represents a responsive factor that controls the precision of exploration during the cooperation of tracking over the repetition interval (α =0.1) in the present paper.

$$M(x) 1/n \sum_{j=1}^{n} x_{(i,j)} \tag{16}$$

4.4 Hunting Phase

Coordination and cooperation are two strategies that crocodiles utilize in tracking. These strategies involve diverse intensification techniques that optimize the exploitation search. They enable crocodiles to get closer to their goal. As a consequence, the exploitation seeking leads to a near-optimal resolution, potentially through multiple attempts. Moreover, the exploitation stage is used to execute an intensification seeking near the optimal resolution, highlighting the relationship among them, as noted in [20], [21].

Two hunting coordination methods and collaboration techniques have been modeled or tested through simulation in RSA and the subsequent formula outlines these behaviors. If $t \leq 3\frac{T}{4}$ and $> 2\frac{T}{4}$, the tracking coordination is carried out, whereas, under the opposite condition, hunting collaboration is performed., when $t \leq T$ and $t > 3\frac{T}{4}$. In this phase, randomized parameters are presumed to exploit the Potential local regions. The following model for location tracking is suggested for the exploitation phase, [20]:

$$x_{(i,j)}(t+1) = \begin{cases} Best_j(t) \times P_{(i,j)}(t) \times rand, \ t < \frac{3T}{4} \ and \ t > 2T/4 \\ Best_j(t) - \eta_{(i,j)} \times \epsilon - R_{(i,j)}(t) \times rand, t \leq T \ and \ t > 3T/4 \end{cases} \tag{17}$$

where $Best_j(t)$ conveys the j^{th} position in the supreme achieved resolution to this point, $\eta_{(i,j)}$ expresses the factor of tracking for the j^{th} position in the i^{th} resolution, $P_{(i,j)}$ symbolizes the change rate between the j^{th} site of the premier achieved resolution and the j^{th} site of the ongoing resolution, $\eta_{(i,j)}$ signifies for the factor of tracking for the j^{th} position in the i^{th} resolution, ϵ reveals a low value, $R_{(i,j)}$ is employed to diminish the search space.

Furthermore, during the exploitation phase, efforts are made to ensure that the search agents avoid being stuck in suboptimal solutions. These tactics support the discovery process by identifying the optimal resolution while preserving variety in the selected results. A comprehensive and visually illustrated depiction of the RSA approach is provided in Figure 2 (Appendix).

5 Outcomes and Discussion

The developed RSA was exercised to 15 and 33 radial distribution grids, as described below. The approach was implemented using MATLAB, [28]. Simulations were conducted in the MATLAB environment on a Lenovo laptop equipped with an Intel Core i7 CPU (2.90 GHz), 4 GB of RAM, and a 64-bit working frame.

5.1 15 Point System

The tested status is a 15-point framework as given in Figure 3 (Appendix). The framework information is illustrated in [27]. The net power for this framework is 1752 kVA with P.F=0.70. The deficits before adding capacitors are 61.9547 kW. The elected points are acquired in Figure 4 (Appendix) as stated by LSF. The order of points are 6, 3, 11, 4, 12,… The advancements in system potentials owing to the integrated capacitors are displayed in Figure 5 (Appendix). According to these findings, RSA is developed with LSF to obtain a better outcome with regard to losses and net cost. The sublimity of the developed RSA is revealed when measured against other approaches in [11], [12], [26] and [29]. The size of the combined size of imaginary power is 1050 kVAr. The minimal potential is reinforced from 0.9424 to 0.9687 p.u. The losses after capacitor installation are reduced to 30.4321 kW as mentioned in Table 1 (Appendix). The rate of alleviation in losses is elevated to 50.88%. Also, the rate of gross cost owing to the suggested charge function is 23105.11$ which is the modest cost. In addition, the gross saving with the developed RSA is enhanced to 29.04 % which is the supreme one when measured against approaches.

5.2 33 Point System

The second case under testing via the recommended LSF and RSA is a 33-point framework. Figure 6 (Appendix) supplies the framework outline which is made up of a key feeder and three laterals. The framework information is shown in [27]. LSF decides the order of candidate points as provided in Figure 7 (Appendix). The significance of the LSF to set the finest site of shunt capacitors and the proposed RSA to detect the size of capacitors is checked compared with those indicated in [8], [15] and [30]. The uncompensated losses are 202.66 kW and are dropped to 104.6849 kW due to compensation devices as displayed in Table 2 (Appendix). The relative drop in losses is elevated to 48.34%. Moreover, the slightest potential has been boosted from 0.9131 p.u to 0.9383 p.u. The advancements in framework potentials and VS1 are specified in Appendix in Figure 8 and Figure 9 respectively due to integrated capacitors. The quantity of the integrated size of non-active power is 1600 kVAr. The gross price due to the suggested cost function is 62822.38$/year which is the lowest one. In addition, the ratio of net savings with the proposed RSA is equivalent to 41.04 % which is the greater one.

6 Conclusion

In this article, RSA has been advantageously implemented to resolve the tasks of ideal sites and volume of parallel capacitors in real RDN that have been settled as a charge objective optimization mission with processing the power deficits, charge of composition, running, and injected imaginary power. The distinction of the developed technique is explained by employing two IEEE test grids. Moreover, the outcomes have been contrasted with those found adopting fresh optimization approaches. Additionally, it prepares a promising and superior attitude relative to other strategies about potential levels, real power loss, gross charge, and gross saving. Application of the grid restructure and installation of renewable generating units with the extreme modernistic optimization approach to reinforce the level of voltage and to lessen the real losses are the outlook domain of this study.

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Conflict of Interest

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APPENDIX

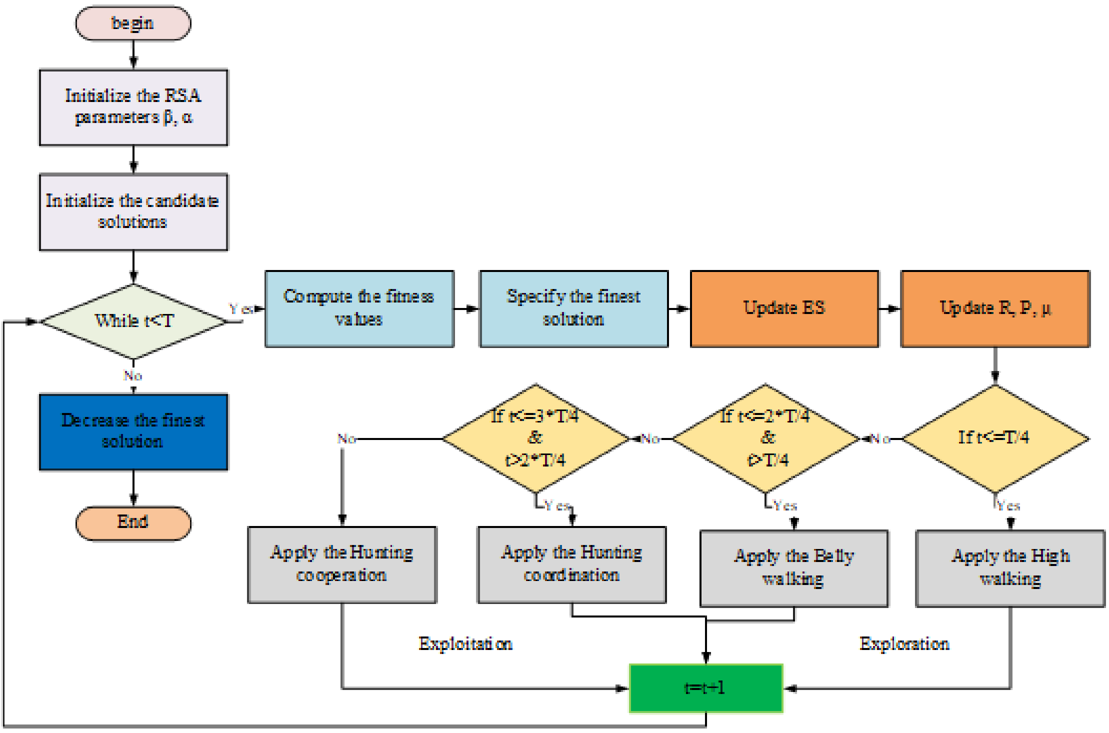

Fig. 2: Suggested Reptile Search Algorithm's flowchart

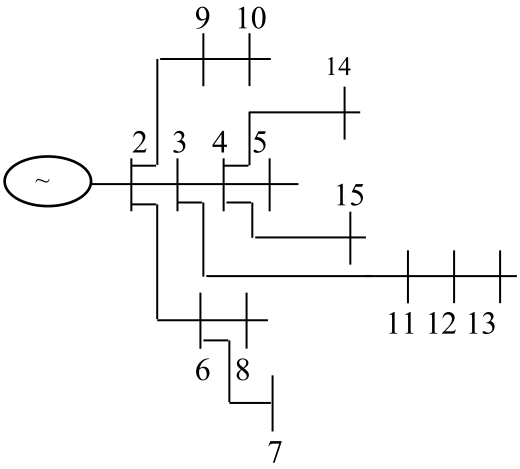

Fig. 3: The graph of the 15 point system

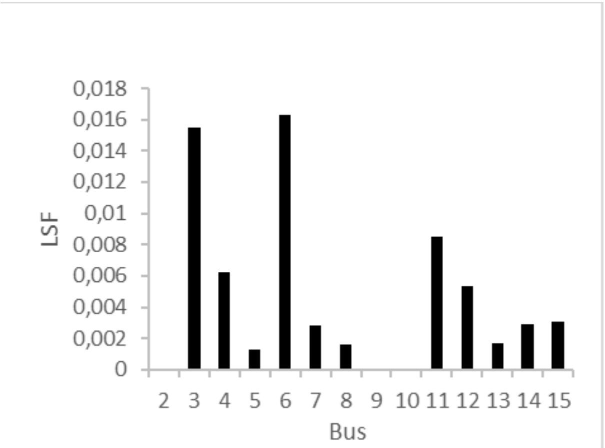

Fig. 4: LSF of the 15 bus system

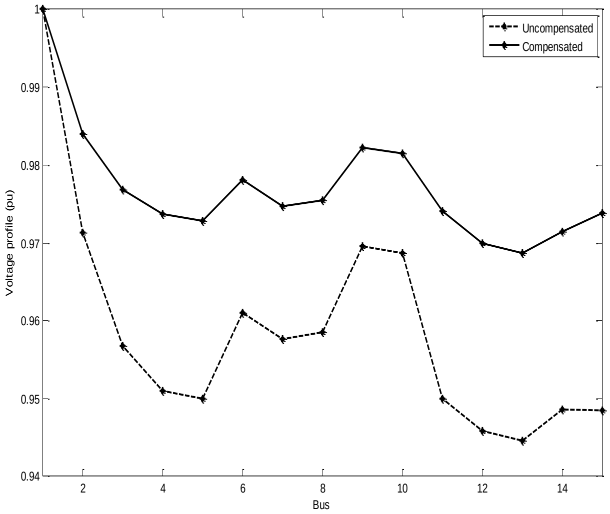

Fig. 5: Effect of adding capacitors for 15 bus system

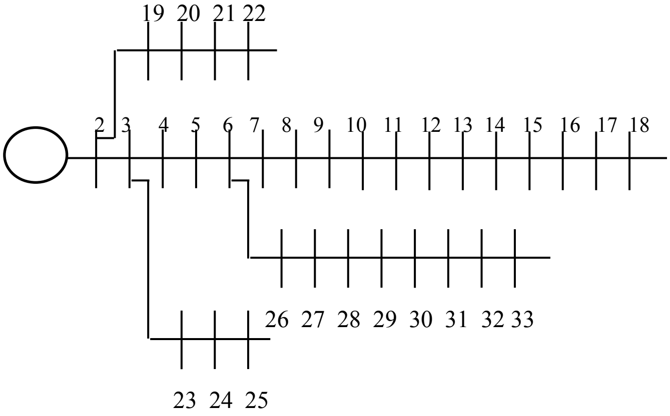

Fig. 6: The graph of the 33 point system

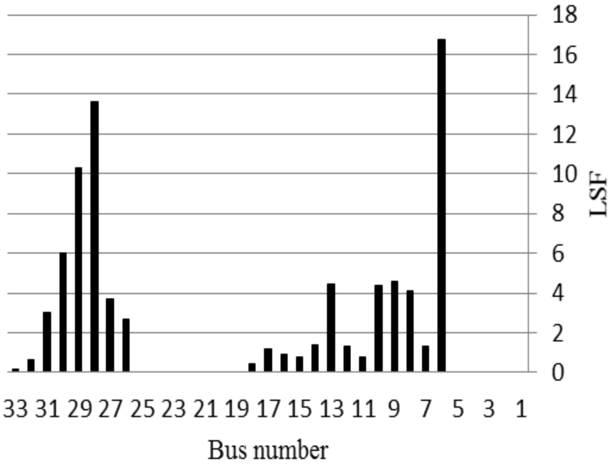

Fig. 7: LSF for 33 point system.

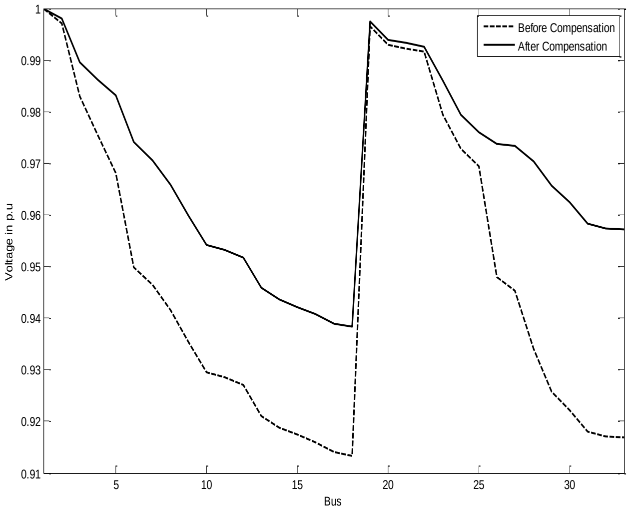

Fig. 8: Effect of capacitors on voltage profiles

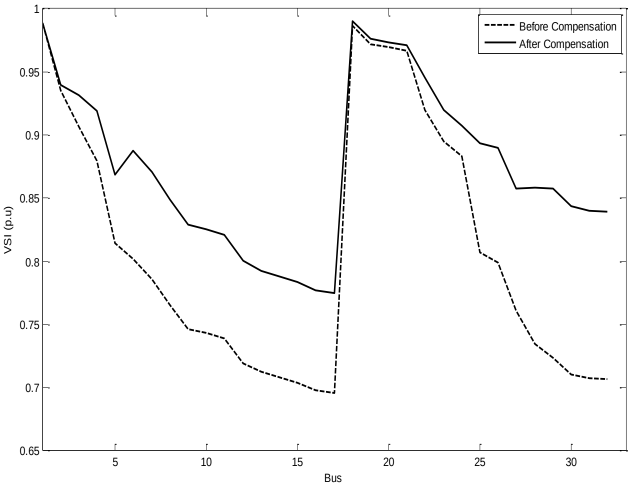

Fig. 9: Effect of capacitors on VSI system

Table 1. Comparison between distinct algorithms for 15 bus systems

Items	Un-compensated	Compensated											
		FGA[12]		In [29]		PSO[11]		DE[26]		In [26]		**Proposed**	
Gross losses (kW)	61.9547	30.4411		32.6		32.7		32.3		33.2		**30.4321**	
Loss reduction (%)	-	50.86		47.38		47.22		47.86		46.41		**50.88**	
Lower potential	0.9424	0.9677		-		-		-		-		**0.9687**	
Optimum siting and size in kVAr	-	4	200	3	805	6	871	3	454	3	150	**6**	**350**
		6	100	6	388	11	321	6	500	4	300	**11**	**350**
		7	300					11	178	6	300	**15**	**350**
		11	300							11	150		
		15	200										
Gross kVAr	-	1100		1193		1192		1132		900		**1050**	
Cost($/year)	32563.4	24599.8		24339.6		24387.1		24496.8		24429.9		**23105.11**	
Gross saving ($/year)	-	7963.6		8223.8		8176.3		8066.4		8133.5		**9458.29**	
% saving	-	24.46		25.26		25.11		24.77		24.98		**29.04**	

Table 2. Outcomes of a 33-bus system for different algorithms

Items	Un-compensated	Compensated							
		PGSA[8]		GSA[30]		FPA [15]		**RSA**	
Gross losses (kW)	202.66	135.4		134.5		134.47		**104.6849**	
Loss reduction (%)		33.19		33.63		33.65		**48.34**	
Lower potential	0.9131	0.9463		0.9672		0.9365		**0.9383**	
Optimal location and size in kVAr		6	1200	13	450	6	250	**6**	**500**
		28	760	15	800	9	400	**28**	**550**
		29	200	26	350	30	950	**29**	**550**
Total kVAr		2160		1600		1600		**1600**	
Annual cost ($/year)	106518.1	83826.24		80553.2		80537.43		**62822.38**	
Net saving ($/year)		22691.86		25964.9		25980.67		**443695.7**	
% saving		21.3		24.37		24.39		**41.04**	