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Research paper

Simultaneous Allocation Renewable DGs and Capacitor for Typical Indian Rural Distribution Network using Cuckoo Search Algorithm

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Abstract

Nowadays, simultaneous allocation of renewable distributed generations (REDGs) along with shunt capacitors (SCs) in RDS distribution networks is getting more attention by the researchers. Since it mitigates the system losses, enhance the bus voltages, power factor improvement, power quality enhancement and reduces the environmental threats. In the proposed work an advanced approach is implemented for simultaneous allocation REDGs and SC for Indian 28- rural bus network. For decrease the losses and maximize the system stability is the main objective of thispaper. The locations and sizing of theses REDGs and SCs have been determined with help of cuckoo search algorithm (CSA).

Keywords: *Renewable Energy based Distributed Generations (REDGs); Shunt Capacitors (SCs); Radial Distribution System (RDS);Voltage stability index; Cuckoo Search Algorithm (CSA).*

1. Introduction

Generally compared with transmission and generation, the distribution system perform a energetic role in power system. It ensures that everyday load is increasing on the distribution system and powered rural distribution consumers. In India the rural electricity is affecting due to penetration of power. Generaly rural homeowners not havingenough energy supply, voltage fluctuations and gadget damaged. Aforementioned problems, the wholeperformance of distribution system becomes inefficient [1]. The RDS performance will be increased by the optimal sittingof REDGs and SCs in the distribution networks. Simultaneous use of these REDGs and SCs provides multiple capabilities in electrical energy distribution system.

It is important to integrate renewable energy based distributed generation (REDG) units like solar, wind and biomass based generation in the RDS.Due to renewable energy sources get a potential benefits than nonrenewable based DG sources as the demand is rises for electrical energy. Owing to the plentifulobtainability of solar and wind in nature, these technologies are used. The power injections from REDG units situated near the load centers deliver a chance for system voltage provision, mitigation in power losses. emissions, and reliability development. Even though, scenario of these REDGs inside the RDS networks can't assure of reactive power requiresthe network, ensuing in growth the losses, lessen the voltage among the buses and produce low power qualitydifficulties inside the distribution [2-4]. With SCs, reactive power compensation has been done in RDS networks.

Forcompensating these disadvantages and for reactive power compensation, it is imporatant to integrate shunt capacitors along with REDGs in the RDS. Still , Majority of research scholars have taken to solve either optimal placingof capacitor or placing of DG problems alone. Very few authors have presented for the concurrent allocation of capacitor and DG in the distribution network [5-10]. The researches have taken an objective feature of minimizing the electricity loss and costs used by Intersect Mutation Differential Evolution algorithm (IMDE) for concurrentplacing of DG and capacitor problem [5].For simultaneous placing of DG and capacitor problem in the RDS, the authors was presented [6], an optimization technique builted on a Particle Swarm Optimization (PSO) to power loss reduction. By considering the similar objective to simultaneous allocate theDG and capacitor is used in the RDS by Bacterial Foraging Optimization Algorithm (BFOA) [7]. In RDS network assign the DG and capacitor simultaneouslyby the authors in [8] have used analytical method. To solve joined DG and capacitor placement trouble within the RDS, a Fuzzy Genetic set of rules (FGA) [9] and Binary Particle Swarm Optimization (BPSO) [10] technique is utilized to improve a voltage profile and to deminise the loss.

From the literature review, it is noticed that utmost of the optimization approaches have positively been utilized to identify the allocation of non-renewable DG and SCs in the RDS simultaneously. Even though, many researchers are still struggling from local optimality, low accuracy, calculation efficiency, slow convergence and large CPU time for optimization.The researchers considered the similar objective function used in all papers (Minimize power losses) for simultaneous allocation of DG and SCs in the RDS. In RDS, voltage related issues, irrespective of voltage stability is the main objective function.

Along with a power loss reduction in the objective function, it is required to incorporate voltage stability enhancement. Researchers have also failed inseeing renewable energy based distributed generation (REDG) units such as wind, solar with SCs in the RDS.

The researchers was inspired by these and proposes a new, fast and efficient nature-inspired optimization method to resolve optimal REDGs and SCs placement in the RDS known as Cuckoo Search Algorithm a unique objective function. The power loss is being reduced along with system stability improvement is the multi-objective function of the current method. By using CSA, the location and sizing of REDG and SCs have been calculated. The present approach efficiency and feasibility is verified with 28-bus Indian rural distribution.

2. Problem Formulation

2.1 Load Flow Analysis

Newton-Raphson, Gauss-Seidal and Fast Decoupled load flow techniques have not acceptable for obtain the voltages and line flows in the RDS because of high R/X ratio. By taking consideration of the above problem in this paper authors specially designed, a straight approach in the distribution system netowrk for load flow solution and obtainable best solution [11-15]. The foremostbenefit of this method is the disadvantage of high ratio of R/X is overridden, and similarly the time-consuming procedures are not necessary in the present method. So it will make the system implementation easier, simple calculation and time-efficient. The sample of single line distribution system is showed in Fig.1.

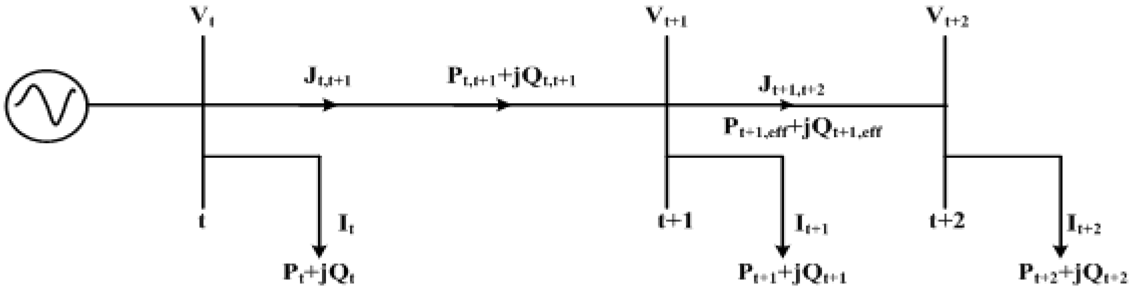

Fig. 1: Simple distribution system

From the Fig.1, the real and reactive power losses between buses t and t+1 can be obtained as

$$P_{Loss(t,t+1)} = \left(\frac{P_{t,t+1}^2 + Q_{t,t+1}^2}{\left|V_{t,t+1}\right|^2} \right) * R_{t,t+1} \tag{1}$$

$$Q_{Loss(t,t+1)} = \left(\frac{P_{t,t+1}^2 + Q_{t,t+1}^2}{\left|V_{t,t+1}\right|^2} \right) * X_{t,t+1} \tag{2}$$

The total power loss P_{TL} of the systems is being calculated by add the losses in all sections

$$P_{TL} = \sum_{t=1}^{nb} P_{Loss(t,t+1)} \tag{3}$$

2.2 Power Loss Reduction using REDG/SCs Placement

The real power loss makes a major role in the RDS. So the optimal REDG and SCs allocation problem is mostly concerned with the mitigation of real power loss in the networks. The total loss isreduced by REDG/SCs allocation in the RDS is the ratio between total power loss with and without REDG/ SCs allocation in the RDS, and is considered as

$$\Delta P_{TL}^{REDG/SCs} = \frac{P_{TL}^{REDG/SCs}}{P_{TL}} \tag{4}$$

The total power loss is reduced by REDG/ SCs allocation in the RDS may be maximized by minimizing $\Delta P_{TL}^{REDG/SCs}$.

2.3 Voltage Stability Index (VSI)

The RDS network is suitable against voltage related problems without consider voltage stability in the objective function, which happenfrequently in the RDS. Hence, while allocating the REDG and SCs, Optimization of the voltage stability is necessary. The system capacity is to regulate voltages in satisfactory range so that when system nominal load is improved, the real power is supplied to the system. It will rise and both voltage and power are controllable is definite as Voltage stability. [12,21,22,23] When REDG and SCs are located simultaneously, the system stability has improved in the distribution networks. At each node, the VSI is calclated using equation (5). The buses which have low values of VSI have chance to voltage collapse.

$$VSI(t+1) = \left|V_t\right|^4 - 4\left[P_{t+1,eff} * X_t - Q_{t+1,eff} * R_t\right]^2 - 4\left[P_{t+1,eff} * R_t + Q_{t+1} * X_t\right]\left|V_t\right|^2 \tag{5}$$

VSI used for calculating the stability level in the radial distribution network and if required suitable action is taken along with value of index by verifying its poor level of stability.

2.3.1 Voltage Stability Index Maximization Using REDG/ Scs Placement

In the RDS, the VSI is maximized using REDG/SCs allocation. It essentialyto be complete with much potential to stopthe voltage collapse. The variation in VSI is observed as the ratio between the VSI with REDG/SCs placement and without REDG/SCs placement and is given by

$$\Delta VSI^{REDG/SCs} = \frac{VSI_{after}^{REDG/SCs}}{VSI_{before}} \tag{6}$$

The VSI is to be maximized by maximizing $\Delta VSI^{REDG/SCs}$.

2.4 Multi-Objective Function

In the past works, it was observed that many of authors took different single objective functions for placement of REDGs and SCs problem in the RDS. Rarely, That objectives are contradictory with each other. Concurrent optimization of the contradictory objectives has become fascinating work for research scholars. Multi-objective function (MOF) holds simultaneous optimization of number of functions, exposed to certain working constraints.

In this proposed work, new MOF which simultaneously decreases the power loss, exploits voltage stability index, increases bus voltage and TOC mitigation is presented.

Mathematically, the proposed MOF for optimal REDGs and SCs location with equality and inequality constraints is shown below

$$Minimize(F) = Min\left[(\beta_1 \Delta P_{TL}^{\text{REDG/DST}}) + \beta_2 (1/\Delta \text{VSI}^{\text{REDG/DST}})\right] \quad (7)$$

Where β_1 and β_2 are the weighting factors related to power loss mitigation and VSI enhancement respectively. The weight for the power loss minimization is 0.6 (β_1=0.6) and voltage stability maximization is 0.4 $(\beta_3 = 0.4)$

$$\sum_{j=1}^{2} \beta_j = 1 \wedge \beta_j \in [0,1] \quad (8)$$

The equality and inequality constraints are applied to the objective function

2.4.1 Power Balance Constraints

Power balance constraints are equality constraints, can be expressed as follows

$$P_{TLoss} + \sum P_{D(t)} = \sum P_{REDG/SCs(t)} \quad (9)$$

Where $P_{D(t)}$ is the power demand at bus *t* and $P_{REDG/SCs(t)}$ is the power generation using REDG/SCs.

2.4.2 Voltage Deviation Constraint

The voltage deviation at every bus should be kept within its limits and is given as

$$V_t^{\min} \le |V_t| \le V_t^{\max} \quad (10)$$

Where $V_t^{\min}$ is the minimum voltage limits of the buses and $V_t^{\max}$ maximum voltage limits of the buses.

2.4.3 Real Power Compensation

Real power constraint where real power is injected at each optimum bus It should be in the suitable range

$$P_{REDG(t)}^{\min} \le P_{REDG(t)} \le P_{REDG(t)}^{\max} \qquad t = 1,2,\ldots\ldots nb \quad (11)$$

Where $P_{REDG(t)}^{\min}$ minimum real power limits of compensated bus *t* and $P_{REDG(t)}^{\max}$ is the maximum real power limits of compensated bus *t*.

2.4.4 Reactive Power Compensation

Reactive power constraint where reactive power has been injected at each optimum bus, it should be in the allowable range.

$$Q_{REDG/SCs(t)}^{\min} \le Q_{REDG/SCs(t)} \le Q_{REDG/SCs(t)}^{\max} \qquad t = 1,2,\ldots\ldots nb \quad (12)$$

Where $Q_{REDG/SCs(t)}^{\min}$ least reactive power limits of compensated bus *t* and $Q_{REDG/SCs(t)}^{\max}$ is the maximum reactive power limits of compensated bus *t*.

3. Wind and Solar Power Generation System Modeling

The generating power of photovoltaic (PV) array and wind turbine generation unit (WTGU) is explained in the following section .

3.1 WTGU Modeling

According to the WTGU's rotation, which can be majorly classified into types: (i) Fixed speed WTGU and (ii) Variable speed WTGU. Fixed speed WTGU contains of direct grid coupled induction generator Variable speed WTGU contains of a wind turbine and an induction generator joined through back to back voltage source converter with grid. In general, The active power output differs based on the wind speed in the the variable speed wing turbine generation unit is employed [13].

The power generation output for a typical WTGU is represented by

$$P_w = \begin{cases} 0 & v_W < v_{cin} \quad or \quad v_W > v_{cout} \\ P_{rated} \dfrac{v_W - v_{cin}}{v_N - v_{cin}} & v_{cin} \le v_W \le v_N \\ P_{rated} & v_{cin} \le v_W \le v_N \end{cases} \quad (13)$$

v_{cin} , v_{cout} , v_N cut-in speed, cut-out speed and nominal speed of wind turbine, correspondingly; P_{rated} is the rated output power of turbine; v_W is the average wind speed and can be given as

$$P_{rated} = 0.5 \rho A v_w^3 C_p \quad (14)$$

Where *A* is the swept area of rotor; v_W is wind speed; ρ is the density of air; and C_p is the power co-efficient.

3.2 PV Array Modeling

With consideration of two governors named as solar radiation and ambient temperature, sizing of PV modelling can be done. It is impossible to generate larger amount of power with PV module. By connecting highest number of PV modules in series and parallel, PV modules can be designed to avoid this drawback. PV array modules enhance the current and voltage which are connected in series and parallel to tailor PV array output [13]. The PV array maximum output power is *NS X NP* PV modules can be derived as

$$P_{pv} = N_S N_P P_{md} \quad (15)$$

P_{md} is the maximum electrical power production by PV module which is derived as

$$P_{md} = FF \times V_{OC} \times I_{SC} \quad (16)$$

$$V_{OC} = \frac{V_{NOC}}{1 + C_2 * \ln \dfrac{G_N}{G_a}} \left(\frac{T_N}{T_a}\right)^{C_1} \quad (17)$$

$$I_{SC} = I_{NSC} \left(\frac{G_a}{G_N}\right)^{C_3} \quad (18)$$

$$FF = \left(1 - \frac{R_S}{V_{OC}/I_{SC}}\right)\left[\frac{\frac{V_{OC}}{nKT/q} - Ln\left(\frac{V_{OC}}{nKT/q} + 0.72\right)}{1 + \frac{V_{OC}}{nKT/q}}\right] \quad (19)$$

Where c_1, c_2 and c_3 are the three different constant.It can be introduced to expose non-linear relationship among solar irradiance, photo-current and cell temperature. n is density factor (n = 1.5); T is the PV module temperature (in Kelvin); K is Boltzmann constant (1.38 * 10^{-23} J/K); and q is the charge of electron (1.6 * 10^{-19} C). G_N is the nominal and Ga is the actual solar irradiance on module; T_N is the nominal and T_a is the actual module temperature, correspondingly; V_{Noc} is the nominal open circuit voltage and I_{Nsc} is the short circuit current of PV module; R_s is the series resistance of module.

4. Cuckoo Search Algorithm

Xin-she Yang and Suash Deb introduced Cuckoo search algorithm [15.17, 18,19]. CSA contains two operators.First one is direct search based totally on Levy flights and the other one is random seek search based totally on the probability for a host bird to discover an alien egg in its nest. In CSA the parameters are used
N: Number of nests or different solutions (25).
Pa: Inventionfrequency of alien eggs/solutions (0.25).
Nd: Dimension Search Space (1 or 3).
Lb: The Lower bound limit
Ub: The Upper bound limit.
CSA includes three steps. They are

- Every cuckoo leaves one egg at a time. It dumps egg in a randomly in chosed nest.
- High quality of eggs in the unique nest will transmit to the subsequent generation.
- The number of possible host nests is fixed, and egg left by a cuckoo is discovered.

4.1 Steps Involved for Optimization

Step 1: Start the direct load flow analysis.
Step 2: Find the base power losses, VSI and Voltage at each bus.
Step 3: Identifythe applicant location for REDGs and SCs.
Step 4: Fix the lower limit and upper limits for the constraints.
Step 5: Recruit random population of n host nests, X_i for amount of kW or kVAr can be added within constraints.
Step 6: Cuckoo find randomly using Levy flights, i
Step 7: Estimate its fitness (F_i) rendering to objective function.
Step 8: A nest randomly acquired from population j.
Step 9: If $F_i > F_j$, then move to step 11. If no move to step 12.
Step 10: Let j as the solution.
Step 11: Change j as the new solution.
Step 12: If fraction of nest is changed by new nests then produce a new nest at new location with the help Levy flights.
Step 13: Selecting the best suitable current nests.
Step 14: For the next generation permit the current best solution.
Step 15 If maximumrepetition is not attained then move to step 6, otherwise it is the finest nest (optimal solution).
Step 16: Show optimal solution.
The steps are used to decrease the objective function.

5. Numerical Results and Discussion

The benefit of the present CSA based optimization technique is studied for 28-bus rural Indian distribution systems. The achieved results of 28-bus RDS are elaborated below in brief. The new approach is performed via Matlab.

5.1 28-bus Indian Rural Distribution Network

To evaluate the capability of present method in real time system an 11kV, 28-bus rural Indian distribution system has been taken and tested. The network is radial in nature with 28- buses and substation is linked at first bus as displayed in Fig. 2. Essential load and bus data of power lines are taken from [16]. In the proposedscheme solar and wind based REDGs are considered along with SCs in the RDS to achieve better objective.

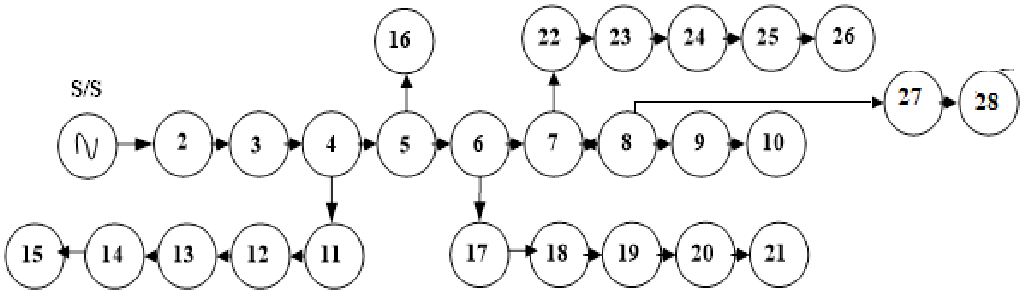

Fig. 2: One line diagram of 28-bus Indian distribution network

To investigate the efficacy of the present scheme in 28-bus Indian rural distribution network, four different cases is taken and analyzed.
Case (i): System without compensation
Case (ii): System with SCs
Case (iii): System with REDGs
Case (iv): System with REDGs & SCs

Case-I

Before compensation i.e., without REDGs or SCs installed in RDS and the power loss is obtained as 68.88 kW. The minimum voltage and VSI of the RDS are 0.9123 and 0.6927 p.u respectively.

Case-II

In this case, two SCs with 480 and 230 kVAr are located at the candidate locations 7 and 12 correspondingly. The size and candidate locations is to be identified using CSA. As a result, the active power loss have decreased to 33.76 kW from 68.88 kW with a minimum voltage of 0.9473 p.u.

Case-III

In this case, two REDGs (solar-1 & wind-1) are optimally situated and sized in the RDS with help of CSA. The total power loss have reduced from 68.88 kW to 6.10 kW after placement of REDGs. The minimum VSI of this system has improved from 0.6927 p.u to 0.9591 p.u after DG placed.

Case-IV

In the last case, REDGs and SCs have placed simultaneously at different optimal locations using CSA. The sizing of the REDGs and SCs can be done by using CSA. The system entire power loss is decreased to 3.49 kW after placement of multiple REDGs and SCs in the RDS. The lowest voltage and VSI of the system have been increased to 0.9988 p.u and 0.9687 p.u. From the considered cases the case-IV gives better objective function value is compared to other cases.

Table 1: Simulation results for the 28-bus Indian distribution network

Items	Without Compensation	With SCs	With REDG		With REDGs and SCs		
			Solar	Wind	Solar	Wind	SCs
Size in kW (Bus No)	--------	--------	220 (12)	470 (7)	210 (12)	460 (7)	--------
Size in kVAr (Bus No)	--------	480 (7) 230 (12)	--------	--------	--------	--------	220 (12)
Power Factor	--------	--------	Unity	0.661	Unity	0.7001	--------
P_{Loss} (kW)	68.88	33.76	6.10		3.49		
% Reduction in P_{Loss}	--------	50.99	91.15		94.94		
$V_{\min}$ (p.u)	0.9123	0.9473	0.9896		0.9988		
$VSI_{\min}$ (p.u)	0.6927	0.8027	0.9591		0.9687		
Total CVD	1.7975	0.2086	0		0		
TOC	--------	3685	3474		4465		
CPU (sec)	--------	8.25	9.75		10.24		

Analysis

Table 1 shows the comparison statement of different parameters are obtained in four different cases: without REDGs and SCs, with REDGs only, with SCs only, and with both REDGs and SCs. From the Table, for above mentioned cases the size of REDGs and SCs is compared. For all the cases the number of buses with voltage stability, voltage minimum and total power losses are compared. Further, at various buses for the different cases considered, the assessments of voltage profile and voltage stability in a 28-bus RDS are specified in Fig. 3 and 4 respectively. From the Table 1 and Fig 3 and 4, it ilso compared to other considered cases, the simultaneous allocation of REDGs and SCs are placed at the optimal placing with optimal sizes in the RDS, the higher level objective function value is possible.

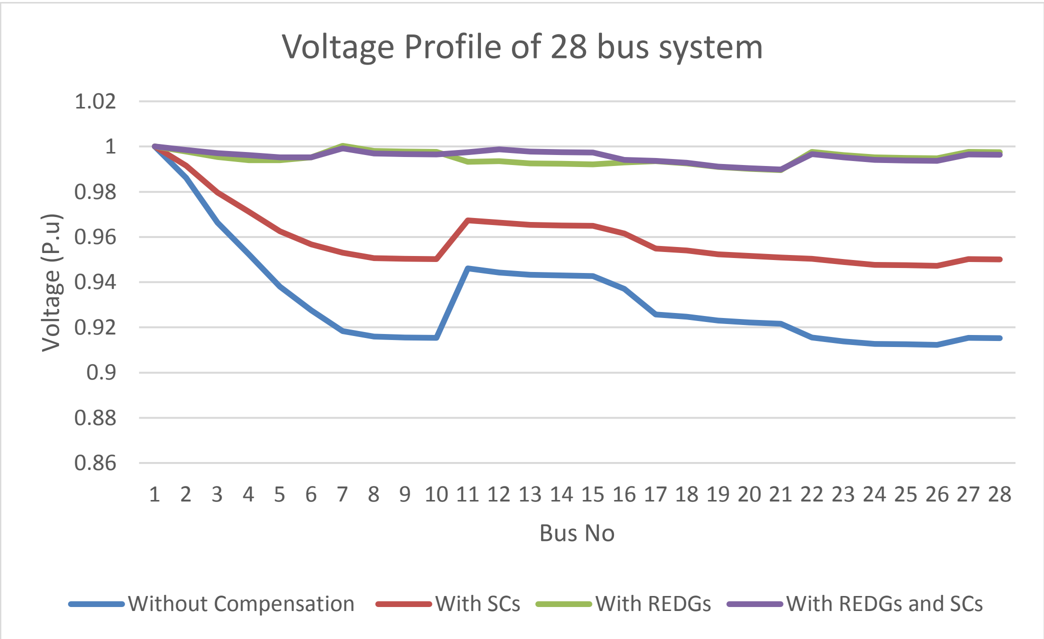

Fig. 3: Voltage profile of 28-bus Indian distribution network

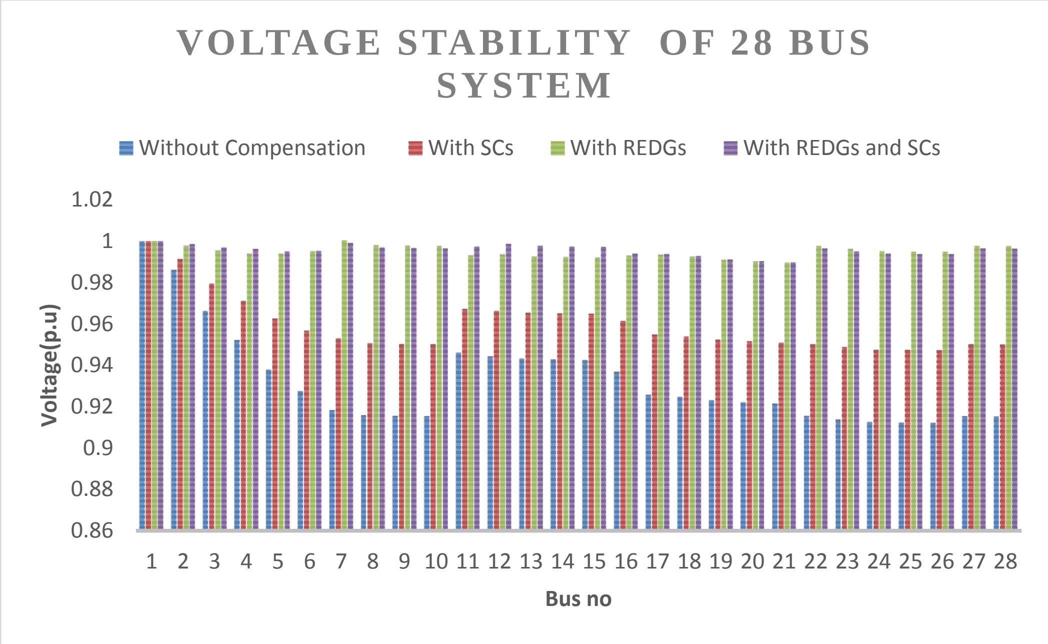

Fig. 4: Voltage stability of 28-bus Indian distribution network

6. Conclusion

In the proposed work, multi objective CSA method for optimal placing and sizing of REDGs and SCs simultaneously in the distribution network has been auspiciously implemented. While acceptable the arrangement constraints a new multi objective function is framed with power loss decrease and maximizevoltage stability. On 28-bus Indian rural distribution system, the planned approach is verified and evaluated. The attained results expressions that the integration of REDGs and SCs produces better results.It displays that the planned method is accurate in identifying the optimal solutions from the presented results. The proposed CSA scheme can able to applied for any kind of distribution systems.

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