Optimal Distribution system feeder reconfiguration and distributed generation placement considering different model of DG sources

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Abstract

This paper presents a methodology for optimal distribution system feeder reconfiguration and distributed generation (DG) placement in distribution system considering different model of DGs with an objective power loss reduction and voltage stability enhancement. The distributed generation availability of wind turbines, solar photovoltaic panels and fuel cell etc., are classified into different models according to their operation modes and control characteristics. Variable scaling hybrid differential evolution (VSHDE) has been applied to solve feeder reconfiguration of DGs. The variable scaling factor is used in the VSHDE method to overcome the drawback of the fixed and random scaling factor and alleviate the problem of the selection of a mutation operator in the hybrid differential evolution (HDE). Aiming to the problem that the reactive power output of PV model sometimes exceeds the limit, this paper researches the impact factors of the output reactive power during reconfigurations, such as rated active power and rated voltage magnitude. The developed methodology is tested on 2 systems with 11-bus, IEEE 33-bus distribution system. The study results indicate that for a given set of distributed generators and their locations, the proposed method can identify optimal on/off patterns of the switches that yield the minimum loss, meliorated voltage profile and while satisfying the constraints.

Keywords: Distribution system reconfiguration, power loss reduction, voltage stability enhancement, variable scaling hybrid differential evolution (VSHDE)

Introduction

Distribution systems consist of groups of interconnected radial circuits. The configuration may be varied via switching operations to transfer loads among the feeders. Two types of switches are used in primary distribution systems. There are normally closed switches (sectionalizing switches) and normally open switches (tie switches). In recent times, electric distribution systems are becoming large and complex leading to higher system losses and poor voltage regulation. Studies indicate that almost ١٠–١٣٪ of the total power generated is lost as I^2R losses at the distribution level (Civanlar et al, 1811), which in turn, causes increase in the cost of energy and poor voltage pro-file along the distribution feeder. Therefore, it becomes important to improve the reliability of the power transmission in distribution networks. Civanlar et al, 1811, present the early work on feeder reconfiguration for loss reduction. In (Baran et al, ١٩٨٩) defined the problem for loss reduction and load balancing as an integer programming problem. Nara et al. ١٩٩٢ presented an implementation using a genetic algorithm (GA) to look for the minimum loss configuration. But traditional GA is CPU cost and encoding complex. In order to achieve better optimization, improved genetic algorithms were used in the distribution network reconfiguration (Zhu, ٢٠٠٢). Goswami and Basu, ١٩٩٢, suggested to employ a power flow method-based heuristic algorithm for determining the minimum loss configuration of radial distribution networks. In (Cheng and Kou, ١٩٩٤), the authors proposed a solution procedure employing simulated annealing (SA) to search an acceptable no inferior solution. Peponis et al, ١٩٩٥, were to outline and validate a methodology for optimization of MV distribution networks operation. Broadwater et al, ١٩٩٣, had considered time-varying load analysis to reduce loss. Fuzzy theory and evolutionary programming were employed to solve feeder reconfiguration systems (Chiou and Wang, ١٩٩٧). Although this problem had been solved by the above methods, either its optimality is not guaranteed or it has to spend much of computation time.

Ma, and Zhang, ٢٠٠٤, used decimal coding and applied genetic algorithm to distribution feeder reconfiguration, decreasing particle dimension and avoiding a large number of infeasible solutions. Distributed generators (DGs) are grid-connected or stand-alone electric generation units located within the distribution system at or near the end user. With the challenges DGs are acting an important role in electrical systems. The accepted connection of high number of DG units to electrical power systems may cause some problems in power system operation and planning. With the advent of DGs, however, locally looped networks would appear in power distribution systems and bidirectional power flows is inevitable. The problems of power system operations and planning schemes will be arising due to the increase of distribution generation units to the distribution power systems. Moreover, the problem of DG allocation and sizing is of great important. Installing DG units at optimal placement and sizing will decrease the system losses and improve the voltage level of system (Al Abri et al, ٢٠١٣) An analytical method is proposed by Caisheng and Nehrir, ٢٠٠٤, to determine the optimal location of DGs. The sitting and sizing of renewable DGs is addressed with the objectives of minimization of cost, emission, and losses by an improved Honey Bee Mating optimization (Niknam et al, ٢٠١١). Gitizadeh et al, ٢٠١٣, presented a multi-objective expansion planning in presence of DGs. PSO techniques has been used to solve the optimal placement of different types of DGs (Wu WC et al, ٢٠١١). As the penetration of distributed generation is expected to increase significantly in the near future, the control, operation and planning of distributed networks need to shift if this generation is to be integrated in a cost-effective manner. So it is necessary to research the distribution feeder reconfiguration considering distributed generators. In recent years, new methodologies of reconfiguration with distributed generations have been presented. Most of recent researches, however, assume that the output of DG units is dispatchable and controllable. Choi and Kim,٢٠٠٠, adopted Genetic algorithm to the problem of network reconfiguration with dispersed generations. Olamaei and Niknam ,٢٠٠٨, applied particle swarm optimization for distribution feeder reconfiguration considering DGs. A tabu search algorithm has been used to the feeder reconfiguration problem with dispatchable distributed generators (Rugthaicharoencheep and Sirisumrannukul, ٢٠٠٩). Wu et al, ٢٠١٠, propose a reconfiguration methodology based on an Ant Colony Algorithm (ACA) that aims at achieving the minimum power loss and increment load balance factor of radial distribution networks with distributed generators. An ant colony algorithm has been adopted to achieve the minimum power loss and increment load balance of distribution system feeder reconfiguration with DGs (Wu et al, ٢٠١٠). Rao et al, ٢٠١٣, presents a new method HAS and different scenarios of DG placement and reconfiguration of network are considered. In most of them, DGs are treated as PQ only, In actually, different models of DGs have their operation modes and control characteristics, so handle DG as PQ model in power flow is not accurate. The work of Niknam et al, 2112, presents a modified evolutionary algorithm based on HBMO to solve the distribution feeder reconfiguration problem. Fuel cells, wind energy, and photo-voltage cells were considered and modeled as PQ or PV node simply. the wind turbines controlled by Fixed speed and slip asynchronous need absorb reactive power from power system to build the magnetic field, this type of DG have not capability of output reactive power, so we cannot model this type of DG as PQ or PV.

In this paper, a VSHDE methodology is proposed to solve the feeder reconfiguration problem with different model of DGs. DGs are classified into four models (PQ, PV, PQ (V) and PI) according to their operation modes and control characteristics. When the system is placed with PV model DGs, the output reactive power sometimes exceeds the limit, this paper researches the relation of rated active power, rated voltage magnitude and output reactive power of PV model DGs in the reconfiguration problem.

Hybrid differential evolution (HDE) is a stochastic search and optimization method. The fitness of an offspring competes one to one with that of the corresponding parent, which is different from the other evolutionary algorithms (EAs). This one-to-one competition gives rise to a faster convergence rate. (Chiou and Wang, ١٩٩٩) However, this faster convergence also leads to a higher probability of obtaining a local optimum because the diversity of the population descends faster during the solution process. To overcome this drawback, a migrating operator and an accelerated operator act as a trade-off operator for the diversity of population and convergence property in HDE. A migrating operator maintains the diversity of population, which guarantees a high probability of obtaining the global optimum. In addition, an accelerated operator is used to accelerate convergence. However, a fixed scaling factor is used in HDE. Using a smaller scaling factor, HDE becomes increasingly robust. However, much computational time should be expanded to evaluate the objective function. HDE with a larger scaling factor generally should result in falling into local solution or miss convergence. Lin et al. [۱٦] used a random number with a value between zero and one as a scaling factor. However, a random scaling factor could not guarantee the fast convergence. The selection of a mutation operator is also a very important issue in HDE. The proper mutation operator can accelerate to search out the global solution (Chiou and Wang, ۱۹۹۹). However, the selection of a mutation operator is one of problem dependence. In HDE, the proper mutation operator is not easy to select.

In this study, a variable scaling hybrid differential evolution (VSHDE) for solving the network reconfiguration of distribution systems is proposed. Here, ۱/۵ success rule of strategies (ESs) (Back and Schwefel, ۱۹۹۳) is used in VSHDE to adjust the scaling factor to accelerate searching out the global solution.

In this paper two case studies ۱٤-bus and IEEE ۳۳-bus distribution system from the literature are solved by the proposed method. From the computational results, it is observed that the convergence property of the VSHDE method is better than that of the other methods.

The novelty of this paper is that it proposes recently developed fireworks optimization algorithm for solving the distribution system network reconfiguration together with DG placement for the problem of power loss minimization and voltage stability enhancement. The proposed technique makes use of VSHDE to pre-identify the candidate bus locations for DG installation. Also the technique monitors the radial nature of the network at all phases of reconfiguration by generating proper parent node-child node path during power flow.

The layout of this paper is as follows: the next section presents the formulation for distributed feeder reconfiguration considering DGs. Models of various DGs are stated in Section 'Models of various DGs'. Basic mechanism of (VSHDE) is presented in Section 'Proposed method'. Finally, in Section 'Experiment results', the method in this paper put forward is tested in ۱٤-bus and IEEE ۳۳-bus distribution systems and other references are compared.

Problem formulation

Distribution feeder reconfiguration problem is to find a best configuration of radial network that gives minimum power losses while the imposed operating constraints are satisfied. Considering N bus distribution system, the objective function for the minimization of real power loss is described as

$$\min(F) = \min(C_p . P_{loss} + C_v . S_v) \quad (۱)$$

$$P_{loss} = \sum_i R_i I_i^2 \quad (۲)$$

$$S_v = \sqrt{\frac{1}{n_b}\sum_{i=1}^{n_b}(v_i - \bar{v})^2}$$
$$\bar{v} = \frac{1}{n_b}\sum_{i=1}^{n_b} v_i \quad (۳)$$

Where P_{loss} is the total real power loss of the system and S_v is voltage standard deviation.

The voltage magnitude at each bus must maintain within its limits. The current on each branch has to lie within its capacity rating. These constraints are expressed as follows:

$$V_{\min} \le V_i \le V_{\max} \quad (٤)$$
$$I_i \le I_{\max}$$

Where

$|V_i|$ voltage magnitude of bus ;

$V_{\min}, V_{\max}$ are bus minimum and maximum voltage limits, respectively;

$|I_i|, I_{i,\max}$ are current magnitude and maximum current limit of branch, respectively.

Subject to

(i) System power flow equations must be satisfied.

$$\begin{cases} P_i + P_{DGi} - P_{Li} - U_i \sum_{i=1}^{N-1} U_j (G_{ij} Cos\theta_{ij} + B_{ij} Sin\theta_{ij}) = 0 \\ Q_i + Q_{DGi} - Q_{Li} - U_i \sum_{i=1}^{N-1} U_j (G_{ij} Sin\theta_{ij} + B_{ij} Cos\theta_{ij}) = 0 \end{cases} \quad (٥)$$

where G_{ij} and B_{ij} are the conductance and susceptance of the line between bus i and bus j. P_{DGi} and Q_{DGi} are power generations of generators at bus i. P_{Li} and Q_{Li} are the loads at bus i; h_{ij} is the d-value of the voltage angle at bus i and j.
(ii) Branch capacity and node voltage constraints:

$$\begin{cases} U_{i\,\min} \le U_i \le U_{i\,\max} \\ S_{ij} \le S_{ij\,\max} \end{cases} \quad (٦)$$

Define S_{ijmax} as the maximum allowable capacity of the branch between bus i and j; Voltage magnitude U_i at each node must lie within their permissible ranges to maintain power quality. Transmission power capacity in each branch must lie within their permissible ranges to maintain safety of network.

(iii) DG capacity constraint

$$P_{DGi\,\min} \le P_{DGi} \le P_{DGi\,\max}\ (1 \le i \le N-1) \quad (٧)$$

where P_{DGimin} and P_{DGimax} are the upper and lower bounds of DG capacity connected to node i.

(iv) Radial network constraint
Distribution system in normal operation should be radial structure and have not islets and loops.
Voltage Stability Index for DG installation
Voltage Stability Index (VSI) that identifies the most sensitive bus is used to determine the candidate bus locations for DG installation in the system . The estimation of these candidate buses initially helps in reducing the search space significantly for the optimization technique.

Consider a line section consisting an impedance of R_k+jX_k and a load of $P_{k+١,eff}+jQ_{k+١,eff}$ connected between k, k+١ buses as shown in fig. ١.
From Fig. ٣, the following equations can be written:

$$J_k = \frac{V_k - V_{k+1}}{R_k + jX_k} \quad (٨)$$

$$P_{Lk+1} - jQ_{Lk+1} = (V_{k+1})^* J_k \quad (٩)$$

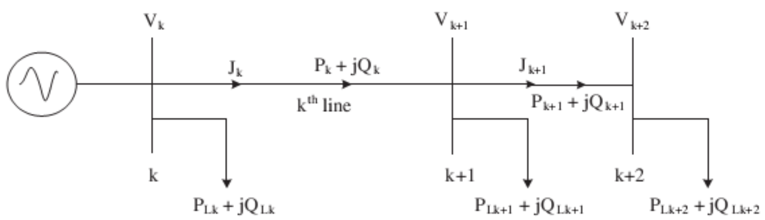

Fig 1. Simple distribution line

Models of various DGs

DGs combine with distribution system through three interfaces: synchronous generator, induction generator and power electronic devices (DC/AC or AC/AC). DGs such as geothermal power, tidal power and internal-combustion engine merge into distribution system using synchronous generator. Photovoltaic system, fuel cells and storage battery merge into distribution system with DC/AC convertor, and micro-turbines use AC/AC convertor. Therefore, this paper divides DGs into four models, (PQ, PV, PQ (V) and PI) and discusses respectively.

PQ model
Direct driven synchronous wind turbines are usually connected to grid by transducer which can control generator's active power output and reactive power respectively. So the direct driven synchronous and doubly fed wind turbines may be described as PQ model in flow calculations as well as power factor controlled combined heat and power generators. The type of DG is capable of injecting both real and reactive power.

PV mode
Generally photovoltaic system is connected to power system by current controlled or voltage controlled inverter. If photovoltaic system equipped with voltage controlled inverter, its voltage may be constant. The active power of fuel cell output is constant. And the voltage of fuel cell can be controlled by converter's parameter. So voltage controlled photovoltaic system, fuel cell and voltage controlled combined heat and power generator may be described as PV model. Usually, for keep the voltage constant, PV node need amounts of reactive power reserve. But output reactive power for photovoltaic system is limited. Therefore, we should set upper limit (Q_{max}) and lower limit (Q_{min}) for reactive power for PV node during simulations. If the output of reactive power of the converter exceeds its limit (Q_{max} or Q_{min}), PV model can be converted into PQ model where the output reactive power Q_{out} is restricted to the limit. This paper adopts Z_{bus} method and a sensitive matrix to solve Q_{out}. It follows that

$$MQ_{out} = \Delta V \quad (٩)$$
$$Q_{out} = \Delta V M^{-1} \quad (١٠)$$

Where Q_{out} and ΔV are the output reactive power mismatch vector and the voltage mismatch vector of PV model DGs respectively. M is the sensitivity matrix. Detailed derivations of the sensitivity matrix can be found in (Chen et al, ٢٠٠٦).
PQ (V) mode
Fixed speed and slip controlled asynchronous wind turbines which absorb reactive power from power system to build the magnetic field, do not have the ability of voltage regulation and this will lend to the increasing of network real power losses. Generally, compensative capacities are used to supply the reactive power which asynchronous generator need. Through this, asynchronous wind turbines need not absorb reactive power from power system, network real power losses will decrease. Actually, the reactive power capacities supplied also depend on the voltage of asynchronous generator. So fixed speed and slip controlled asynchronous wind turbines may be described as PQ (V) model. And the reactive power should be modified according to the node voltage calculated in each iteration step. The approximate model of asynchronous generator is depicted in Fig. ٢.
Assume that U is the voltage of asynchronous generator s is slip; R is rotor resistance; x_r is the sum of stator reactance and rotor reactance; x_m is excitation reactance; P and Q are the asynchronous wind turbines active power output and reactive power absorbed; s and Q can be calculated by the following Eqs. (١١) and (١٢):

$$s = \frac{R(U^2 - \sqrt{U^4 - 4x_\sigma^2 P})}{2x_\sigma^2 P} \quad (١١)$$

$$Q = \frac{R^2 + x_\sigma (x_\sigma + x_m) S^2}{R x_m S} P \quad (١٢)$$

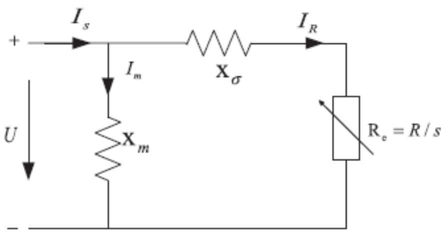

Fig. ٢. The approximate model of asynchronous generator.

Parallel capacities need output compensative reactive power QC to increase the power factor of wind turbines from cos φ۱ to cos φ۲. It follows that:

$$Q_c = P(\sqrt{\frac{1}{(\cos\varphi_1)^2}-1}-\sqrt{\frac{1}{(\cos\varphi_2)^2}-1}) \quad (۱۳)$$

Define UN as rated voltage; U as the actual voltage of wind turbines; $Q_{N\text{-}Unit}$ as the unit capacity of parallel capacitors. In actual operation, the number of capacitors paralleled must be integer. So assume n as Parallel capacitors number, n is calculated as

$$n = \text{int}(Q_c / Q_{N-unit}) \quad (۱٤)$$

where int() is the function for integer arithmetic. Under Rated voltage UN, Parallel capacitors output compensative reactive power is Q_{CN}.

$$Q_{CN} = nQ_{N-Unit}U^2/U_N^2 \quad (۱٥)$$

Through compensative reactive power, the power factor of wind turbines will improve to cosφ. It follows that

$$Cos\varphi = P/\sqrt{P^2+(Q_{CN}-Q)^2} \quad (۱٦)$$

If cosφ is in the permissible range, e.g. ۰,۹ to ۱,۰, the compensation process stop; if not, the number of parallel capacities will increase or decrease until cosφ is accepted.

PI model

Photovoltaic system only supplies active power to power system. If photovoltaic system equipped with current inverter, the current output is constant. The corresponding compensative reactive power can be gotten by Eq. (۱۷).

$$Q^{k+1} = \sqrt{|I_m|^2(e_k^2+f_k^2)-P^2} \quad (۱۷)$$

Proposed method

The variable scaling factor is used in VSHDE to overcome the drawback of the fixed and random scaling factor and alleviate the problem of selection of mutation operator in HDE. The rule of updating a scaling factor based on the ۱/٥ success rule of the ESs (Back et al, ۱۹۹۱) is used to adjust the scaling factor. The ۱/٥ success rule emerged as a conclusion of the process of optimizing convergence rate of two functions. The rule of updating scaling factor is as follows:

$$\begin{aligned} F^{t+1} &= c_d * F^t \qquad if \quad p_s^t < 1/5 \\ F^{t+1} &= c_i * F^t \qquad if \quad p_s^t > 1/5 \\ F^{t+1} &= F^t \qquad if \quad p_s^t = 1/5 \end{aligned} \quad (۱۸)$$

Where P_s^t is the frequency of successful mutations measured. The successful mutation defining the fitness value of the best individual in the next generation is better than the best individual in the current generation. The initial value of the scaling factor F is set to ۱,۲. The factors of C_d=۰,۸۲ and C_i=۱/۰,۸۲ are used for adjustment, which should take place in every q iterations. The iteration index suggested by (Back and Schwefel, ۱۹۹۳) is equal to $10\times b$ where is a constant. When the migration operator is performed, the value of scaling factor is defined as follows:

$$F = 1-\frac{iter}{iter_{\max}} \quad (۱۹)$$

Where *iter* and $iter_{max}$ are the number of current iteration and the maximum iteration, respectively. Also, the scaling factor can be reset as (١٩) when the scaling factor is too small to find a better solution in the solution process. Formally, the variable scaling hybrid differential evolution is briefly described in the following.

Step ١) Initialization Input system data and generate the initial population. The initial population is chosen randomly and would attempt to cover the entire parameter space uniformly. The uniform probability distribution for all random variables is assumed as follows:

$$Z_i^0 = Z_{i,\min} + round(\sigma_i .(Z_{i,\max} - Z_{i,\min}))\ ,\ \ i = 1,....,N_p \qquad (٢٠)$$

Where $\sigma_i \in (0,1]$ is a random number, and *round(b)* represents the nearest integer for the real number b . The initial process can produce N_p individuals of Z_i^0 randomly.

Step ٢) Mutation operation five strategies of a mutation operator have been introduced by [٢٢]. The essential ingredient in the mutation operation is the difference vector. Each individual pair in a population at the th generation defines a difference vector D_{jk} as

$$D_{jk} = Z_j^G - Z_k^G \qquad (٢١)$$

The mutation process at the *G*th generation begins by randomly selecting either two or four population individuals $Z_m^G, Z_l^G, Z_k^G, Z_j^G$ for any *j, k, l* and *m*. These four individuals are then combined to form a difference vector D_{jklm} as

$$D_{jklm} = D_{jk} + D_{lm} = (Z_j^G - Z_k^G) + (Z_l^G - Z_m^G) \qquad (٢٢)$$

A mutant vector is then generated based on the present individual in the mutation process by

$$\hat{Z}_i^{G+1} = Z_i^G + round(F.D_{jklm}),\quad i = 1,...,N_p \qquad (٢٣)$$

Where scaling factor F is a constant. In addition, *j, k, l, m* are randomly selected.

The perturbed individual in (١٤) is essentially a noisy replica of Z_p^j Herein, the parent individual Z_p^G depends on the circumstance in which the type of mutation operations is employed.

Step ٣) Crossover operation

In order to extend the diversity of further individuals at the next generation, the perturbed individual of $\hat{Z}_i^{G+1}$ and the present individual of Z_i^G are chosen by a binomial distribution to progress the crossover operation to generate the offspring. Each gene of th individual is reproduced from the mutant vectors $\hat{Z}_i^{G+1} = [\hat{Z}_{1i}^{G+1}, \hat{Z}_{2i}^{G+1}, ..., \hat{Z}_{ni}^{G+1}]$ and the present individual $Z_i^G = [Z_{1i}^G, Z_{2i}^G, ..., Z_{ni}^G]$ That is:

$$\hat{Z}_{gi}^{G+1} = \begin{cases} Z_{gi}^G & \text{if a random number} > C_r \\ \hat{Z}_{gi}^{G+1} & \text{otherwise} \end{cases} \qquad (٢٤)$$

Where $i=١,...,N_p$ و $g=١,..,n$ and the crossover factor $C_r \in (0,1]$ is assigned by the user.

Step ٤) Estimation and selection: The parent is replaced by its offspring if the fitness of the offspring is better than that of its parent. Contrarily, the parent is retained in the next generation if the fitness of the offspring is worse than that of its parent. Two forms are represented as follows:

$$Z_i^{G+1} = \arg\min(f(Z_i^G), f(\hat{Z}_i^{G+1})) \qquad (٢٥)$$

$$Z_b^{G+1} = \arg\min(f(Z_i^G)) \qquad (٢٦)$$

Where arg min means the argument of the minimum.

Step ٥) Migrating operation (if necessary): In order to effectively enhance the investigation of the search space and reduce the choice pressure of a small population, a migration phase is introduced to regenerate a new diverse population of individuals. The new population is yielded based on the best individual Z_b^{G+1} The $G+١$th gene of

the *i*th individual is shown in (١٨) at the bottom of the page, where σ_i , δ are randomly generated numbers uniformly distributed in the range of [٠، ١]; *i*= ١,...,N_p and *g*= ١,...,*n*.
The migrating operation is executed only if a measure fails to match the desired tolerance of population diversity. The measure is defined as follows:

$$\varepsilon = \sum_{\substack{i=1 \\ i \neq b}}^{N_p} \sum_{g=1}^{n} \frac{\eta_z}{(n.(N_p - 1))} < \varepsilon_1 \qquad (٢٧)$$

Where

$$\eta_z = \begin{cases} 0, & if \;\; Z_{gi}^{G+1} = Z_{bi}^{G+1} \\ 1, & otherwise \end{cases} \qquad (٢٨)$$

Parameter $\varepsilon_1 \in [0,1]$ expresses the desired tolerance for the population diversity and the gene diversity with respect to the best individual. η_z is the scale index. From (١٩) and (٢٠), it can be seen that the value ε is in the range of [٠، ١]. If ε is smaller than ε_1, then the migrating operation is executed to generate a new population to escape the local point; otherwise, the migrating operation is turned off.
Step ٦) Updating the scaling factor if necessary
The scaling factor should be updated as (٩) in every *q* iterations. When the migrating operation performed or the scaling factor is too small to find the better solution, the scaling factor reset as (١٠).
Step ٧) Repeat steps ٢–٦ until the maximum iteration quantity or the desired fitness is accomplished.

The computational procedures find configurations with different status of switches so that the objective function is successively reduced. This computational process of the VSHDE for solving network reconfiguration of distribution systems and DG allocation is stated using a flowchart, as shown in Fig. ٣.

IV. APPLICATION OF THE PROPOSED METHOD
Implementation of the problem begins with the parameter encoding.

$$Z_{ig}^{G+1} = \begin{cases} Z_{bg}^{G+1} + round(\sigma_i .(Z_{g\,\min} - Z_{bg}^{G+1})); & if \;\; \delta < \dfrac{Z_{bg}^{G+1} - Z_{g\,\min}}{Z_{g\,\max} - Z_{g\,\min}} \\ Z_{gi}^{G+1} + round(\sigma_i .(Z_{g\,\max} - Z_{bg}^{G+1})); & otherwise \end{cases} \qquad (٢٨)$$

A tie switch and some sectionalizing switches with the feeders form a loop. A certain switch of each loop is then selected to open to make the loop become radial, and the selected switch naturally becomes a tie switch. The network reconfiguration problem is identical to the problem of selection of an appropriate tie switch for each loop so that the power loss can be minimized. A coding scheme that recognizes the tie switch position is proposed. The total number of tie switches is kept constant, regardless of the change in the system's topology or the tie switches' positions. Different switches from a loop are, respectively, selected to cut as a tie switch to decide its associated fitness value to determine a feasible solution (radial configuration) with minimum loss and minimum standard deviation of voltages.
Three-feeder distribution system from the literature and one ٣٣ bus distribution network are investigated, and the results are used to compare the performance of the proposed VSHDE method with the GA and SA methods. The Matlab code is used to solve the network reconfiguration of distribution systems.

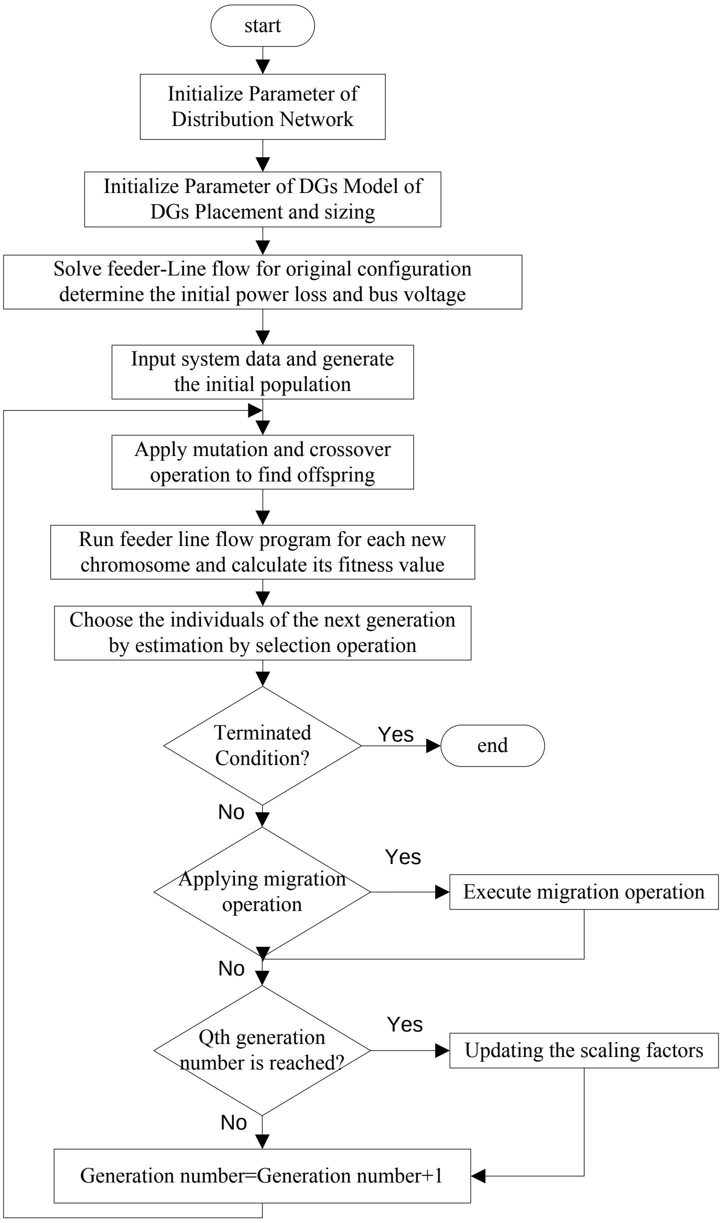

Fig3: computational process of the VSHDE for solving network reconfiguration of distribution systems and DG placement

Results and discussions

To demonstrate and examine the applicability of the proposed technique in solving the network reconfiguration and installation of DG units simultaneously using VSHDE, it is applied to two ١٢ , ٦٦kV test systems consisting of ١٦ and ٣٣ buses. For both the test systems, the substation voltage is considered as ١p.u, and all the tie and sectionalizing switches are considered as candidate switches for solving reconfiguration problem. The maximum number of DGs installed for the given test systems is limited to three since it is studied that the rate of improvement of percentage loss reduction decreases when the candidate locations increases more than three at all load levels. However, the proposed technique can be implemented for any number of DGs. The VSHDE parameters initialized in the above section is taken common for both the test systems. In the simulation of the test systems, five different scenarios at normal load levels are considered to analyse the superiority and performance of the proposed method.

Scenario I: The system is without reconfiguration and DG units (base case).

Scenario II: The system is optimally reconfigured by the available sectionalizing and tie switches.

Scenario III: Optimal size of DG units installed at the candidate buses of the system.
Scenario V: The system is optimally reconfigured in presence of DG units installed (i.e. reconfiguring the distribution network with the distributed energy resources).

Example ١:

The first example is a three-feeder distribution system (Civanlar et al, 1811), as shown in Fig. ٤. The system consists of three feeders, ١٣ normally closed switches, and three normally open switches. The system load is assumed to be constant, and S_{base}= ١٠٠*MW*.

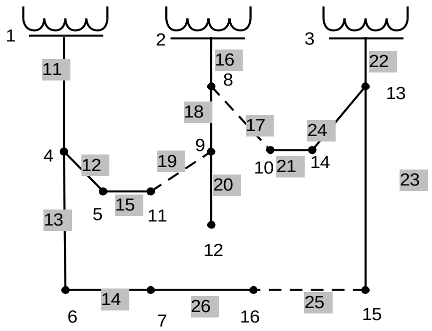

Fig 4. 14-bus distribution system

The setting factors used in VSHDE to solve this example are as follows. The application of the VSHDE algorithm is briefly described below. In Step ١, the population size N_p is set to five, and the maximum generation *itermax* is set to ٥٠. Then, Steps ٢–٦ are repeated until the maximum iteration quantity or the desired fitness is reached. There are six parameters employed in the proposed VSHDE method, including population size N_p, maximum iterations *itermax*, crossover factor C_r, iteration index *i*, iter, tolerance of gene diversity, and tolerance of population diversity ε_1 are relatively hard to handle. According to the authors' experience, if the objective function is sensitive to these two parameters, these parameters are given smaller values. On the other hand, if the objective function is not sensitive to these two parameters, they are given greater values.
Both ε and ε_1 are set to ٠,١. Five strategies of mutation operation are, respectively, used to solve this example. To verify the performance of the proposed algorithm, this example was repeatedly solved for ١٠٠ runs. Table ٢ shows the best computational results. As shown in table ٢, the best solution is reached by VSHDE compare with other algorithms.
From the computational results, the selection of the mutation operator in VSHDE does not affect the performance of the proposed method significantly.

Table ٢. Optimal configuration results for ١٦-bus distribution network (comparison VSHDE and other solution)

System	*Power loss*	*Voltage profile (p.u.)*	*Tie lines*
Before reconfiguration	۵۱۱,۴۳	Vmin= ۰,۹۶۹۳	(5–11), (11–11), (7–16)
After reconfiguration using MTS	۴۶۶,۱	Vmin = ۰,۹۶۹۴	(1–11), (8–11), (7–16)
After reconfiguration using (TS+SA)	۴۶۶,۱	Vmin = ۰,۹۶۹۴	(1–11), (8–11), (7–16)
After reconfiguration using ACSA	۴۶۶,۱	Vmin = ۰,۹۶۹۴	(1–11), (8–11), (7–16)
After reconfiguration using VSHDE	***۴۶۶,۱***	***Vmin = ۰,۹۷۱۳***	***(8–11), (9–11), (11–11)***

Table ٣. Optimal configuration results for ١٦-bus distribution network (reconfiguration and DG allocation)

Scenario	Item	Load Nominal (1.1)
Base case (scenario I)	Switches opened	15-21-26

	$P_{T,Loss}$ (kW)	511.1
	V_{Worst} in p.u.	1.8683
	(Bus no)	12
Only reconfiguration (scenario II)	Switches opened	18-17-25
	$P_{T,Loss}$ (kW)	166.1
	V_{Worst} in p.u.	1.8716
	(Bus no)	(12)
	% Loss reduction	1.168
Simultaneous reconfiguration and DG installation (scenario V)	Switches opened	17-18-26
	DG size in MW (candidate bus)	1.8111 (7)
	$P_{T,Loss}$ (kW)	367.67
	V_{Worst} in p.u.	1.8771
	(Bus no)	(11)
	% Loss reduction	21.18

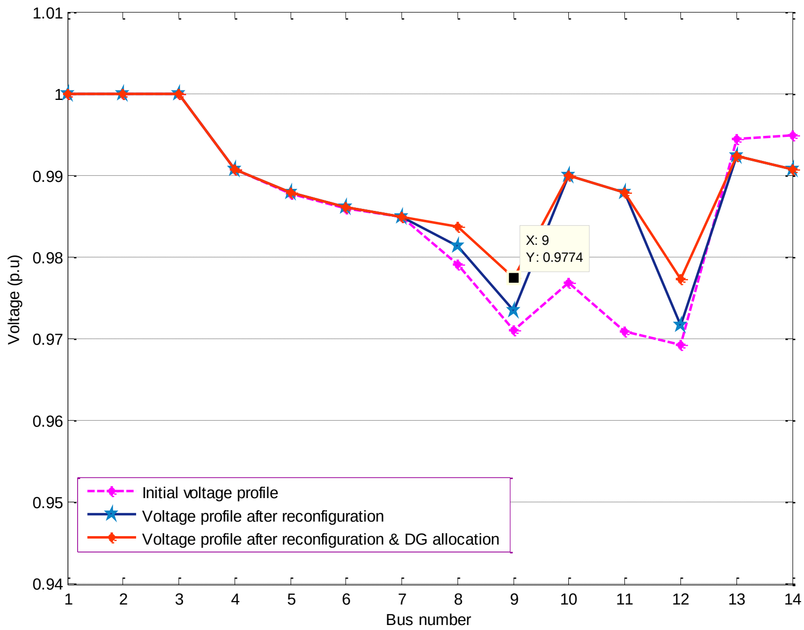

Fig٥. Comparison of voltage profiles of Civanlar network

Example 2:

In order to illustrate the details of the proposed VSHDE method, a worked example is provided here on a 33-node test system (fig 6).

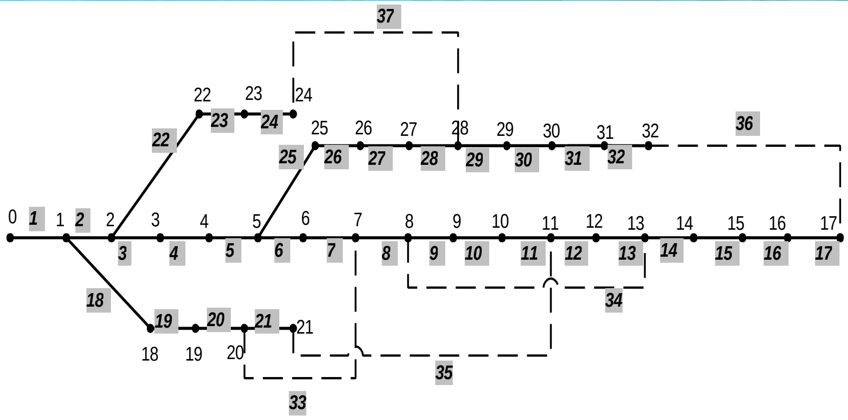

Fig ٦. Single Line diagram of ٣٣-bus radial system

Table ٤.Optimal configuration results for ٣٣-bus distribution network

System	*Power loss*	*Voltage profile (p.u.)*	*Tie lines*
Before reconfiguration	۲۰۰,۵ kW	Vmin=۰,۹۱۳۱	۳۳،۳۴،۳۵،۳۶،۳۷
After reconfiguration using proposed PSO	۱۴۱,۳ kW	Vmin=۰,۹۳۷۹	۶،۹،۱۴،۳۲،۳۷
After reconfiguration using GCPSO and GA	۱۴۲,۱kW	Vmin=۰,۹۳۷۵	۷،۹،۱۴،۳۲,۳۶
After reconfiguration using VSHDE	***۱۳۹,۶۸kW***	***Vmin=۰,۹۳۷۸***	***۷،۹،۱۴،۳۲،۳۷***

Table 1. Optimal configuration results for 33 -bus distribution network (reconfiguration and DG allocation)

Scenario	Item	Load Nominal (1.1)
Base case (scenario I)	Switches opened $P_{T,Loss}$ (kW) V_{Worst} in p.u. (Bus no)	33 ،31 ،35 ،36،37 211.5 1.8131 (11)
Only reconfiguration (scenario II)	Switches opened $P_{T,Loss}$ (kW) V_{Worst} in p.u. (Bus no) % Loss reduction	7 ،8 ،11 ،32 ،37 138.1135 1.8371 (31) 31.13%
Only DG installation (scenario III)	Switches opened DG size in MW,KVAR (candidate bus) $P_{T,Loss}$ (kW) V_{Worst} in p.u. (Bus no) % Loss reduction	33 ،31 ،35 ،36،37 11 11 (3) 81 11 (6) 111 21 (21) 111 -- (28) 163.1656 1.8227 (11) 11.15%

Reconfiguration after DG installation (scenario IV)	Switches opened	7 ،8،11،31،37
	DG size in MW,KVAR (candidate bus)	11 11 (3) 81 11 (6) 111 21 (21) 111 -- (28)
	$P_{T,Loss}$ (kW)	116.1661
	V_{Worst} in p.u. (Bus no)	1.811 (32)
	% Loss reduction	16.68%
Simultaneous reconfiguration and DG installation (scenario V)	Switches opened	7،11 ،11،32،37
	DG size in MW,KVAR (candidate bus)	117.68 51.63 (31) 116.21 12.16 (28) 116.18 11.12 (11) 178.18 -- (11)
	$P_{T,Loss}$ (kW)	11.6711
	V_{Worst} in p.u. (Bus no)	1.8576 (31)
	% Loss reduction	57.77%

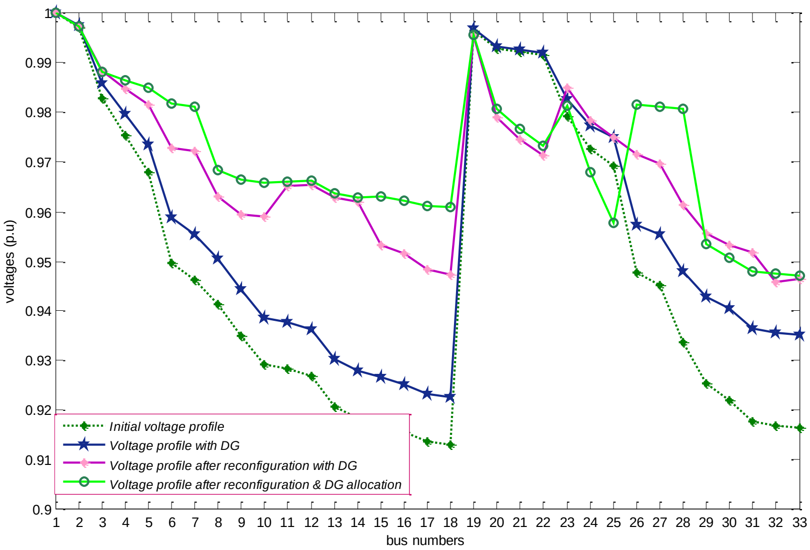

Fig٦. Comparison of voltage profiles of ٣٣-bus distribution network

CONCLUSION

In this paper, the application of integrating the network reconfiguration and DG placement for the problem of minimization of power loss and voltage deviation using VSHDE has been detailed and investigated. Proposed method maintains the radial nature of the network and proper current flow direction through-over all reconfiguration phases, by method utilized the 1/5 success rule of the ESs to adjust the scaling factor to accelerate searching out the global solution. The variable scaling factor is used to overcome the drawback of fixed and random scaling factor used in HDE. The computational results obtained from solving two instances, including one three-feeder distribution system and 33-bus IEEE distribution system are investigated. The computational results of example 1 showed that the performance of the VSHDE method is better than the other algorithm. Also, the VSHDE method can alleviate the problem of the selection of mutation operator in the HDE method. From example 2, it is observed that the VSHDE method is especially suitable for application to the large-scale practical network reconfiguration of distribution systems.

The proposed method is tested on 11- and 33-bus test systems. The results obtained clearly indicates that scenario V (network reconfiguration with simultaneous DG installation) is found to be more effective in minimizing the power loss and improving the voltage profile compared to the other scenarios considered. However, the proposed method is very efficient in finding the optimal solution for all the scenarios. The simulated results are compared with the results of MTS , TS+SA, ACSA , PSO and GCPSO and GA available in the literature. The computational results showed that the performance of the VSHDE is better than MTS , TS+SA, ACSA , PSO and GCPSO and GA. The proposed method can be easily applied and adapted to any large scale radial distribution networks.

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