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Solving Reconfiguration Problem Using Multi Objective Particle Swarm Optimization for Power Distribution System

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Abstract: This paper introduces a new Multi Objective Particle swarm Optimization algorithm (MOPSO) for the purpose of solving the DSR problem& optimal placement of DGs .The objectives of the problem are to minimize real power losses and improve the voltage profile with minimum switching operations. the best solution is determined by simply considering the sum of the normalized objective values. Radial system topology is satisfied using graph theory by formulating the branch bus incidence matrix (*BBIM*) and checking the rank of each topology. To test the algorithm, it was applied to widely studied test systems and a real one. The results show the efficiency of this algorithm as compared to other methods in terms of achieving all the goals simultaneously with reasonable population and generation sizes and without using a mutation rate, which is usually problem dependent.

***Index Terms*—Distribution system reconfiguration, Multi Objective Particle swarm Optimization algorithm (MOPSO),Distribution Generations (DG's).**

I INTRODUCTION

The distribution system constitutes a significant part of a total power system. A distribution system is one from which the power is distributed to various users through feeders, distributors and service mains. Feeders are conductors of large current carrying capacity and carry the current in bulk to the feeding points. Power losses in the lines account for the major portion of the distribution system losses. These power losses mainly depend on the type of conductor and its resistance, size and length. To meet the present growing domestic, industrial and commercial load day by day, effective planning of the radial distribution network is required. Increasing costs of energy and costs of generating capacity are encouraging the electric utility to spend capital to improve the efficiency of the distribution system. The objective of distribution system planning is to assure the growing demand for electricity, in terms of increasing growth rates and high load densities that can be satisfied in an optimum way by additional distribution systems.The single line diagram of a sample radial distribution feeder is shown in Figure 3.1 where the digits indicate branch and alphabets represent the node.

Proper selection of branch conductors for connecting the load point is required to reduce the planning cost. Although the uniform conductor can reduce the loss of the system, it increases the planning cost.

An electric distribution system is an electric power system interface between the power source and the consumer's service switches. The efficiency of a distribution system in fulfilling the functions is measured in terms of voltage regulation, service continuity, flexibility, efficiency and cost. The cost of distribution is a significant factor in the delivered cost of electric power. The power sources are located in the load area to be served by the distribution system that generates power substations supplied over transmission lines.

(a)Sub-Transmission Circuits

The sub-transmission circuits extend from the bulk power source or source to the various distribution substations located in the load area. They may be radial circuits connected to a bulk power source at only one end or loop and ring circuits connected to one or more bulk power sources at both ends. The sub-transmission circuits consist of underground cable, aerial cable or overhead open-wire conductors carried on poles or some combination of them. The sub-transmission voltage is usually between 11/33KV.

(b)Distribution Substation

Each distribution substation normally serves its

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own load area, which is a sub division of the area served by the distribution system. At the distribution substation, the sub-transmission voltage is reduced for general distribution throughout the area. The substation consists of one or more power transformer banks together with the necessary voltage regulating equipment, buses and switchgear.

(c)Primary Feeders

The area served by the distribution substation is also sub-divided and each sub-division is supplied by a distribution or primary feeder. The three-phase primary feeder is usually run out from the low-voltage bus of the substation to its load centre, where it branches into three phase sub feeders and single-phase laterals.

(d)Distribution Transformers

Distribution transformers are ordinarily connected to each primary feeder and its sub feeders and laterals. These transformers serve to step down from the distribution voltage to the utilization voltage. Each transformer orbanks of transformers supply a consumer or group of consumers over its secondary circuit. Each consumer is connected to the secondary circuit through his service leads and meter. The secondary and service connections may be either cable or open-wire circuits.

(**e)Classification of Distribution Systems**

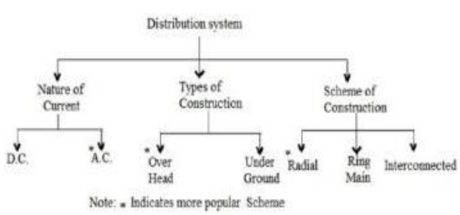

Fig1. Classifications of Distribution Schemes

Three different ways exist to lay out a power distribution system used by electric utilities, each of which has variations in its own design. A considerable amount of effort is necessary to maintain an electric power supply within the requirements of the various types of consumers.

The size of the conductor of a feeder is governed by the current carrying capacity, voltage drop and overall economy. The current carrying capacity of a conductor depends on the conductor losses and surrounding. For determining the voltage drop, it is necessary to calculate the inductive reactance of the feeder. After calculating the inductive reactance, the voltage drop of the conductor can be calculated. If the voltage drop is high, another conductor size is selected to reduce the voltage drop. The value of the conductor size obtained above should be checked for overall economy. By the application of Kelvin's Law, the most economical conductor size can be calculated. According to Kelvin's law the most economical cross-section is that which makes the annual value of interest and depreciation of the conductor equal to the annual cost of the energy wasted in the conductor.

II SOLUTION METHOD

A. Problem Formulation

The DSR problem is to determine the optimum open/closedstatus of all the switches in the system. The problem is formulatedas a multi-objective optimization problem to achieve thefollowing four objectives, which lead to optimum system performance.These objectives are expressed as fitness functions tobe implemented in the FNSGA.

1) Real power loss minimization, expressed as

$$\sum_{k=1}^{N_k} R_k \frac{P_K^2+Q_K^2}{V_K^2} \ldots\ldots.(1)$$

where

Nb number of branches;

Rk resistance of branch ;

Pk real power at sending end of th branch;

Qk reactive power at sending end of th branch'

Vk voltage at sending end of th branch.

2) Voltage profile optimization to enhance the system quality. This can be achieved by choosing the topology w

$$\max\left(min\{V_j\}\right) \quad \forall\in N \ \ (2)$$

Where N is the number of buses, and Vj is the voltage atbus.

3) Load balancing optimization to minimize the likelihood of system overloading which is achieved by transferring loads from heavily loaded feeders to less loaded ones. This requires a modification of the radial topology of the system, and it is characterized by minimizing the system load balancing index (*SLBI*) [7]. This objective is expressed as

$$\text{min SLBI=min}\left(\frac{1}{N_b}\sum_{j=1}^{Nb}\frac{S_j}{S_j^{max}}\right)\ldots..(1)$$

Where Sj is the apparent power flow in branch j, and Sjmaxis the maximum apparent power capacity of branch .

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4) Minimization of the number of switching operations. Weassume that there is a switch associated with each branch.

This number of operations should be minimized in order toreduce the switching transients and operating costs due tocontinuous change in the distribution system. This objectiveis expressed as

$$min \sum_{i=1}^{aw} x_i (2)$$

wheresw is the number of tie switches, and is the statusof the th tie switch in the initial topology after reconfiguration(0 or 1).

These four objectives are subject to the following constraints:

1) The power flow equations must be satisfied. Thus

$$g(z) = 0$$

where (7) take into account the fundamental circuit laws,assume balanced conditions, and are based on the Newton-Raphson algorithm.

2) Voltage should be constrained within maximum and minimumallowable limits, i.e.,

$$V^{min} \leq V_j \leq V^{max} \ \forall j \in N \quad (3)$$

2) In order to achieve the load balancing objective, branches should not exceed their current capacities, i.e.,
$|i_K| \leq i_k^{max} \forall k \in N_b$ (4)

Where ik is the th branch current, and is ik max the current capacity of branch .

4) The final system topology must be radial without isolatingany load buses.

The four objectives are evaluated for a given system topologyand sorted according to the above-described nondominated set concept, with real power loss minimization chosen as the principalobjective. The new algorithm is illustrated by the flowchartshown in Fig. 1 and described in some detail in the followingSections III-B through III-H. It produces a list of the nondominated set of solutions satisfying these four objectives, and theoperator has the option of selecting the topology that best fitshis requirements.

III Conventional FNSGA Codification

The system topology refers to the state of the power system,including feeders, buses, loads, closed branches (sectionalizingswitches), and open branches (tie switches). A chromosome isa description of which branches are closed and which are open.Thus, every chromosome defines a unique system topology.

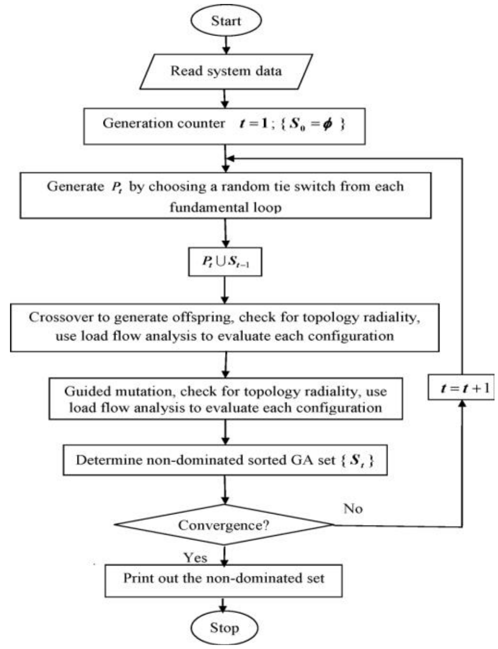

Fig. 2.Flowchart of the new FNSGA.

Avalid or feasible chromosome is a chromosome that satisfies theabove-described power flow, voltage, current and radiality constraints.Different methods for generating valid chromosomes for GAapplication to the DSR problem have been developed. The firstone was introduced by Huang [13], whoused binary coding of all closed branches in the system. Otherresearchers used each branch code plus its open/closed status.These codes suffer from three main issues: 1) "Hamming cliffs"such as the transition from 0111111 to 1000000, which requiresalteration of many bits or genes; 2) long chromosomes, whichconsume excessive computing time; and 3) in order to deal withreal optimization problems, coding and decoding processes arerequired, which are time consuming.

A second method for coding individual chromosomes usesfloating point representation of real numbers. Carrano*et al.* [14] represented every switch in the system ineach chromosome, which is very difficult to process, especiallyfor large scale systems. Finally, Hong *et al.* [15] introducedPrefer number encoding and decoding to the DSR problem. Thismethod guarantees generation of a minimum number of spanningtrees (feasible chromosomes), where a spanning tree is definedin graph theory as a tree that connects all vertices withoutforming any loops. The spanning tree with the minimum sum ofedges weight

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factors [16] is called the minimum spanning tree,and it is the optimum solution.

The disadvantage of this methodis that it is excessively time consuming.In the current work, valid chromosomes are generatedfollowing the method described in [17] by first forming thefundamental loops matrix, where a fundamental loop is onethat does not contain any loops within itself, and the numberof fundamental loops L of the meshed system is equal tothe number of tie (open) switches sw , and it is given by thefollowing relation:

$$L = N_b - N + 1 \quad (5)$$

Where Nb and N are the respective numbers of branches andbuses in the system, as defined above. Then, all possible chromosomesare generated by choosing a random branch from eachfundamental loop to represent the switch to be opened in thatloop, and without using that branch to represent a subsequentloop.

C. Crossover

In the present work, a uniform crossover is generally appliedfor each topology with a crossover rate of 1.0. However, for small number of fundamental loops, as in the case of the threefundamental loops 16-bus test system to be described, a one point crossover is sufficient for convergence.

D. Guided Mutation

Most GAs use random mutation with a very small mutationrate. A novel guided mutation process is introduced here, whichdepends on the results of load flow analysis of each chromosome-defined topology. The following steps describe this newguided mutation process:

1) Find the bus with the smallest voltage (the minimumvoltage bus) (Nmin v).
2) Find the branch b1 that connects bus (Nmin v) to thesystem.
3) Search b1 for in the current chromosome.
4) If b1 exists, search for another branch b2 that connects bus (Nminv) to the system but is not present in the currentchromosome.
5) If b2 exists, mutate it with b1 in the current chromosome.
6) If neither b1 nor b2 exist, mutation is skipped for thistopology.

This procedure changes the mutation process in order to improve(raise) the minimum voltage and thereby improve systemquality and reduce the power losses.

E. Radial Topology

In order to determine whether a given topology is radial,a novel approach based on the branch-bus incidence matrix*BBIM*, is introduced here. A graph of (N-1)buses (vertices),excluding the reference bus, and (Nb-L) branches (edges) isformulated as follows [40]. For each element bij in the *BBIM*

$$b_{ij} = \begin{cases} 1 & \text{if bus } i \text{ is at the sending end of branch } j. \\ -1 & \text{if bus } i \text{ is at the receiving end of branch } j. \\ 0 & \text{if branch } j \text{ is not connected to bus } i. \end{cases}$$

The dimensions of the *BBIM* are the number of energizedbranches in the system and the number of buses. The number ofenergized branches is equal to the total number of branches inthe system minus the number of fundamental loops, i.e.,(Nb-L). Thus, the *BBIM* has dimension ((Nb-L)*N) , or, if (10)is used, ((Nb-1)*N).

The column corresponding to the reference node is omittedfrom the *BBIM*, and a square matrix is obtained. The nonreferencebuses are called independent buses. Then the rank (themaximum number of independent rows or columns) of the newmatrix is calculated, and if is equal to (Nb-L) or, equivalently,(N-1), the system is radial; otherwise it is not. In caseof isolated buses or the system topology is not radial, and the rank will be smaller than (N-1). This last step is a novelfeature of the present work.

F. Selection and Elitism

Selection of the best solution is based on the nondominatedset described above. Entering the nondominated set into the nextgeneration to compete with the next populations and ensure conservationof the best solutions satisfies elitism.

G. Convergence and Stopping Criteria

The algorithm stopping criteria is that either:

1) The number of generations (iterations) exceeds its limit,which is set by the operator, or
2) No changes occur in the nondominated solution set for foursuccessive iterations.

The second criterion here gives the algorithm some flexibilityto search for other best solutions.

H. Evaluation of Equal Importance Objectives

After one of the above-mentioned convergence criteria is satisfied,and if there is a preference objective from the operationaland practical points of view, the best solution is simply identifiedfrom the set of nondominated solutions. Otherwise, i.e., ifthere is no preferred objective, a simple approach to identifyingthe best solution is implemented by summing all the normalizedvalues of the

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objective functions. The minimized objective functions(power loss, number of switching operations, and *SLBI*)are normalized using [41].

$$obj_{min}(norm) = \frac{obj - obj_{min}}{obj_{max} - obj_{min}} \quad (6)$$

and the maximized objective function (voltage) is normalizedusing

$$obj_{max}(norm) = \frac{obj_{max} - obj_{min}}{obj_{max} - obj_{min}} \quad (7)$$

where $obj_{min} and\ obj_{max}$ are the minimum and maximumvalues, for that objective function in the nondominatedset, respectively. The optimum solution is defined as the one withthe smallest sum of normalized objective functions. The applicationof (12) and (13) to the DSR problem is a novel featureof the present work.

PARTICLE SWARM OPTIMIZATION

There is no known single advancement strategy accessible for taking care of all enhancement issues. A ton of advancement routines have been produced for taking care of diverse sorts of enhancement issues lately. The present day streamlining techniques (some of the time called nontraditional enhancement strategies) is effective and famous systems for taking care of complex building issues. These strategies are molecule swarm improvement calculation, neural systems, hereditary calculations, subterranean insect province advancement, fake insusceptible frameworks, and fluffy streamlining. The Particle Swarm Optimization calculation (truncated as PSO) is a novel populace based stochastic hunt calculation and an option answer for the complex non-direct advancement issue. The PSO calculation was initially presented by Dr. Kennedy and Dr. Eberhart in 1995 and its essential thought was initially enlivened by reproduction of the social conduct of creatures, for example, flying creature running, fish educating et cetera. It is taking into account the common procedure of gathering correspondence to share singular information when a gathering of winged animals or creepy crawlies look sustenance or relocate et cetera in a seeking space, albeit all feathered creatures or bugs don't know where the best position is. In any case, from the way of the social conduct, if any part can figure out an alluring way to go, whatever remains of the individuals will take after rapidly.

The individual particle in this case is composed of set of tie switches that are to be opened in operating the distribution system in radial configuration only. The size of the particle is equal to number of tie switches in a system. Therefore individual *i*‟s position in 0th iteration can be represented as a vector X_{i0}=(TS_1,TS_2,TS_3……TS_n) where *'n'* is the number of tie switches for a given radial distribution system. The velocity of individual *'i'* i.e., V_{i0} = (V_{il}, …, V_{in}) represents the switch number updating quantity covering all tie lines and maneuver lines. The position and velocity of each element of a particle in this case is mere integer number. Here it is very important to note that while creating the individual particles it is very much essential to check for the radial nature of the network. To do this the below procedure is used to generate the particles at random.

Steps involved in MOPSO Algorithm

Step1: Initialization-initialize all particles as per the above algorithm.

Step2: Set iteration count=0

Step3: Evaluate the fitness function i.e. the Load Balancing Index for the each particle and fix the individual LBI to Pbest and from LBI of all theparticles find the minimum LBI the fix it as Gbest for this iteration

Step4: Evaluate the velocity of each population by using the equation

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand * (Pbest_{id} - s_{id}^{k}) + c_2 rand * (gbest_{id} - s_{id}^{k}) \quad (8)$$

Step5: Update the position of each population by using the equation

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (9)$$

Step6: Find the new values of fitness function (LBI) for all the population and replace it with Pbest if it less than the former value and also fix the least value of Pbest among all the population to Gbest

Step7: Increase the iteration count by 1

Step8: Check the stopping criterion, if not satisfied go to step3 Finally the optimum solution can be obtained through „Gbest‟.

IV RESULTS AND DISCUSSION

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The proposed algorithm was programmed using MATLAB7.12 and implemented on a 1.64-GHz Notebook PC with 4 GBof of RAM. It was applied to two widely-studied test systems, a16-bus system and a 69-bus system; and a real one consistingof 136 buses. In order to test the convergence performance ofthe new FNSGA, it was applied 100 times to each system andthe most repeated solution set (the mode) was selected as theactual or representative solution set. The mode set represented96% of all solutions sets for the 16-bus system, 92% of all solutionssets for the 69-bus system, and 95% of all solution setsfor the real system. All three systems were assumed to be operatedat balanced conditions, and each chromosome was evaluatedaccording to (3)–(6) using a Newton-Raphson based load flow program. The results are presented in the following andcompared with results from other work.

6.1 69-Buses Test System

The system data is given in [18]. As shown in Fig. 3, thesystem consists of 69 nodes, 73 branches, and five fundamentalloops. The base MVA and kV are 10 and 12.66, respectively,and the total system loads are 3.80 MW and 2.70 MVAR. Thecurrent carrying capacity of branch Nos. 1–9 is 400 A, that ofNos. 46–49 and Nos. 52–64 is 300 A, and that of the remainingbranches, including the tie lines, is 200 A. Initially, branches69, 70, 71, 72, and 73 are open, as shown in Fig. 3, and the totalsystem power loss is 224.93 kW. The new FNSGA produceda set of 34 nondominated solutions. Only the optimum topologies(from that set) according to the four objective functions are listed in Table I. The results shown in Table I were obtainedafter ten generations and with an initial population of 30 chromosomes,and it required 20.2 s of CPU time.Solution 1 in the first row of Table III is the optimum in termsof number of switching operations, since it is the initial topology.

If all objectives are of equal importance, the optimum solutionis determined using (12) and (13) and the smallest sum ofnormalized objectives procedure described above. That wouldmake Solution 10, in the fifth row of Table I, with a summationvalue of 0.748, the optimum solution.as compared to four other methods, all of which satisfied onlythe power loss objective with nearly the same value.

TABLE I

OPTIMUM SOLUTIONS OF THE FOUR OBJECTIVES RESULTING FROM THE APPLICATION OF FNSGA TO THE 69-BUS SYSTEM

Methods	Power Losses In KW	Minimum Voltage in pu	Loss Improvement in %
Base Case	225.006	0.9092	0
FNSGA	99.625	0.9428	55.7212
FPSO	94.64	0.9521	5.01

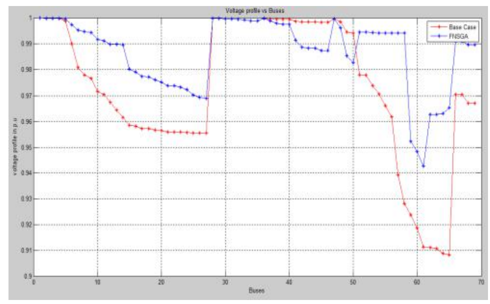

Fig3 Comparison of the Voltage profile in pu for base case & FNSGA Optimization

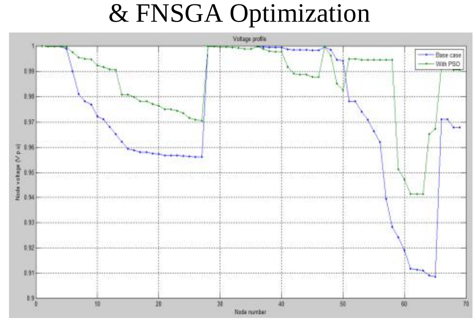

Fig 4 Comparison of the Voltage profile in pu for base case & PSO Optimization

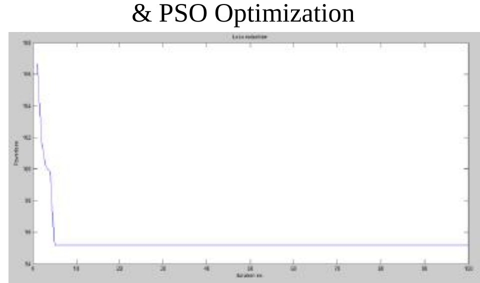

Fig5 Power Losses in KW using Particle Swarm Optimization

V CONCLUSION

An improved version of the PSO and its application, forthe first time, to the multi-objective DSR problem are described.The main characteristic of the PSO is that it deals with onlythe rand solution set and classifies it into only onerank, while other methods, such as the

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FNSGA, search for allsolutions and classify them into more than one rank, which isrelatively time consuming. Power loss minimization is definedas the primary objective, while the other objectives are powerquality improvement, defined by both the voltage profile and minimization of the number of switching operations.The set of nondominated solutions provides the operator withalternatives, depending on needs. If there is (are) no preferredobjective(s), the optimum solution is defined as that with thesmallest sum of normalized objectives.Improvements to the PSO introduced here include a novel particles, which eliminates the need to chooseor adapt mutation rates for each system; a novel approach toverifying system radiality, which eliminates the need to createinfeasible solutions at each stage of the genetic evolution; anda novel approach to determining an optimum solution in thepresence of equal importance objectives.Results of application of the revised PSO to two populartest systems and a real one are described and comparedwith results obtained with other algorithms.

The matlabresultsillustratethe ability of the algorithm to produce PSO solutionsets in which all four objectives, rather than just one, areoptimized simultaneously, and with relative smaller populationsizes and/or numbers of generations, resulting in convenientlyfast CPU times.

FUTURE SCOPE

This work is being extended to the case of servicerestoration, characteristic of system operation in the presenceof fault or maintenance conditions.

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