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Integrated approach of network reconfiguration with distributed generation and shunt capacitors placement for power loss minimization in radial distribution networks

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ABSTRACT

This article presents the significance of efficient hybrid heuristic search algorithm(HS-PABC) based on Harmony search algorithm (HSA) and particle artificial bee colony algorithm (PABC) in the context of distribution network reconfiguration along with optimal allocation of distributed generators and shunt capacitors. The premature and slow convergence over multi model fitness landscape is the main limitation in standard HSA. In the proposed hybrid algorithm the harmony memory vector of HSA are intelligently enhanced through PABC algorithm during the optimization process to reach the optimal solution within the search space. In hybrid approach, the exploration ability of HSA and the exploitation ability of PABC algorithm are integrated to blend the potency of both algorithms. The box plot and Wilcoxon rank sum test are used to show the quality of the solution obtained by hybrid HS-PABC with respect to HSA.The computational results prove the integrated approach of the network reconfiguration problem along with optimal placement and sizing of DG units and shunt capacitors as an efficient approach towards the objective. The results obtained on 69 and 118 node network by proposed method and the standard HSA reveals the powerfulness of the proposed approach which guarantees to achieve global optimal solution with less iteration.

1. Introduction

The locality of electrical energy generation is far away from the consumer loads connected with lengthy feeder lines leads to additional power loss in the transmission and distribution network. Power loss reduction is achieved by reconfiguring the existing network topology and by installing fixed/switched shunt capacitor banks and distributed generation units (DG) in close proximity to the consumer loads in transmission and distribution networks. The allocation of such sources has numerous advantages such as postponement for investing new transmission and distribution network construction, reduction in power loss, bus voltage profile enhancement. Prior to the implementation of loss reduction techniques in the distribution network; there is a necessary to investigate their consequence, such as power loss, bus voltage magnitude, harmonic distortion and system voltage stability. A suitable planning method must be implemented to get the benefits of integrating the DG units and shunt capacitors into the distribution networks.

The network reconfiguration of the RDN is the method of changing the topological structure of the network by opening and closing of sectionalizing and tie switches to achieve optimal topology with minimum power loss. During the reconfiguration process, the system radiality should be maintained with all loads connected to the network. In recent years, a noticeable research work has been carried out for loss reduction using network reconfiguration problem. Since there are numerous candidate switching combinations to find the optimal topology of the network, the reconfiguration problem is modeled as combinatorial, non-differentiable, constrained optimization problem. The discrete nature of sectionalizing and tie switches along with radiality constraints avert the application of classical optimization methodologies. So there has been a growing interest in various population based heuristic search algorithms such as Artificial Immune (AIS) Systems [1], Modified particle swarm optimization [2], Binary group search optimization [3], Adapted ant colony [4], Fireworks algorithm [5], Harmony search [6] algorithm. A fuzzy multi objective network reconfiguration methodology for radial distribution systems has been proposed in

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Nomenclature

Q^{DG}_i	Reactive power injection of ith DG unit
$p.f^{DG}_{max}$	Maximum allowable power factor of DG unit
$p.f^{DG}_{min}$	Minimum allowable power factor of DG unit
$p.f^{DG}_i$	Power factor of ith DG unit
nbus	Total number of nodes in the RDN
nb	Total branches in the RDN
n_c	Total number of capacitors to be installed in RDN
$I_{i,i+1}$	Current flow between ith branch and i + 1th branch
$I_{i,i+1max}$	Allowable maximum permissible current at branch i + 1
$I_{Bmax(i)}$	Maximum allowable branch current
$I^{Wcomp}_{Bmax(i)}$	Branch current flow in ith branch with compensation
$P^{w/comp}_{loss(i,i+1)}$	Real ower loss in the branch between nodes i and i + 1 with DG units, shunt capacitor
$P^{w/comp}_{Tloss}$	Total power loss in the RDN with DG units, shunt capacitor
$\|V_i\|$	Bus voltage magnitude of ith bus
V^{spec}_{min}	Specified lower bound of bus voltage of the RDN
V^{spec}_{max}	Specified upper bound of bus voltage of RDN
P^{DG}_{max}	Maximum size of DG unit in kilowatts
P^{DG}_{min}	Minimum size of DG unit in kilowatts
Qc^L	Sum of total reactive demand of the RDN
Qcj	Reactive power injection by the jth shunt capacitor
P^{DG}_i	Size of ith DG unit in kilowatts

[7]. Tabu search approach has been proposed for network reconfiguration in [8–10]. Mathematical illustration of radiality constraints associated with the radial distribution network reconfiguration problem has been addressed in [11]. Optimal network reconfiguration along with the placement of distribution generation units for power loss minimization has been proposed in [12,13]. As compared with classical optimization techniques, meta-heuristic algorithms are capable to achieve a near optimal solution for DG units and shunt capacitors sizing and placement problem in distribution networks. Artificial Bee Colony (ABC) algorithm which mimics the foraging nature of honey bees swarm has been proposed in [14] to find the best possible sizing of static capacitors. Various models and methods applied for the optimal DG allocation, impact of dispatchable and non-dispatchable type DG units integration in the modern distribution system, current and future trends in this field has been addressed in [15,16]. Analytical approach based DG units sizing and its optimal operating power factor for different types of DG unit's for power loss reduction has been addressed in [17]. An analytical approach for simultaneous allocation and sizing of DG units and shunt capacitor to achieve power loss reduction is proposed in [18].

In [19] a heuristic algorithm, mimicking the improvisation process of musical instruments to get a pleasant harmonious melody so called harmony search algorithm (HSA) is proposed. The performance of the developed algorithm is demonstrated with a traveling salesman problem and minimum-cost pipe network design problem. In [20] an improved harmony search algorithm (IHSA) is proposed which intelligently generates new solution vector for the best solution and convergence of HSA. HSA is a stochastic search procedure which does not need any derivative information to solve the complex combinatorial optimization problem. In [21] the discrete search strategy of HSA is utilized for structural size optimization problem with discrete design variables. In [22,23] a hybrid heuristic search approach is proposed which makes use of ABC algorithm and its variants to enhance the solution vector in the HS algorithm and the simulation results are compared with the harmony search algorithm (HSA), improved harmony search algorithm (IHSA), global harmony search algorithm (GHSA) and self adaptive global harmony search (SGHS) algorithm. The parameters of hybrid algorithm and its impact has been studied with uniform design experiments optimization problems. In [24,25] the optimal design of water distribution networks is addressed using HSA incorporated particle swarm algorithm (PSO) and the result outcomes are better than the genetic algorithm, simulated annealing and Tabu search technique. In [26] a self-adaptive global best harmony search algorithm (SGHS) is proposed which utilize a new harmony memory enhancement strategy by dynamic adaptation of HMCR and PAR, distance bandwidth (BW) as learning mechanism to balance the exploration and exploitation ability. In [27] a hybrid heuristic algorithm is proposed which makes use of sequential quadratic programming technique (HSA-SQL) to accelerate the local search ability and to get better accuracy in HSA solutions. To exhibit the effectiveness and sturdiness of the proposed hybrid HSA-SQL algorithm, various benchmark engineering optimization problems are taken into consideration. The intelligent honey bee foraging behavior of bee swarm is utilized in [28–30] to obtain the optimal solution in multi-dimensional numerical optimization problems. The simulation results outperform the results obtained with the other meta-heuristic algorithms such as a particle swarm optimization algorithm, differential evolution algorithm and genetic algorithms. In calculus based methods, the optimal solution is obtained by using derivatives which is suitable only for continuous-valued functions rather than discrete-valued functions. In [31,32] a new HS algorithm is proposed for solving engineering optimization problems with continuous as well as discrete design variables. In [33,34] the overview of the recent applications of HSA, which uses a 'probabilistic-gradient' to select the neighboring values of decision variables is addressed. It is an efficient meta-heuristic optimization tool for practitioners to solve complex optimization paradigms such as construction, telecommunications, engineering, health and energy, and robotics. The HSA provides probabilistic-gradient based search to get the local or global optimal solution instead of mathematical gradient as in conventional optimization techniques. In [35–38] a HSA based optimal solution is obtained for complex optimization problems like scheduling of multiple dam systems, broadcast scheduling in packet radio networks, estimation of the success of companies and vehicle routing. In [39] a hybrid grouping HSA is proposed for the multiple-type access node location problem to determine the optimum location. In [40] a hybrid approach is used to deploy 24-h medical emergency resources by combining the HSA with the grouping encoding concept to repair infeasible solutions. In [41] a multi-objective harmony search for urban road network reconfiguration problem to offer near-optimal solution to improve the vehicles mobility is proposed. In [42] a quasi-oppositional harmony search algorithm is proposed to investigate the optimal controller gains to enhance the performance of Automatic Generation Control (AGC) of the power system. A new hybrid PSO algorithm has been addressed in [43] to augment the exploration and exploitation capability by introducing the global dimension selection strategy using HSA and validated with the PSO variants, and other meta-heuristic algorithms. In [44] a new self-adaptive HS-PSO search algorithm is proposed with an effective initialization scheme by utilizing the PSO algorithm to improve the solution quality of the initial harmony memory in the HSA. A new self-adaptive adjusting method for control parameters PAR and BW is designed to accelerate the convergence rate and solution accuracy of the proposed algorithm. The poor exploitation ability of the ABC algorithm makes an issue of slow convergence in solving nonlinear and constrained optimization nature of engineering design problems. To overcome these insufficiencies, a modified version of the ABC algorithm is suggested in [45–49] by incorporating adap-

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