Dispatchable DG Planning in Distribution Networks considering costs

S. Kayalvizhi[1] and D.M. Vinod Kumar[2]
Department of Electrical Engineering
National Institute of Technology Warangal, India
[1]Kayaleee89@gmail.com, [2]Vinokumar.dm@gmail.com

***Abstract*— This paper presents an optimal planning of dispatchable Distributed Generation (DG) connected to distribution networks. This planning model is proposed in multi-objective framework. Pareto based multi-objective optimization using Harmony Search Algorithm is proposed for optimizing the location and size of DGs and a fuzzy set theory approach has been used to find the best solution from the obtained Pareto solutions. The three objectives considered for minimization by this model are: real power loss, voltage deviation and the total imposed costs (fuel costs, investments cost, operation and maintenance cost and pollution associated expenses since the DG technology considered here is diesel generator). The proposed approach is tested on IEEE-33 bus and IEEE 69-bus distribution systems and the results are validated with well known NSGA-II technique. The comparison has shown that the proposed technique resulted better compared to NSGA-II.**

Keywords—Distributed Generation, Pareto optimal, Harmony Search.

I. INTRODUCTION

Electric power system is slowly transforming from the centralized bulk generations to the decentralized generations with smaller rating (typically ranges from less than a kW to tens of MW) connected directly to the distribution network closer to the end users. This type of generating units is called as distributed or dispersed generations (DG). These DG technologies can be further categorized as renewable and non-renewable [1]. Renewable technologies include: Solar, photovoltaic and thermal, Wind turbine, Geothermal and Ocean. Non–renewable technologies include: IC engines, Gas turbines, Micro turbines and Fuel cells. Therefore Distributed generation can be either renewable or non-renewable. This evolution from the central generation at farther end of distribution network to the distributed generation (DG) connected near to the load centre will improve the system performance technically and in economic point of power generation it is playing a vital role if the DG technology is renewable source. Various economic and technical benefits are[2]-[3]: Increase in overall efficiency of distribution network, enhanced system reliability and security, improved power quality, relieves Transmission and Distribution Congestion, peak shaving, price hedging, fuel switching and improved environmental performance (reduced emission).

In order to exploit all the potentialities of DG connected distribution network, the renewable and non-renewable mix of the different DG technology have to be chosen and incorporated effectively. In particular, the special technical and economic challenges associated with intermittent source of DG are to be taken care to maintain the security and reliability of the distribution system. The aspects which are influenced by the connection of DG units are as follows [4]-[5]: Voltage stability improvement; Voltage deviations and Grid losses; Power quality; Fault level; Protection system; Reliability; Environmental issue (Emission).

Optimally locating these DG units with proper size into existing distribution networks seems to be a challenging task in planning and operation of DG connected distribution network. Since the objectives such as real power loss, voltage deviation and costs etc. are more than one and are conflicting with each other, this problem of optimal placement and sizing should be attempted as multi-objective model by using any of the heuristic techniques. This multiple objective model can either be static or dynamic. The static models assume all investments are done at the beginning of planning horizon, where as the dynamic one consider the timing of investment decisions in the planning period.

In this paper the optimal placement and sizing of the DG units in distribution system is modeled as multi-objective problem with harmony search algorithm. Moreover, static planning has been done considering only dispatchable DG i.e diesel generator. In [6], a dynamic multi-objective model for DG planning in distribution systems is proposed by considering the timing of DG investments and the network reinforcement. In [7] a probabilistic approach is proposed for the energy and operation management of renewable Micro grid under uncertain environment by using 2m point estimate method and self-adaptive Gravitational search algorithm. A benefit-cost analysis has been done in [8] for optimal investment planning of multiple DG units for minimizing losses and enhancing voltage stability. In [9], a time based dynamic planning model for Distribution network expansion is proposed using optimal power flow and binary enhanced particle swarm optimization to minimize investment and operation cost following the load growth in a specific planning period. A multi-objective approach has been proposed in [10] using NSGA-II technique for optimal location of distributed generations considering technical and economical constraints and moreover, a probabilistic approach has been used to model the uncertainties. In [11], hybrid optimization method combining quadratic programming and PSO method is proposed for optimizing the capacity of the DG units as well as operational strategy of the micro grid. Moreover net present value is used to justify the investment in micro grid and fuzzy set theory is employed to account for the uncertainties in electrical price.

Further, this paper is organized as follows: In Section II Multi-Objective Harmony Search (MOHS) algorithm is discussed. Optimization problem is formulated in Section III. Simulation and results of proposed method on distribution systems are presented and validated in Section IV and section V concludes the paper.

II. MULTI-OBJECTIVE HARMONY SEARCH ALGORITHM

Harmonic Search (HS) algorithm is music based meta-heuristic optimization inspired by search of perfect state of harmony in the music through improvisation process. The steps involved in HS algorithm are as follows [12]:

Step 1: Input system parameters and limits of decision variable.

The HS algorithm parameters are specified in this step. They are the harmony memory size (HMS) or the number of solution vectors in harmony memory, the harmony memory considering rate (HMCR), the distance bandwidth (bw), the pitch adjusting rate (PAR), and the number of improvisations or stopping criterion which is same as the total number of function evaluations.

Step 2: Initialize the harmony memory, HM (set of decision variables). The harmony memory is randomly initialized in the range $[X_{iL} - X_{iU}]$, $(i = 1,2,3 \ldots N)$.

$$X_i^j = X_{iL} + rand\ () * (X_{iU} - X_{iL}) \tag{1}$$

Where $j = 1,2,\ldots HMS$

Step 3: Improvise a new harmony from the harmony memory. Generating a new harmony x_i^{new} is called improvisation, which is based on 3 rules: memory consideration, pitch adjustment and random selection. First of all, a uniform random number is generated in the range [0, 1]. If it is less than the HMCR, the decision variable x_i^{new} is generated by the memory consideration; otherwise, x_i^{new} is obtained by a random selection. Then, each decision variable x_i^{new} will undergo a pitch adjustment with a probability of PAR if it is produced by the memory consideration. The pitch adjustment rule is given as follows:

$$X_i^{new} = X_i^{new} + rand\ () * bw \tag{2}$$

Step 4: Update harmony memory. After generating a new harmony vector X^{new}, the harmony memory will be updated. If the fitness of the improvised harmony vector $X^{new} = X_1^{new}, X_2^{new}, \ldots\ldots, X_N^{new}$ is better than that of the worst harmony, the worst harmony in the HM will be replaced with X^{new} and become a new member of the HM.

Step 5: The X and X^{new} matrices are passed together to the non-dominated sorting algorithm and only best learners are selected for the next iteration with size of initial population**.**

Step 6: Repeat Steps 3–5 until the stopping criterion (maximum number of improvisations) is met and the final set of solution give the pareto optimal front.

Pseudo code for Harmony search in multi-objective frame
begin *Objective function f(x), x=(x₁,x₂, …,x_d)^T* *Generate initial harmonics (real number arrays)* *Define pitch adjusting rate (r_pa), pitch limits and bandwidth* *Define harmony memory accepting rate (r_accept)* ***while** (t<Max number of iterations)*   *Generate new harmonics by accepting best harmonics*   *Adjust pitch to get new harmonics (solutions)*   ***if** (rand>r_accept), choose an existing harmonic randomly*   ***else if** (rand>_rpa), adjust the pitch randomly within limits*   ***else** generate new harmonics via randomization*   ***end if***   *Accept the new harmonics (solutions) if better*   *New harmonies and old harmonies are passed for*   ***non-dominated sorting** for choosing best population* ***end while*** *Find the current best solutions* ***step***

Best compromise solution based on fuzzy set theory:

For the purpose of decision making, a best compromise solution is computed using a technique based on fuzzy set theory. The procedure of this technique can be explained as follows:

- Search through all solutions, to find F_{max} and F_{min} corresponding to each objective function.
- Use the following linear membership function to calculate a membership function for each objective

$$\mu_i = \begin{cases} 1 & F_i = F_i^{\min} \\ \dfrac{F_i^{\max} - F_i}{F_i^{\max} - F_i^{\min}} & F_i^{\min} < F_i < F_i^{\max} \\ 0 & F_i = F_i^{\max} \end{cases} \tag{3}$$

The above equation gives a measure of the degree of satisfaction for each objective function for a particular solution and also maps the objectives into the range 1 to 0. The corresponding membership function for the non-dominated solution k is calculated as follows:

$$\mu_k = \frac{\sum_{i=1}^{No} \mu_i^{ko}}{\sum_{k=1}^{M} \sum_{i=1}^{No} \mu_i^{k}} \tag{4}$$

Where
M: Number of Pareto solutions.
No: Number of objectives.
The best compromise solution is the one achieving the maximum member ship function.

III. PROBLEM FORMULATION

Objective functions and the constraints are described in this section. The main aim is to determine the optimal placement and sizing of DG units by minimizing the planning objectives simultaneously. This problem is attempted as multi-objective problem as the objectives considered are conflicting with each other. Formulation of objective functions and the constraints are as follows:

A. First objective:

The real power loss in distribution system is taken as one of the objective to be minimized and Backward-Forward sweep load flow algorithm has been utilized to evaluate the loss in the considered distribution systems.

$$F_1 = P_{loss} \tag{5}$$

B. Second objective:

Summation of squared voltage deviation at all the buses of the system is considered as next objective to be minimized.

$$F_2 = \sum_{i=1}^{n} (V_i - 1)^2 \tag{6}$$

Where, P_{loss} is the total real power loss in the system, n is the total number of buses, V_i is the voltage magnitude of bus.

C. Third objective:

The DG technology considered in this paper is diesel generator (controllable DG) and the various costs involved are fuel costs, investments cost, operation and maintenance cost and expenses related to pollution associated with diesel generator. Thus , the overall costs is taken as third objective for minimization and it is given by (7)

$$F_3 = f(p) + C_e(p) + OM(p) + C_{inv} + C_{pur} \tag{7}$$

Where
$f(p)$: Fuel cost
$C_e(p)$: Pollution associated expenses.
$OM(p)$: M&O cost.
C_{inv} : Investment cost.
C_{pur} : Cost of power purchased from the Grid.

$$f_{DE}(P_{DE}) = C_{gasoil} * (\alpha.P_{DE}^{\ 2} + \beta.P_{DE} + \gamma) \tag{8}$$

$$OM_i(p_i) = k_{OMi} * p_i \tag{9}$$

$$C_e(p) = \sum_{e=1}^{m} \sum_{i=1}^{ndg} \mu_{ei} * C_{ei} * P_{ei} \tag{10}$$

$$C_{inv} = \sum_{i=1}^{ndg} CI_i * CAP_i \tag{11}$$

$$C_{pur} = C_{purchase} * P_{PfG} \tag{12}$$

Where,
C_{gasoil} - Price of the gasoil feeding the diesel engine
k_{OMi} - The constant coefficient of M&O
μ_{ei} - The coefficient of the eth pollution source for the ith DG where e=1 for SO_2, e=2 for CO, e=3 for CO_2 and e=4 for NO_x.
C_{ei} - The penalty expenses associated with the eth pollution source for ith DG.
ndg - Number of DG units;
m - Total number of pollutants
CI_i - Coefficient of the initial investment for the ith unit.
CAP_i - Installed capacity of the ith unit.
$C_{purchase}$ - Cost of electricity purchased from the grid (($/kW)
P_{PfG} - Amount of electricity purchased from the grid (kW).

Subjects to constraints:

$$0 \le P_{DG} \le P_{DG}^{\max} \tag{13}$$

$$V_{i\min} \le V_i \le V_{i\max} \tag{14}$$

P_{DG} is the real power of DG and $P_{DG}^{\max}$ is the maximum power of DG. $P_{DG}^{\max}$ is 1.2 MW for IEEE 33-bus system and 2 MW for IEEE 69-bus system.

Various parameters and cost coefficient associated with diesel generator used in this paper are provided in Table I [11].

TABLE I
PARAMETERS AND COST COEFFICIENT ASSOCIATED WITH DIESEL GENERATOR

Pollution-associated expenses			Constant coefficient of M&O cost	Coefficient of Initial investment
Gases	Emission levels (g/kwh)	Penalty expenses ($/Kg)	0.01258 ($/kWh)	500 ($/kW)
NO_x	4.3314	0.28		
CO_2	232.037	0.0013		
CO	0.4641	0.022		
SO_2	2.3204	0.131		

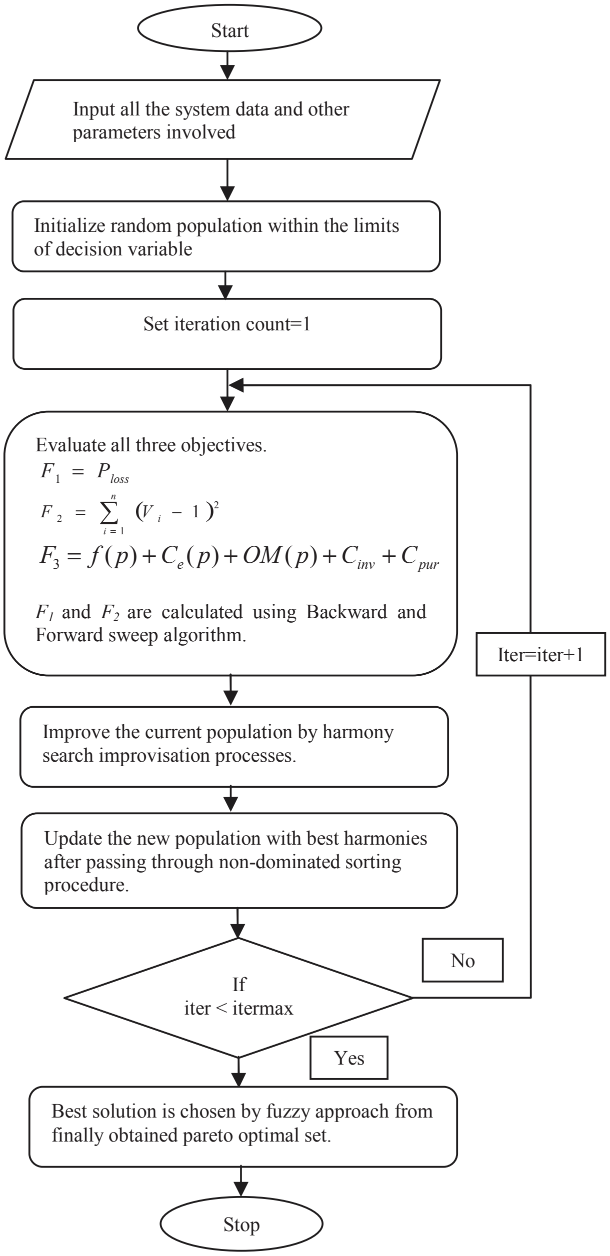

Fig.1. Implementation procedure

IV. SIMULATION AND RESULTS

The proposed multi-objective harmony search algorithm has been tested in two IEEE test systems. IEEE 33-bus radial distribution system shown in Fig.2 with the total load of 3.72 MW, 2.3 MVAr ; IEEE 69-bus radial distribution system shown in Fig.3. with the total load of 3.8 MW, 2.69 MVAr ; In both cases PQ model is considered for DG and working at power factor of 0.85 lead. Various controlling parameters used in NSGA-II algorithm are: **population size-30; maximum no. of iterations-150; cross over probability-0.9; mutation probability-0.1.** For the ease of comparison, same population size and iterations are considered in MOHS and NSGA-II algorithms. The simulations have been carried out using MATLAB software package on a DELL laptop of intel®core™ i5 processor with 2.5GHz speed and supported by 4GB RAM.

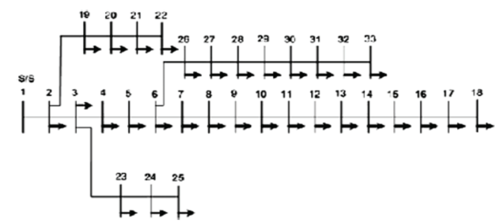

Fig.2. IEEE 33- bus radial distribution system

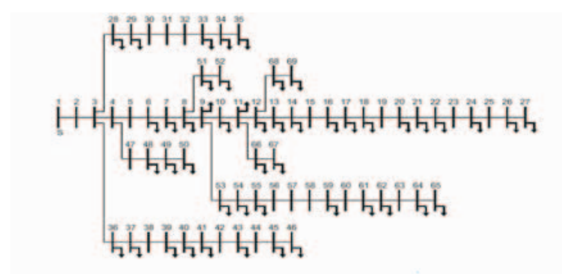

Fig.3. IEEE 69- bus radial distribution system

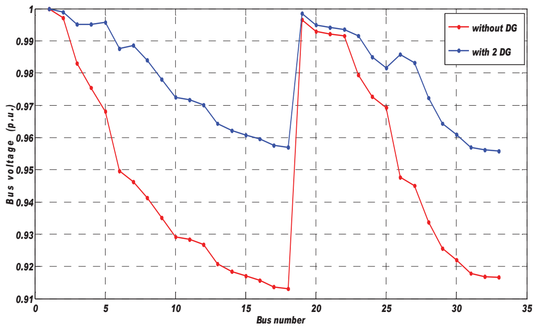

Fig.4. IEEE 33-bus system: Voltage profile at all buses for 2DG

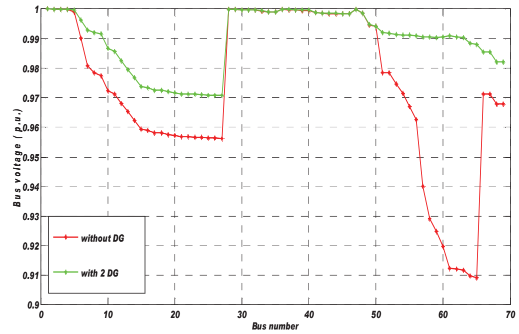

Fig.5. IEEE 69-bus system: voltage profile at all buses for 2DG

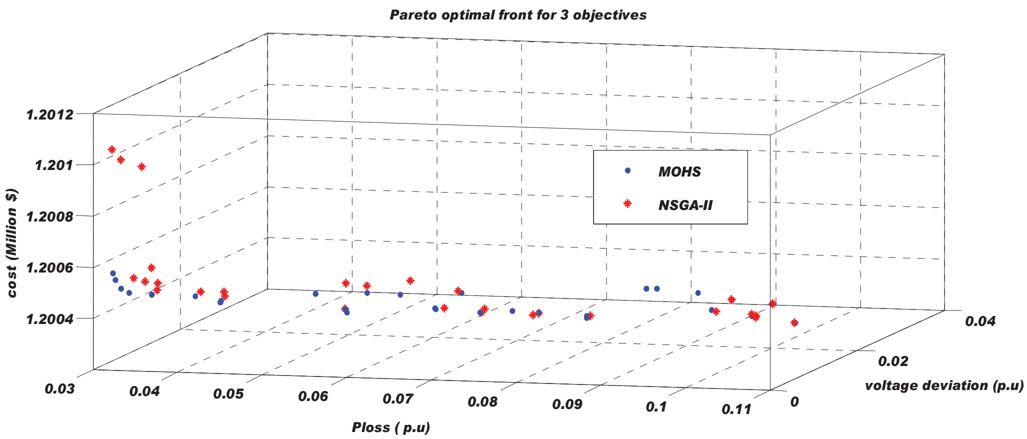

Fig.6. IEEE 33- Bus system: Pareto optimal fronts of MOHS and NSGA-II

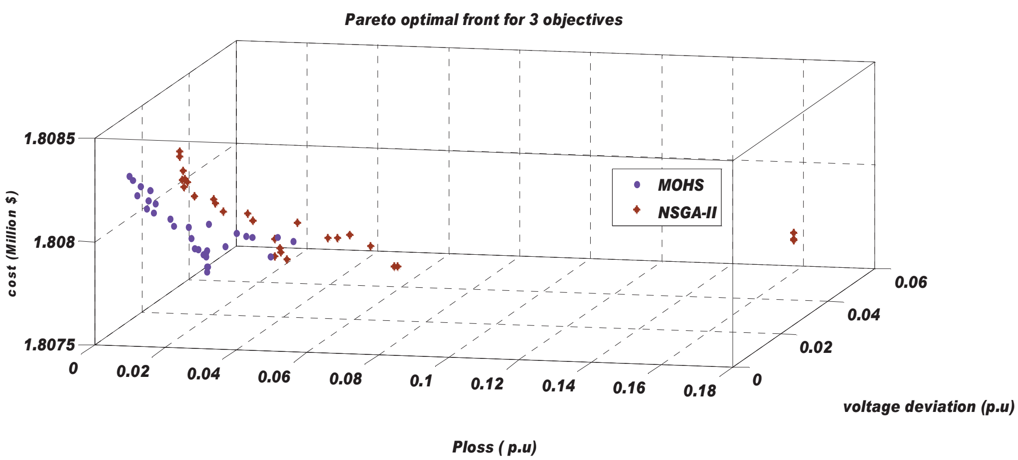

Fig.7. IEEE 69- Bus system: Pareto optimal fronts of MOHS and NSGA-II

Fig.4 and Fig.5 shows the improvement in voltage profile with DG units in the IEEE 33-bus and IEEE 69-bus system respectively. It is observed that the minimum voltage at the buses reached above its minimum limits with 2 DG of total capacity of 2.1837MW penetration.

With further intrusion of DG units in the system will improve the system losses and the voltage profile. Fig.6 and Fig.7 shows the pareto optimal front obtained by MOHS and the NSGA-II methods for 2 DG case and it is inferred that the spread of pareto solutions are better for IEEE 33-

bus system when compared to 69-bus systems. It is clear from the figures that the obtained solutions by MOHS is giving more dominated solutions with respect to all objectives and also exhibits good diversity among the solution.

Table II and Table III shows the comparison of the obtained best solutions of MOHS and NSGA-II algorithms. The comparison shows that the proposed MOHS algorithm is performed well with better results .

TABLE II
IEEE 33-BUS SYSTEM: COMPARISON OF MOHS AND NSGA-II RESULTS

System parameters	Without DG	MOHS	NSGA-II
		With 2DG	With 2DG
DG location	-	30,11	11,30
DG size(MW)	-	1.2 0.9837	1.1237 1.2
Ploss(p.u)	0.2027	0.0314	0.0327
% loss reduction	-	84.51	83.86
Vmin(p.u)	0.9131	0.9644	0.9711
Vmax(p.u)	1	1	1.00071
Voltage deviation(p.u)	0.1010	0.0017	0.0012
Cost(Million$)		1.2006	1.2010

TABLE III
IEEE 69-BUS SYSTEM: COMPARISON OF MOHS AND NSGA-II RESULTS

System parameters	Without DG	MOHS	NSGA-II
		With 2DG	With 2DG
DG location	-	61, 13	64,13
DG size(MW)	-	1.779 0.7286	1.6668, 0.8704
Ploss(p.u)	0.2247	0.0093	0.0251
% loss reduction	-	95.86	88.83
Vmin(p.u)	0.9092	0.9714	0.9833
Vmax(p.u)	1	1	1.005
Voltage deviation(p.u)	0.1010	0.0007	0.0005
Cost (Million $)		1.8083	1.8083

V. CONCLUSION

In this paper, the impact of dispatchable DG placement in distribution network is evaluated by considering the real power losses, voltage profile and also the imposed costs of DG units as planning objectives in the network. DG location and size has been optimized using multi-objective harmony search algorithm and a set of trade-off solutions called pareto solution is obtained by the same. Moreover, the best solution is found by fuzzy approach. The effectiveness of the proposed method of planning is tested on IEEE-33 bus and IEEE 69-bus distribution test systems and a qualitative comparison is made with well known NSGA-II technique. The Pareto front of MOHS dominates the NSGA-II which implies the superiority of the proposed algorithm in terms of both better objectives and diversity among the solutions.

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