Incentive Driven Distributed Generation Planning with Renewable Energy Resources

Sandeep KAUR[1,2], Ganesh Balu KUMBHAR[1]
[1] *Indian Institute of Technology Roorkee, 247667, India*
[2] *PEC University of Technology, Chandigarh,160012, India*
skapsdee@iitr.ac.in, gkumbfee@iitr.ac.in

***Abstract*—Renewable DGs may not be economically viable due to the stochastic generation and huge capital investment, but are an inevitable choice for sustainable energy development and future planning. An appropriate incentive scheme for clean Distributed Generation (DG) technologies is able to address this issue in an economical manner and is considered in proposed distributed generation planning model. The proposed model minimizes the annualized cost with Emission Offset Incentive (EOI) and the penalty for Green-house Gas (GHG) emissions. A meta-heuristic approach with dynamic tuning of control parameters is adopted to improve the success and the convergence rate of optimal solutions. The algorithm provides the optimal solution in terms of type, size, and location of DG. The proposed technique is implemented on IEEE 33-bus system. Proposed model helps the Distribution Network Operators (DNOs) to decide the proper DG technology from an economic prospective for eco-friendly energy planning.**

***Index Terms*—Distributed power generation, Heuristic Algorithms, Optimization, Power generation planning, Sustainable development.**

I. INTRODUCTION

The traditional distribution system planning is aimed at the least cost scenario for fulfilling the load demand. However, environmental factors and regulatory consideration have gained equal importance against stakeholder's interest. In recent years, exponential load growth, power system deregulation, and environmental concern have paved ways for the distributed generation due to its technical, economical, and environmental benefits. Broad classifications of DGs consist of dispatchable resources (such as internal combustion engine, micro turbines, fuel cells, etc.) and non-dispatchable sources (such as wind, solar etc.). Each class of DG possesses its own merits and demerits. Dispatchable resources provide a cost effective solution with threat to sustainable growth. Renewable DGs provide solution to stringent environmental conditions adhering to the Kyoto protocol. However, the generation is stochastic, less efficient and investment intensive.

DG resources can contribute towards line loss reduction by injecting real and reactive power locally, thereby relieving feeder loading by reducing line flows and improving the voltage profile. Studies have indicated that inappropriate selection in terms of both site and size of DG units, may lead to increased system losses than the losses without DG units. By optimal allocation of DG units, utilities can take advantage of reduced system losses, improved voltage profile, investment deferral towards network up-gradation, system reliability, and expansion planning with sustainable growth.

Researchers have investigated distribution system in the presence of DG, from different perspectives [1][2]. [3] proposes a heuristic approach based cost benefit analysis for DG integration without considering environment constraint. To promote green energy by offering an incentive in terms of emission reduction is proposed in [4-6]. The optimization models aim to provide incentive as grant function for low carbon energy for economical generation settlement. DG planning for voltage improvement, loss reduction, maximizing MVA loading and emission reduction is proposed in [5] without economic criterion. [6] proposed multi-objective planning model for cost, loss and emission reduction, including renewable and fuel cell DG. Quantification of emission reduction from the distribution network by integration of alternate resources is proposed in [7] without installation and operational cost. [8] developed eco-friendly non-renewable DG resource planning model and [9] proposed profit centric DG planning model for voltage dependent load. It is observed that DG planning is dealt with either from an economic prospective or from the incentive aspect or penalty for GHG emissions. Incentive for promoting green energy and penalty for GHG emissions in integrated manner can be explored further.

A Genetic Algorithm (GA) and Optimal Power Flow (OPF) based hybrid approach in [10] is applied for pre-specified number of DGs in a given network. Annual energy loss minimization for stochastic generation [11] and DG planning model with loss incentive is proposed in [12]. Particle Swarm Optimization (PSO), ant colony, artificial bee colony, differential evolution, hybrid and other meta-heuristic techniques for optimal allocation of DGs are reviewed in [1][2]. These techniques are iterative and simple, but computationally expensive in terms of memory and speed.

It is observed that optimal DG injection can be considered as a viable option to improve the network performance, therefore, an Improved Harmony Search (IHS) algorithm is proposed for computing the optimal location, size, and type of DG for minimizing the annual cost comprised of grid energy, DG injection, incentive and penalty cost. National action plan to climatic change in India has set an ambitious Renewable Purchase Obligation (RPO) of 15% by 2020. Since renewable DGs cannot compete with the conventional generation system in its present form, thereby results in reduction in RPO targets by most of the states. Clean technologies must receive incentive to enable it to join the

Digital Object Identifier 10.4316/AECE.2014.04004

regional/ national generation system. Proposed formulation with Emission Offset Incentive (EOI) along with penalty for high carbon energy is an effort to encourage power operators to meet RPO policy. The key features of the research paper are:

- Low carbon energy planning for minimizing annual cost with emission offset incentive for encouraging clean energy participation and penalty for harmful emissions to encourage the distribution operators to accomplish RPO targets.
- A novel approach, namely Improved Harmony Search is proposed for optimal placement of renewable DGs. The proposed technique with dynamically tuned control parameters improves to harness exploration and exploitation for an improved optimal solution.

The paper is organized as follows: The proposed planning model is formulated in section II, followed by the description of the proposed algorithm in section III. The simulated results on IEEE 33-bus system are discussed in section IV, followed by conclusions drawn in section V.

II. METHODOLOGY

Integration of DG units into the electricity grid exhibits numerous advantages. However, the eco-environment criterion is equally vital for planning. The basic aim of the proposed optimization problem is sustainable economic planning with renewable DGs to minimize the annual cost. Therefore, optimal DG planning in terms of location, size and type is achieved by minimizing the total annual cost comprised of grid energy, installation and other associated costs of candidate DGs. The penalty for voltage and line loading limit violation, is included in the objective function. The emission cost for high carbon energy and incentive for clean energy is considered. DG location and size are taken as decision variables. Mathematical model of the same is described below.

A. Problem Formulation

The objective of the proposed work is minimization of annualized cost. The objective function for cost minimization consisting of cost incurred in terms of purchase of grid energy, DG's capital, operational, and emission cost, revenue earned by promoting green energy and penalty cost for emissions and violating network constraints is represented as (1)

$$Min\ C_{tc} = C_{cpt}^{DG} + C_{op}^{DG} + C_{o\&m}^{DG} + C_{en}^{SS} + C_{Loss} + C_{emi} - C_{inc\_emi}^{DG} + C_{pen} \quad (1)$$

where $C_{tc}, C_{cpt}^{DG}, C_{op}^{DG}, C_{o\&m}^{DG}, C_{en}^{SS}, C_{Loss}, C_{emi}, C_{inc\_emi}^{DG}, C_{pen}$ are total, capital, operation, maintenance, grid energy, loss, emission, emission incentive, and penalty cost respectively.

The annualized capital cost of selected DGs is evaluated in terms of net present value. Annualized capital cost of all the DGs is represented as (2)

$$C_{cpt}^{DG} = PWF \sum_{n=1}^{N} (c_{cpt}^{bmg} S_n^{bmg} + c_{cpt}^{wg} S_n^{wg} + c_{cpt}^{spv} S_n^{spv}) \quad (2)$$

where present worth factor (PWF) is given as (3)

$$PWF = 1 / \left[\frac{(1+r)^t - 1}{r(1+r)^t} \right] \quad (3)$$

and $c_{cpt}^{bmg}, c_{cpt}^{wg}, c_{cpt}^{spv}$ are capital cost factor (\$/MVA) for biomass, wind and Solar Photo-voltaic (SPV) DG and $S_n^{bmg}, S_n^{wg}, S_n^{spv}$ are their installed capacities (KVA) respectively. r, t are the interest rate and useful life.

The operating cost of DG is calculated by considering its fuel cost factor and energy generation in the given period. The fuel cost factor of wind and solar PV are zero. Thus, the operating cost of biomass generator is given in (4)

$$C_{op}^{DG} = \sum_{n=1}^{N} c_{fl}^{bmg} E_n^{bmg} \quad (4)$$

where c_{fl}^{bmg} is fuel cost factor (\$/MWh) of biomass DG and $E_n^{bmg}, E_n^{wg}, E_n^{spv}$ is annual energy produced by biomass, wind and SPV DG.

The annual operational and maintenance cost of all the DGs is calculated based on energy generated and associated cost factors. Total operation and maintenance cost is given as (5)

$$C_{o\&m}^{DG} = \sum_{n=1}^{N} c_{o\&m}^{bmg} E_n^{bmg} + c_{o\&m}^{wg} E_n^{wg} + c_{o\&m}^{spv} E_n^{spv} \quad (5)$$

where $c_{o\&m}^{bmg}, c_{o\&m}^{wg}, c_{o\&m}^{spv}$ is Operation and Maintenance (O&M) cost factor (\$/MWh) for biomass, wind and SPV DG.

The cost of energy supplied by grid is calculated depending on total power demand and DG power injection. The total cost of grid energy, including annual energy losses is given in (6)

$$\left.\begin{aligned} C_{en}^{SS} &= c_{en}^{ss} H \sum_{n=1}^{N} (P_{LD} LF - (P_n^{bmg} Cf^{bmg} + P_n^{wg} Cf^{wg} + P_n^{spv} Cf^{spv})) \\ C_{Loss} &= c_{en}^{ss} H \sum_{l \in NBr} I_l^2 R_l LLF \end{aligned}\right\} \quad (6)$$

where LF, LLF, and P_{LD} are Load Factor, Loss Load Factor and peak load respectively. I_l is line current and R_l is the respective line resistance of i^{th} feeder section. H is the annual time of operation in hours. $Cf^{bmg}, Cf^{wg}, Cf^{spv}$ and $P_n^{bmg}, P_n^{wg}, P_n^{spv}$ are capacity factor and power output of biomass, wind and SPV DG respectively.

The penalty for GHG emissions is imposed on part of grid energy generated from fossil fuel and energy generated by biomass DG. The emission cost is represented in two parts as (7)

$$C_{emi} = c_{co2}^{emi} \left(\sum_{n=1}^{N} c_{ef}^{bmg} E_n^{bmg} + \beta c_{ef}^{ss} E_{ss} \right) \quad (7)$$

where c_{co2}^{emi} is the cost factor (\$/ton) for carbon emission and $c_{ef}^{ss}, c_{ef}^{bmg}$ are the emission factor (ton/MWh) for grid energy and biomass energy. β is the fraction of grid energy responsible for harmful emissions.

The DG incentive for equivalent emission offset for major pollutant is described in (8)

$$C_{inc\_emi}^{DG} = \sum_{n=1}^{N} \sum_{i=1}^{p} c_i^{em} e_i (E_n^{Bmg} + E_n^{wg} + E_n^{spv}) \quad (8)$$

where c_i^{emi} is the cost factor (\$/ton) for offsetting i^{th} emission pollutant and e_i is the emission factor of i^{th} pollutant.

DG penetration must adhere to the network operational limits. A penalty is imposed for violating voltage and thermal limits on the bus. Penalty cost of the violation is given as (9)

$$C_{pen} = CV_{pen} + CS_{pen} \quad (9)$$

Where $CV_{pen} = \sum_{i=1}^{N} VP_i$

VP_i represents the penalty for voltage violation and is represented as (10)

$$VP_i = \begin{cases} cv_{pen}(V_{\max} - V_i)^2 & if\ V_i > V_{\max} \\ cv_{pen}(V_i - V_{\min})^2 & if\ V_i < V_{\min} \\ 0 & otherwise \end{cases} \quad (10)$$

where cv_{pen} is voltage penalty factor (in \$/volt). $V_{\min}, V_{\max}$ is minimum and maximum permissible bus voltages.

The penalty imposed for violating thermal limits on any feeder section is given in (11)

$$CS_{pen} = \sum_{ij=1}^{NBr} SP_{ij} \quad (11)$$

Where SP_{ij} represent the penalty for violating thermal limit of *eight* line feeder and is represented as (12)

$$SP_{ij} = \begin{cases} cs_{pen}(S_{ij}^{\max} - S_{ij})^2 & if\ S_{ij} > S_{ij}^{\max} \\ 0 & otherwise \end{cases} \quad (12)$$

where cs_{pen} is line loading penalty factor (in \$/MVA). $S_{ij}, S_{ij}^{\max}$ are power flow in line feeder *ij* and its maximum limit .

B. Network constraints

(I) Power balance: Sum of all incoming and outgoing real and reactive power at each bus must be zero.

$$\left.\begin{array}{l} P_G^j - P_D^j - P_i^j = 0 \\ Q_G^j - Q_D^j - Q_i^j = 0 \\ \text{where } j \in \{1, 2....N\} \end{array}\right\} \quad (13)$$

where P_G^j , P_D^j , P_i^j are real power generated, load demand and injected power at j^{th} bus.

(II) Penetration limit for DG units: The injected power of DG units must be less than the maximum defined penetration limit.

$$\sum_{n=1}^{N} (S_n^{bmg} + S_n^{wg} + S_n^{spv}) \le \alpha S_{LD} \quad (14)$$

where α is a fraction of DG injection with respect to the peak load.

(III) Maximum number of DG units: Total number of DG units installed on candidate buses should not exceed maximum permissible DG units to be installed.

$$0 \le N_{DG} \le N_{DG}^{\max} \quad (15)$$

Where, N_{DG} is a number of DGs placed on load buses.

III. Proposed Algorithm

The DG planning problem is computing the optimal location and the size of respective DG technologies adhering to network and DG constraints. It is complex constrained combinatorial mixed integer non-linear programming problem. Search for the best possible solution is extensive computationally and in terms of search space. Classical techniques based on sensitivity analysis for optimal locations may lead to sub-optimal solution. Therefore, heuristic techniques are widely adopted. Novel improved Harmony Search (IHS) technique is proposed for the above formulated optimization problem to explore the entire search space effectively.

Harmony search is derivative free random search optimization technique, which does not require the initial setting of decision variables [13] [14]. The conventional algorithm may lead to slow convergence and local optimal solution due to static tuning parameters and population variance mismatch during the improvisations [15]. If the variance decreases, conventional harmony search (HS) algorithm leads to premature convergence or trapping in local minima.

Hence, variation operators Parity Adjustment Rate (*PAR*) and bandwidth (*bw*) are adjusted dynamically to obtain balance between exploration and exploitation, and improve the problem solving ability [16] [17]. In the proposed algorithm, Harmony Memory Consideration Rate (HMCR) is also improvised dynamically in every iteration as shown in Fig. 1, which has proved to have a strong search mechanism and improves exploration and exploitation. The flow chart for executing HIS algorithm is shown in Fig. 1.

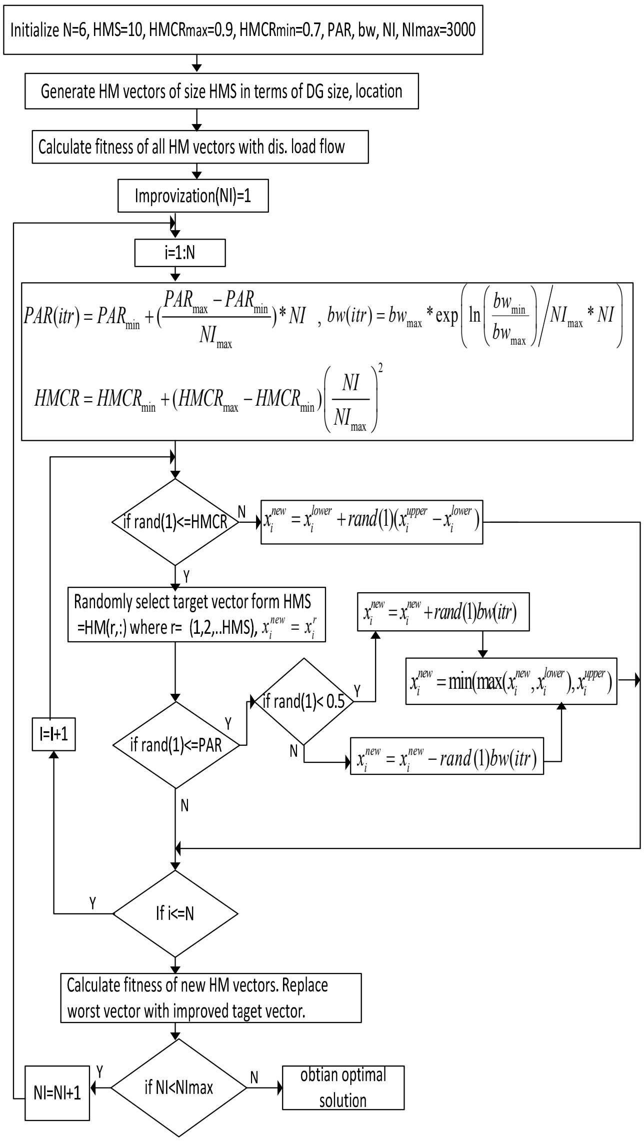

Figure 1. Flowchart of Improved Harmony Search (IHS) Algorithm

Steps to execute this algorithm are as follows.

1) All harmony search parameters e.g. harmony vector (*HM*), number of solution vectors (*HMS*), number of design variables (*N*), *HMCR*, *PAR* and *bw* are defined in step1. Parameter values are represented in Fig.1. Minimum and maximum values for *HMCR*, *PAR*, and *bw* are taken as 0.7 and 0.9, 0.4 and 0.9, 0.001 and 1 respectively. *NI* and *NImax* are current and maximum number of iterations or improvisations.

2) *HMS* harmony vectors for continuous and discrete variables are generated randomly as (16)

$$\left.\begin{aligned} x_i^j &= x_i^{lower} + rand()(x_i^{upper} - x_i^{lower}) \quad where\, i = 1...N,\ j = 1...HMS \\ x_i^j &= round(x_i^{lower} + rand()(x_i^{upper} - x_i^{lower})) \end{aligned}\right\} \quad (16)$$

where x_i^{upper} and x_i^{lower} are upper and lower bounds are design variables. *Rand()* is a function to generate random number between 0 and 1.

3) Evaluate $f(x)$ for each vector in the HM database as shown in (17).

$$HM = \begin{pmatrix} x_1^1 & x_2^1 & \dots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \dots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & & x_{N-1}^{HMS} & x_N^{HMS} \end{pmatrix} \quad (17)$$

4) Perform the improvisation of all the design variables by *HMCR* or *PAR* as shown in Fig.1. Calculate the fitness function of the new improved vector.

5) Replace the worst *HM* with improved harmony vector; if solution is better than the worst harmony vector otherwise proceed for the next improvisation.

6) If the stopping criterion, i.e. number of improvisation (NI_{max}) is satisfied or improvement in solution is less than (10^{-5}) for 100 consecutive iterations, select the best solution vector otherwise go to step 4 and 5.

IV. Simulation, Results And Discussion

The proposed methodology is studied on IEEE 33 bus distribution system with peak load of 3.72 MW and 2.37 MVAr [17]. The parameters used for calculating different costs are obtained from [18][19]. *LF* and *LLF* for the considered load profile [19] is 0.78 and 0.66 respectively calculated from [20].

Three DG types, namely biomass, wind, and solar PV are considered in the proposed formulation. Maximum DG injection cannot exceed the system peak load. Lower and upper permissible voltage levels are set at 0.90 pu and 1.0 pu. DG is considered as negative PQ load.

The parameters used in the simulation are presented in Table I. Equipment lifetime of 25 years and interest rate of 10% is considered. Average annual grid energy cost is $60/kWh with annual carbon price as $20/ton [18]. Biomass and wind DG units are considered to be a synchronous and doubly fed induction generator respectively, and solar DG is inverter based SPV.

The capital cost of SPV DG is highest, therefore, one time incentive as 20% subsidy on the capital cost of SPV DG is considered in proposed formulation.

Emission offset incentive (EOI) is proposed to encourage renewable DGs. EOI can be offered for all pollutants, e.g. carbon, nitrogen and sulfur, only carbon offset is considered in simulated results.

TABLE I. PARAMETERS FOR THE CONSIDERED DGs [18][19]

Cost parameter	Value
Capital cost of biomass DG (type-1)	$2436/kVA
Capital cost of biomass DG (type-2)	$2296/kVA
Capital cost for the wind DG	$1882/kVA
Capital cost of SPV DG	$4004/kVA
O & M cost for biomass DG	$0.012/kWh
O & M cost for the wind and SPV DG	$0.01/kWh
Fuel cost of biomass DG	$0.04/kWh
Emission rate of biomass DG	0.003kg/kWh
Power factor of biomass, wind and SPV DG	0.88,0.8,1.0
Capacity factor of biomass, wind and SPV DG	0.85, 0.3,0.25
Feeder emission factor	0.9kg/kWh

65% of grid energy demand is met from coal-fired plants in Indian context [21]. Therefore, this part of grid energy, responsible for harmful emissions and hence penalized for carbon emissions. Following planning scenarios are considered.

1) Base-case without DG.
2) DG planning with different DG types considered independently and in combination.
3) Mandatory wind or solar or both injections (5% each) with emission offset incentive (EOI).

1) Scenario 1: Base case without DG

Load flow solution of the considered system without DG injection is obtained. Real and reactive power losses are 211 kW and 143 kVAr and power drawn from the grid is 3.92 MW and 2.44 MVAr at peak load. The total annual cost incurred is 1.91 M$. Min. voltage of 0.90 pu is recorded at bus no. 18.

2) Scenario 2: DG planning with different DG types

In this scenario, DNO has no binding on minimum wind and solar injection. Three DG technologies, namely biomass, wind, SPV DGs are considered. Depending on the availability of Distributed Energy Resources (DERs), each DG type is considered independently taking one at a time. Two types of biomass DG technologies are considered. Type-1 DG fired by Landfill gas (LFG) and type-2 fired by bagasse. Optimal solution with each DG technology considered independently is shown in Table II.

TABLE II. OPTIMAL DG LOCATION AND SIZES FORR SCENARIO 2

DG type	Biomass DG Type-1	Biomass DG Type-2	Wind DG
Optimal DG size (MVA)	1.1	1.7	0.5
Bus no	30	30	15
Total annual cost (M$)	1.88	1.86	1.90

Optimal location of biomass DGs are same. However, the optimal DG size of type-1 biomass DG is smaller as compared to type-2 technology due to the high capital cost of former DG. The annualized DG injection cost in terms of installation, fuel, and O&M cost is higher in type-2 biomass due to its higher size as shown in Fig. 2.

This is the reason that emission incentive earned by offsetting equivalent carbon is more by type-2 DG than type-1 biomass DG. As wind DG can provide better reactive power support, optimal location of wind DG differs from biomass DGs. Due to high capital cost, and low capacity factor, SPV DG is not economically viable, in spite of 20% subsidy on investment cost.

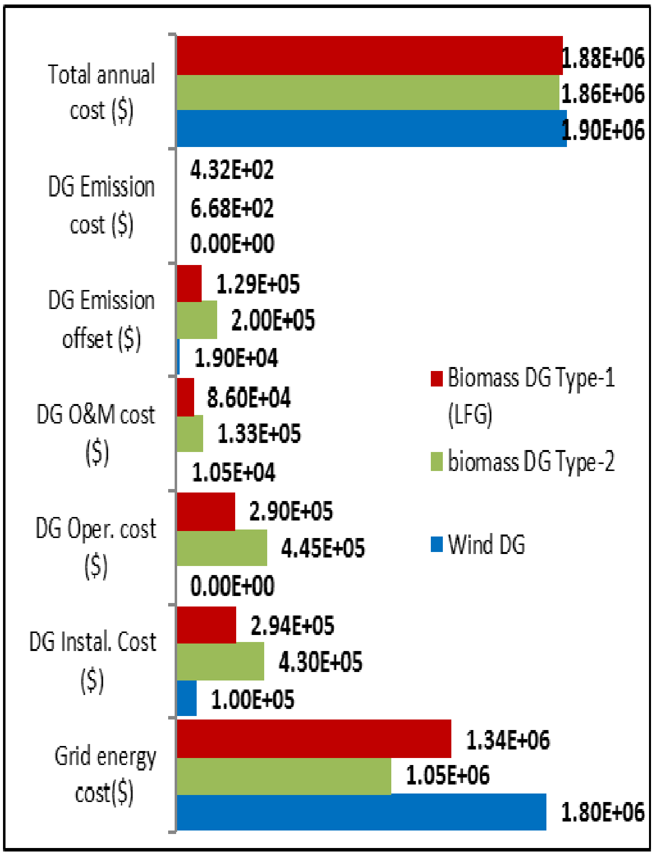

Figure 2. Comparison of cost associated with the optimal allocation of DG.

Grid energy cost reduction with three economically viable technologies in this scenario, i.e. type-1, type-2, and wind DG is 30%, 45% and 6% respectively. An annual cost reduction is 1.2%, 2.3%, and 0.44% respectively for 3 DG technologies. None of the configuration in combination is economically feasible, therefore not shown in Table II. Type-2 biomass DG with a minimal annual cost is the profitable option can be considered by DNO.

Fig. 3 shows the bus voltage profile at peak load with different type of DG selected. Bus number 18 experiences lowest voltage at 0.90 pu. The Bus voltage at bus number 18 is boosted to 0.94 pu with type-2 DG placement. Although each DG contributes to the voltage profile improvement, however, the comparatively flat voltage profile is obtained with type-2 biomass DG. The Voltage profile of the buses near bus number 15 is improved due to wind DG placement, however, tail end buses still experiences a poor voltage.

3) Scenario 3: Mandatory wind and solar injection (5% each) with Emission Offset Incentive (EOI)

Power utility in India must meet its RPO target by means of its own generation or power procurement from eligible renewable energy developers [21-23]. National policy in 12th five-year plan targets for 15% energy from renewables by 2020. This scenario shows the planning scheme with the obligation of minimum wind or solar or both injections on DNO. DG planning results with mandatory wind and solar injection (5% each) considering EOI is presented in Table III.

It is concluded that the highest cost is incurred with wind and solar DG due to the high capital cost of SPV DG and low capacity factor of 0.3 and 0.25 respectively.

TABLE III: OPTIMAL DG LOCATION AND SIZES FOR SCENARIO 3

DG type	Biomass & Wind DG	Wind & SPV DG	Biomass & SPV DG	Biomass, Wind &SPV DG
DG Size (MVA)	1.5,0.3	0.5,0.2	1.6,0.2	1.5,0.3,0.2
Bus no	30,17	32,17	30,17	30,14,17
Annual cost (M$)	1.86	1.92	1.8917	1.8949

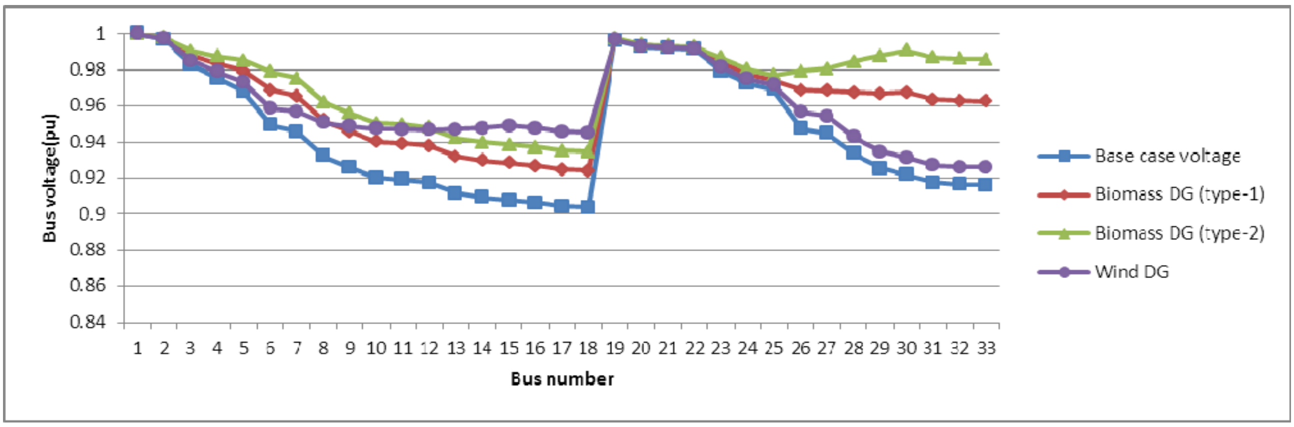

Figure 3 Comparison of voltage profiles without and with eacg DG type

The annual cost is more with the wind and the SPV DG combination even in comparison to without DG scenario. DNO has to bear the additional burden of 0.02 M$ annually in comparison to without DG case to meet its RPO target. However, when SPV or wind DG is planned with biomass DG, it becomes a profitable option for DNO as evident from Table III. If the capacity factor of wind DG is increased from 0.30 to 0.35, 3 DG combination becomes equally viable economically as biomass and wind combination.

Although the minimum wind injection requirement as per RPO target is 5% of peak load, however the optimal size of wind DG is higher than this. When only wind DG is considered, 0.5 MVA wind injection is optimal thereby saving 6% grid energy cost and 0.44% annual cost with respect to base case investment.

The annual cost is minimum with biomass and wind DG combination. This is due to higher capacity factors and lower capital cost of biomass DG and reactive power support by wind DG.

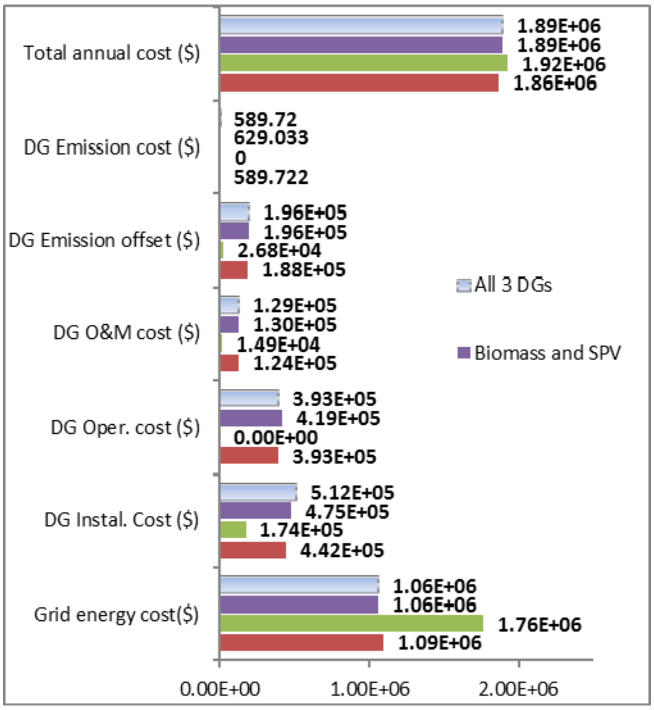

Figure 4. Cost comparison with optimal allocation of DGs for scenario 3.

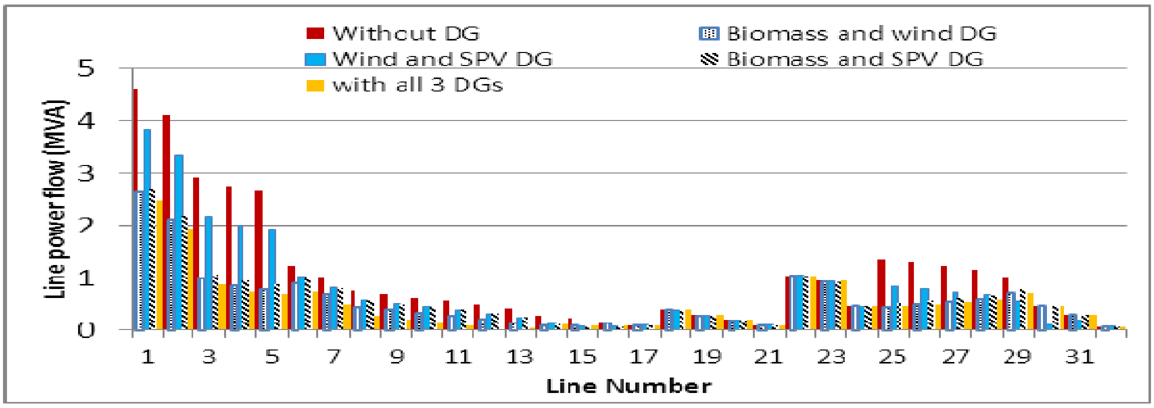

Figure 5 Line power flows without and with DGs for Scenario 3

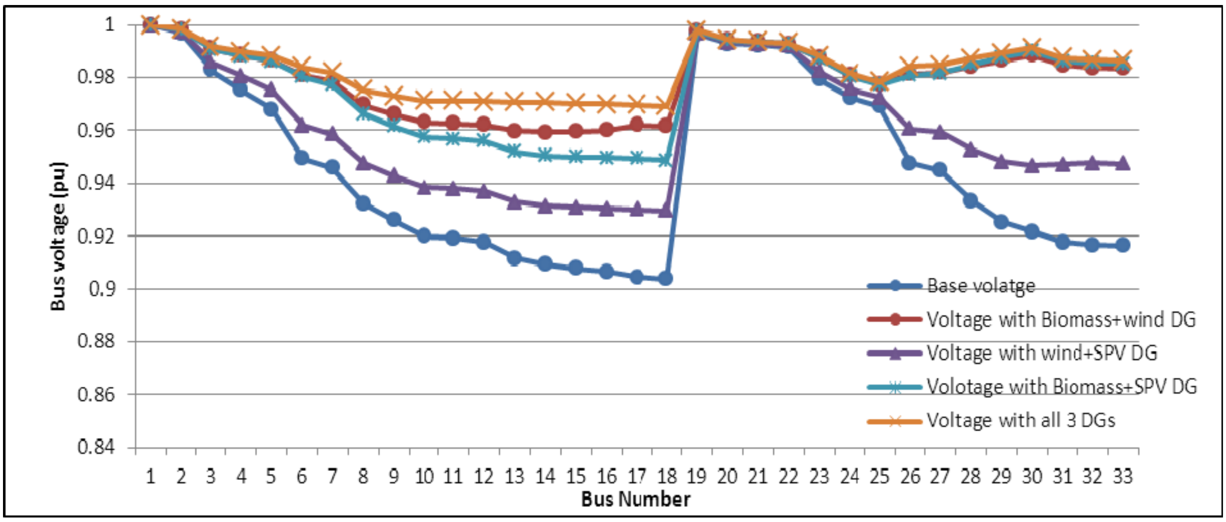

Figure 6. Voltage profile for all DG combinations for Scenario-3

When all the three technologies are considered simultaneously, highest capital cost results in higher annual cost in-spite of the lowest grid energy requirement as evident in Fig. 4. Emission offset incentive earned is same for 3 DG combination and 2 DG (biomass and SPV DG) combination. Minimum solar injection is viable in this scenario in comparison to scenario 2. Biomass and wind DG is the most promising option in this scenario. Fig. 5 shows the line power flow in each branch for scenario 3, with and without DGs. Power flow through lines are reduced depending on the optimal location, size, and DG technology.

DG planning results in line power reduction, thereby reducing the line stress, and improving the network life. Power flow reduction is maximum with 3DG combination due to the more dispersed generation followed by biomass and wind DG combination.

Fig. 6 shows the voltage profile at each bus for scenario 3, with and without DGs. Voltage-profile of biomass and wind, DG is close to 3 DG combination. Although the size of DG for biomass and wind DG is same as biomass and SPV DG, former combination has a better voltage profile as compared to the latter due to the better reactive power support.

V. Conclusion

An evolutionary approach for renewable DG planning is presented. Optimal solution in terms of optimal size, location, and DG types to balance the economic and environment criteria is obtained. The appropriate renewable DG combination can be selected based on the incentive schemes and planner's objective, such as energy loss or grid energy minimization, emission offset or incentive maximization. Planning schemes discussed is a step to encourage eco-friendly energy planning over conventional resource planning, by awarding incentive in terms of emission offset, and penalizing grid energy for GHG emission.

An improved harmony search algorithm is adopted to harness both exploration and exploitation during the search process. The key advantage of the proposed algorithm is that the adopted meta-heuristic search algorithm is made robust by dynamic tuning of control parameters. Control parameters *HMCR*, *PAR* and *bw* are tuned iteratively to maintain the balance between explorative and exploitative potential.

Findings suggest that low carbon planning can be made viable by selecting appropriate DG technology of optimal size and location. The algorithm may also be helpful for energy planners to decide the incentive mechanism depending on the technology decided to maintain the financial and environmental balance.

Acknowledgment

The authors would like to thank the AICTE's Quality Improvement Programme (QIP) and the Board of Governor's of PEC University of Technology, Chandigarh (India) which made this work possible.

References

[1] A. Keane, L.F. Ochoa, C. Borges, G. Ault, A. Alarcon, R. Currie, F. Pilo, C. Dent, G.P. Harrison, "State of the art techniques and challenges ahead for DG planning and optimization," IEEE Transactions on Power Systems, vol. 28, no. 2, pp. 1493-1502, May 2013. [online]. Available: http://dx.doi.org/10.1109/TPWRS.2012.2214406

[2] P.S. Georgilakis, N.D. Hatziargyriou, "Optimal distributed generation placement in power distribution Network: Models, methods and future", IEEE Transactions on Power Systems, vol. 28, no. 3, pp. 3420-3428, 2013. [online]. Available: http://dx.doi.org/10.1109/TPWRS.2012.2237043

[3] W. El-Khattam, K. Bhattacharya, Y. Hegazy, M. M. A. Salama, "Optimal investment planning for distributed generation in a competitive electricity market," IEEE Transactions on Power Systems, vol. 19, no. 3, pp. 1674–1684, 2004. [online]. Available: http://dx.doi.org/10.1109/TPWRS.2004.831699

[4] A. Zangeneh, S. Jadid, A. R. Kian, "Promotion strategy of clean technologies in distributed generation expansion planning," Renewable Energy, vol. 34, no. 12, pp. 2765–2773, 2009. [online]. Available: http://dx.doi.org/10.1016/j.renene.2009.06.018

[5] W.S. Tan, M.Y. Hassan, H.A. Rahman, M.P. Abdullah, F. Hussin, "Multi-distributed generation planning using hybrid partical swarm optimization - gravitational search algorithm inclusing voltage rise issue," Generation, Transmission & Distribution, IET, vol. 7, no. 9, pp. 929-942, 2013. [online]. Available: http://dx.doi.org/10.1049/iet-gtd.2013.0050

[6] T. Niknam, S. I. Taheri, J. Agahei, S. Tabatabaei, M. Nayeripour, "A modified mating optimization algorithm for multiobjective placement of renewable energy resources," Applied Energy, vol. 88, no. 12, pp. 4817–4830, 2011. [online]. Available: http://dx.doi.org/10.1016/j.apenergy.2011.06.023

[7] M. A. Abdullah, A. P. Agalgaonkar, K. M. Muttaqi, "Quantification of emission reduction from electicity network with the integration of renewable resources," in *Proc. IEEE Power and Energy Society General Meeting*, 2011 , pp. 1-7. [online]. Available: http://dx.doi.org/10.1109/PES.2011.6039512

[8] A. Soroudi, M. Eshan, H. Zareipour, "A practical eco-environmental distribution network planning model including fuel cells and non-renewable distributed energy sources," Renewable Energy, vol. 36, no. 1, pp. 179–188, 2011. [online]. Available: http://dx.doi.org/10.1016/j.renene.2010.06.019

[9] R. Ebrahimi, M. Eshan, H. Nouri, "A profit-centric strategy for distributed generation planning considering time varying voltage dependent load demand," International Journal of Electrical Power & Energy Systems, vol. 44, no. 1, pp. 168–178, 2013. [online]. Available: http://dx.doi.org/10.1016/j.ijepes.2012.07.039

[10] G. P. Harrison, A. Piccolo, P. Siano, A. R. Wallace, "Hybrid GA and OPF evaluation of network capacity for distributed generation connections," Electric Power System Research., vol. 78, no. 3, pp. 392–398, 2008. [online]. Available: http://dx.doi.org/10.1016/j.epsr.2007.03.008

[11] Y.M. Atwa, E.F.E. Saadany, M.M.A. Salama, R. Seethapathi, "Optimal renewable resources mix for distribution system energy loss minimization," IEEE Transactions on Power Systems, vol. 25, no. 1, pp. 360-370, 2010. [online]. Available: http://dx.doi.org/10.1109/TPWRS.2009.2030276

[12] P. Siano, L.F. Ochoa, G.P. Harrison, A. Piccolo, "Assessing the strategic benefits of distributed generation ownership for DNOs," Generation, Transmission & Distribution, IET, vol. 3, no. 3, pp. 225-236, March 2009.[online]. Available: http://dx.doi.org/10.1049/iet-gtd:20080235

[13] Z. W. Geem, J. H. Kim, G. V. Loganathan, "A New Heuristic Optimization Algorithm: Harmony Search," SIMULATION, vol. 76, no. 2, pp. 60–68, 2001. [online]. Available: http://dx.doi.org/10.1177/003754970107600201

[14] K. S. Lee, Z. W. Geem, S. Lee, K. Bae, "The harmony search heuristic algorithm for discrete structural optimization," Engineering Optimization, vol. 37, no. 7, pp. 663–684, 2005. [online]. Available: http://dx.doi.org/10.1080/03052150500211895

[15] S. Das, A. Mukhopadhyay, A. Roy, A. Abraham, B. K. Panigrahi, "Exploratory Power of the Harmony Search Algorithm: Analysis and Improvements for Global Numerical Optimization," IEEE Transactions on System Man and Cybernetics, Part B: Cybernetics, vol. 41, no. 1, pp. 89–106, 2011. [online]. Available: http://dx.doi.org/10.1109/TSMCB.2010.2046035

[16] M. Mahdavi, M. Fesanghary, E. Damangir, "An improved harmony search algorithm for solving optimization problems," Applied Mathematics and Computation, vol. 188, no. 2, pp. 1567–1579, 2007. [online]. Available: http://dx.doi.org/10.1016/j.amc.2006.11.033

[17] K. Nekooei, M. M. Farsangi, H. Nezamabadi-Pour, K. Y. Lee, "An Improved Multi-Objective Harmony Search for Optimal Placement of DGs in Distribution Systems," IEEE Transactions on Smart Grid, vol. 4, no. 1, pp. 557–567, 2013. [online]. Available: http://dx.doi.org/10.1109/TSG.2012.2237420

[18] K. Zou, A. P. Agalgaonkar, K. M. Muttaqi, S. Perera, "Distribution System Planning With Incorporating DG Reactive Capability and System Uncertainties," IEEE Transactions on Sustainable Energy,

vol. 3, no. 1, pp. 112–123, 2012. [online]. Available: http://dx.doi.org/10.1109/TSTE.2011.2166281

[19] N. Jain, S. N. Singh, S. C. Srivastava, “A Generalized Approach for DG Planning and Viability Analysis Under Market Scenario,” IEEE Transactions on Industrial Electronics, vol. 60, pp. 5075–5085, 2013. [online]. Available: http://dx.doi.org/10.1109/TIE.2012.2219840

[20] D. Olivera, P. Feltrin, “Investigation of the relationship between load and load factors for a Brazillian electric utility,” in *Proc. Electric utility Transmission and distribution conference and exposition*, Latin America, 2006, pp. 1-6 [online]. Available: http://dx.doi.org/10.1109/TDCLA2006.311390.

[21] N. Jain, S.N. Singh, S.C. Srivastava, "Planning and impact evaluation of distributed generators in Indian context using Multi-Objective Particle Swarm Optimization," in *Proc. IEEE Power and Energy Society General Meeting*, 2011, pp. 1-8. [online]. Available: http://dx.doi.org/ 10.1109/PES.2011.6039202.

[22] L.R.A. Deepa, N. Praveen, "Impact of Climate change and adaptation to green technology in India," in *Proc. Recent Advances in Space Technology Services and Climate Change (RSTSCC)*, 2010, pp. 460-465. [online]. Available: http://dx.doi.org/ 10.1109/RSTSCC.2010.5712889.

[23] A.M. Jain, B.E. Kushare, "Techno-economics of solar wind hybrid system in Indian context: A case study," in *Proc IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES 2007),* 2007, pp. 39-44.