ISSN (Print) : 2320 – 3765
ISSN (Online) : 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

Multi Objective Optimization for Distributed Generation Allocation in Distribution Systems

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ABSTRACT: Due to the rapid increase of electricity consumption, operations of conventional power systems have several disadvantages, e.g. considerable amount of transmission loss; transmission line congestion; increasing environmental impact, etc. These problems can be solved via installing Distributed Generation (DG) in distribution systems. For realizing technical and economical advantages for the distribution systems, proper allocation and type of these units have been investigated.

The aim of this paper is to propose an algorithm for solving DG allocation problem in distribution systems taking into consideration technical and economic aspects. To realize this objective, the revised non-dominated sorting genetic algorithm (NSGA-II) has been utilized. The proposed algorithm has been applied on IEEE 69- bus system. The results show good agreement with the previous given in literature results of that standard distribution system.

KEYWORDS: Distributed Generation, NSGA-II, Multi objective Optimization, Cost, Losses, Voltage Deviations.

I. INTRODUCTION

Electricity demand is growing in faster rate compared to the other forms of energy because it can be generated efficiently, transmitted easily and utilized ultimately at a very reasonable cost. The electrical energy is generated in bulk at a centralized place, called Generating Station and is transmitted over a long distance (Transmission System) to Distribution System, and finally is used ultimately by a large number of users. During all these processes, several technical and non-technical problems such as amount of transmission loss, transmission line congestion, increasing environmental impact etc., arise. These problems can be solved/minimized by the installation of Distributed Generation (DG) [1]. A number of studies were conducted to investigate the criteria, e.g. power loss reduction, improve system voltage profile, and increase system reliability, for optimal sizing and sitting of DGs units. Different techniques, such as particle swarm, genetic algorithm, and differential evolution, have been adopted to solve the problem of DG allocation in Distribution Systems [2] - [7]. These techniques have been applied on standard test systems, such as 33-bus and 69 bus systems, etc. Table -1 summarizes the literature results of IEEE-69 Test system including the related objectives and the used optimization technique.

In this Paper, an analysis has been done for obtaining maximum benefits in terms of optimum cost and loss for different types of distributed generation units with the help of modified non-domination based genetic algorithm (NSGA-II). The main contributions of this Paper are using multi objective function to formulate DG allocation problem in Distribution System and considering economical aspects. Different technologies of DG applications can be presented in the developed model. The objectives are the minimization of the capital and operation cost of DG units; minimization of system peak loss; and minimization of voltage deviations with respect to nominal bus voltage. The proposed methodology can determine the optimal compromise solution according to the considered objectives. The proposed algorithm has been applied on IEEE 69- bus system. Comparative results with that given in literature studies of 69 standard distribution system are discussed.

DOI: 10.15662/IJAREEIE.2015.0409071

Table -1: Literature Survey of IEEE-69 Test System

Research	DG Number	Size		Location	Objective	Technique
		MW	MVAR			
Distribution System planning with incorporation the renewable energy resources[7]	1	0.93	-	65	Voltage Support	Newton Raphson
	1	1.035	-	64	Voltage Support	Forward - Backward
	1	0.99	-	64	Global Solution	Global Solution
	1	0.852	-	65	Power Loss Minimization	Newton Raphson
	1	0.957	-	64	Voltage Support	Forward - Backward
	1	0.9	-	64	Global Solution	Global Solution
Optimal Placement of Distributed Generations in Radial Distribution Systems Using Various Particle Swarm Optimization (PSO) and Differential Evolution (DE) Algorithms [3]	1	0.603	-	17	M.O (Loss Reduction and voltage improvement)	PSO
	1	0.542	-	33	M.O (Loss Reduction and voltage improvement)	PSO
	1	0.7	-	60	M.O (Loss Reduction and voltage improvement)	PSO
	1	0.577	-	34	M.O (Loss Reduction and voltage improvement)	PSO
Optimal Design of Multi type DG Resources Using Particle Swarm Optimization [4]	1	0.25	0.25	64	Minimize Power Losses	PSO
Optimal Sizing And Location Of Distributed Generation Using Improved Teaching-Learning Based Optimization(TLBO) Algorithm [5]	3	0.52 0.478 1.83	- - -	8 1 62	Minimize Power Losses	TLBO
	3	0.613 0.54 1.42	- - -	9 18 62	Minimize Power Losses	TLBO

II. METHODOLOGY

The formulation of DG location and sizing problem as a mono-objective optimization is not quite practical. Power system planners aim to take advantage of multi-type DG considering several objectives at the same time. This study proposes a multi-objective optimal placement of multi-type of DG for enhancement of primary distribution system performance. A Pareto-based NSGA-II is proposed to find locations and sizes of a specified number of DG within distribution system. Multi objective functions include levelized voltage deviation LVD, minimize system real power loss and total investment cost. The final decision can be made by the fuzzy method to find the trade off solutions among the three different objective functions.

Objective Function

DG planning problem formulation:

The multi-objective optimization technique to determine the optimal locations and sizes of DG units within primary distribution system is as follows:

$$\text{Min } f(x, u) = [f_1(x, u), f_2\ (x, u), f_3\ (x, u)] \qquad (1)$$

Where, f_1, f_2 and f_3 are the system real power loss , annualized investment cost, and load voltage deviation, respectively.

The first objective is to **minimize the system real power loss**

$$\text{Min } f_1\ (\text{x, u}) = P_l \qquad (2)$$

Minimize the annualized Investment Cost:

$$\text{Min } f_2\ (\text{x ,u}) = \sum_{i=1}^{NDG} \frac{\mathrm{r}*(1+\mathrm{r})^{\mathrm{n}}}{(1+\mathrm{r})^{\mathrm{n}}-1} * (\mathrm{C}_{\mathrm{Cap.}} + (\mathrm{h} * \mathrm{C}_{\mathrm{variable}} + \mathrm{C}_{\mathrm{Fixed}}) * \mathrm{n}) * \mathrm{P}_{\mathrm{DG}} \qquad (3)$$

Where, ‘r’ is the interest rate, ‘n’ study period to be 5 years, $\mathrm{C}_{\mathrm{Cap.}}$& $\mathrm{C}_{\mathrm{variable}}$&$\mathrm{C}_{\mathrm{Fixed}}$ ($/KW) are the capital and variable operation and maintenance costs ($/KWH) and fixed operation and maintenance costs ($/KW-year) respectively, h is number of operation hour per year and P_{DG} (KW) is the DG active Power.

Minimize the bus voltage deviation:

$$\text{Min } f_3(\text{x , u}) = \sum_{k=1}^{nB} \left(\frac{\mathrm{V}_{\mathrm{k}}^{ref} - \mathrm{V}_{\mathrm{K}}}{\mathrm{V}_{\mathrm{k}}^{ref}} \right)^2 \qquad (4)$$

nB is the number of system buses (exclude main feeding bus)

Constraints:

$$V_{min} \leq V_i \leq V_{max} \qquad (5)$$

$$S_{min} \leq S_i \leq S_{max} \qquad (6)$$

S is the transmission capacity of branch i

NSGA-II Algorithm

Non-dominated Sorting Genetic Algorithm (NSGA) has established itself as a benchmark algorithm for Multi objective Optimization. The determination of pareto-optimal solutions is the key to its success. However, the basic algorithm suffers from a high order of complexity, which renders its useful for practical applications. Among the variants of NSGA, several attempts have been made to reduce the complexity. Though successful in reducing the runtime complexity, there is scope for further improvements, especially considering that the populations involved are frequently of large size. The improved algorithm NSGA-II is applied to the problem. Results of comparative tests are presented showing that the improved algorithm performs well on large populations [8]-[10].

Load Flow Analysis

Distribution systems are mainly radial system. Therefore, the traditional Newton-Raphson or Gauss Siedle method may not converge, and special load flow method must be used, such as forward-backward sweep method [11]. Simply, the forward sweep (FW) starts the calculation from the root to final bus in the system. The backward sweep (BW) is the opposite which starts calculation from the last order bus to the root bus. In the following, the standard BW/FW sweep power flow method is written in metrical notation using complex variables. Branch impedances are given as a vector Z corresponding to distribution line model containing a series positive sequence impedance for line or transformer. Shunt impedances are not considered in this approach. Branches are organized according to an appropriate numbering scheme (list), which details are provided in [11].

$$Z = [Z01 \ldots Zij \ldots ZmnB]$$

where,

$$Zij = Rij + jXij \qquad (7)(8)$$

A. Step 1 - Backward Sweep

For each iteration k, branch currents are aggregated from loads to origin:

$$J^k = -T \cdot I^k \tag{9}$$

The relationship between nodal currents Ik and branch currents Jk is set through an upper triangular matrix T accomplishing the Kirchhoff Current Laws (KCL). Each element Ii^k of I^k associated to node i, is calculated as function of injected powers Si and its voltage profile V^k as shown below

$$Ii^k = Si^*/Vi^{k*} \qquad i = 1, ..., nB \tag{10}$$

B. Step 2 - Forward Sweep

Nodal voltage vector V is updated according to the Kirchhoff Voltage Laws (KVL), using previously calculated branch currents vector J, branch impedances vector Z, and TT is the Transpose of matrix T.

$$V^{k+1} = V0 - TT \cdot DZ \cdot J^k \tag{11}$$

Where, V0 is nB elements vector with all entries set at voltage at origin (swing node), and the branch impedances DZ is the diagonal matrix of vector Z.

$$V^{k+1} = V0 + TT \cdot DZ \cdot T \cdot I^k \tag{12}$$

$$V^{k+1} = V0 + TRX \cdot I^k \tag{13}$$

$$\text{where, } TRX = TT \cdot DZ \cdot T \tag{14}$$

C. Convergence

Updated voltages are compared with previous voltages in order to perform the convergence check

$$\varepsilon \geq |Vi^{k+1} - Vi^k| \qquad i = 1, ..., nB \tag{15}$$

Fuzzy Decision Making

Fuzzy ranking method is employed to extract the best compromise solution out of the available non-dominated solutions depending upon its highest rank. In real applications, due to imprecision of judgments by decision makers a fuzzy membership function adopted to provide the best compromise solution out of the pareto-optimal solutions which satisfies different goals to some extent.

The membership value (μ) ‘0’ indicates incompatibility with the sets, while ‘1’ means full compatibility. In other words, the membership value indicates the degree of satisfaction of the solution for an objective. μ (Fi) is a strictly monotonic decreasing function [12].

III. DEVELOPED ALGORITHM

Step 1: Read Power System Data.
Step 2: Enter the cost optimization function constants that illustrated later in Table - 2.
Step 3: Start NSGA-II with the initial population.
Step 5: Start Backward/Forward Sweep to calculate the load flow from equations (9) and (10).
Step 6: Calculate objective function values.
Step 7: Creating New population, crowding sort, creating offspring population.
Step 8: Perform tournament selection, crossover and mutation.
Step 9: Perform the non dominated sorting algorithm to find the optimal solutions for the design variables (Size and Location) .
Step 10: Select the best compromise solution in the output result.
Step 11: Rerun the system Power flow to calculate the power losses, voltage profile and voltage deviation and calculate the solution overall cost.
Step 12: Repeat the previous steps for the various types of distributed generation unit.

IV. APPLICATIONS

General Assumptions

Study Period is 5 Years. Loads are constant PQ loads with constant power factor and constant during study period. DG power factor is unity. All DG resources can install at every bus within system (except at the slack bus). Interest rate is 10 %. For Wind and Solar DGs, there are main factors which affect the placement of DG for example the value of the average wind speed for the wind DG and the solar irradiation value for the solar DG. These factors did not consider in this paper, i.e. all buses are suitable for DG location irrespective of each type. DG placement of different types do not allow at the same bus. Multiple DG placement of the same type is allowed at the same bus. Cost function constants of equation (3) are given in Table 1[13]. The revenue from power loss saving is not taken into account in this work. The approach is minimizing the system peak real power loss (f_1), annualized investment cost (f_2) and LVD (f_3). NSGA-II Parameters are as follows [10]:

Objective functions (M): 3
Population size: 600
Iteration: 200

The study is applied on the IEEE 69 Bus system. The parameters, namely C_1 , C_2 and C_3 in equation (3) take the values given in Table -2 [13] according to the type of DG. Then, after the optimization process ended, selected solutions are studied beside the compromise solution.

Table -2: Constant parameters of the studied cases

	(C1) $/KW	(C2) $/KWH	(C3) $/KWH-YEAR	(n)
Biomass	3830	15	95	5
Micro turbine	2250	3.67	6.31	5
Solar	3180	0	48	5
Wind	1980	0	60	5
Hydrothermal	3500	6	15	5
CHP	1647	16	6.5	5
Fuel Cell	2334	35	6.5	5

V. RESULTS AND DISCUSSION

In this paper, modified NSGA-II technique is utilized to solve the DG optimization allocation problem and find the optimal size and Location according to the type of DG unit and the developed algorithm. Seven Different types are studied in this paper, namely, Biomass, Micro Turbine, Solar, Wind, Hydro, Combined Heat and Power CHP, and Fuel Cell. Single DG Solution has been studied as well as the Multi DG Solutions.

Table -3 shows the Single DG Studied solutions brief. Highlighted solution refers to the matching results with the literature survey in Sec. I.

Table -3: Single DG Studied Solutions Brief

Technology	P loss (KW)	DG Size (KW)	Location	Loss Reduction	Voltage Deviation	min Voltage p.u.	Total Cost M$
Biomass	173	459	58	23%	7%	0.9247	2.3
Biomass	198	723	67	12%	7%	0.915	3.6
MicroTurbine	215	138	25	4%	8%	0.9111	0.3
MicroTurbine	141	633	64	37%	8%	0.9133	1.5
Solar	199	534	19	11%	6%	0.9138	1.8
Solar	199	920	23	11%	5%	0.9164	3.1
Wind	129	764	64	43%	5%	0.9442	1.7
Wind	198	725	66	12%	7%	0.915	1.7
Hydro	202	430	26	10%	7%	0.9135	1.7
Hydro	164	408	64	27%	6%	0.9301	1.6
Hydro	194	493	10	14%	7%	0.9159	1.9
CHP	196	815	20	13%	6%	0.9157	1.9
Fuel cell	201	499	11	10%	8%	0.9141	1.9

Fig. 1 illustrates the DG size (KW); the corresponding Ploss (KW) and the total cost (M$). The presentation is according to the cost in ascending manner.

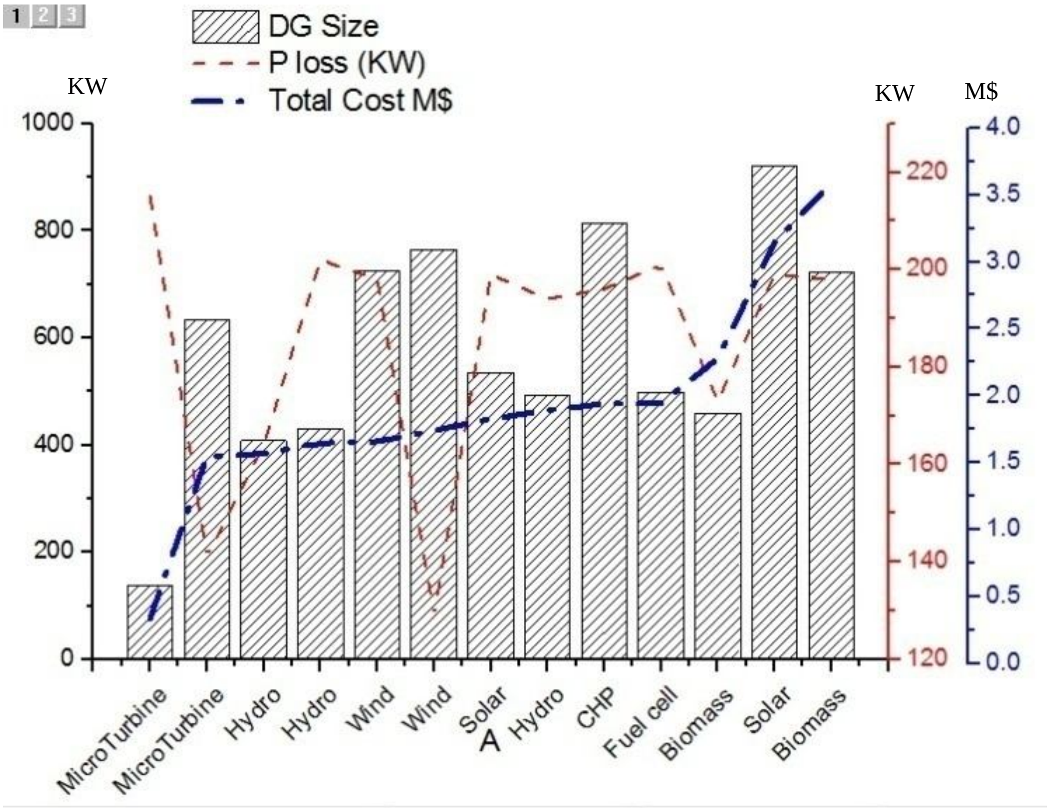

Fig. 1: Single DG Size Studied Cases (Cost Ascending) Summary

Fig. 2 depicts the DG size (KW) and the corresponding min voltage (p.u.); percentage Loss reduction and percentage voltage deviation.

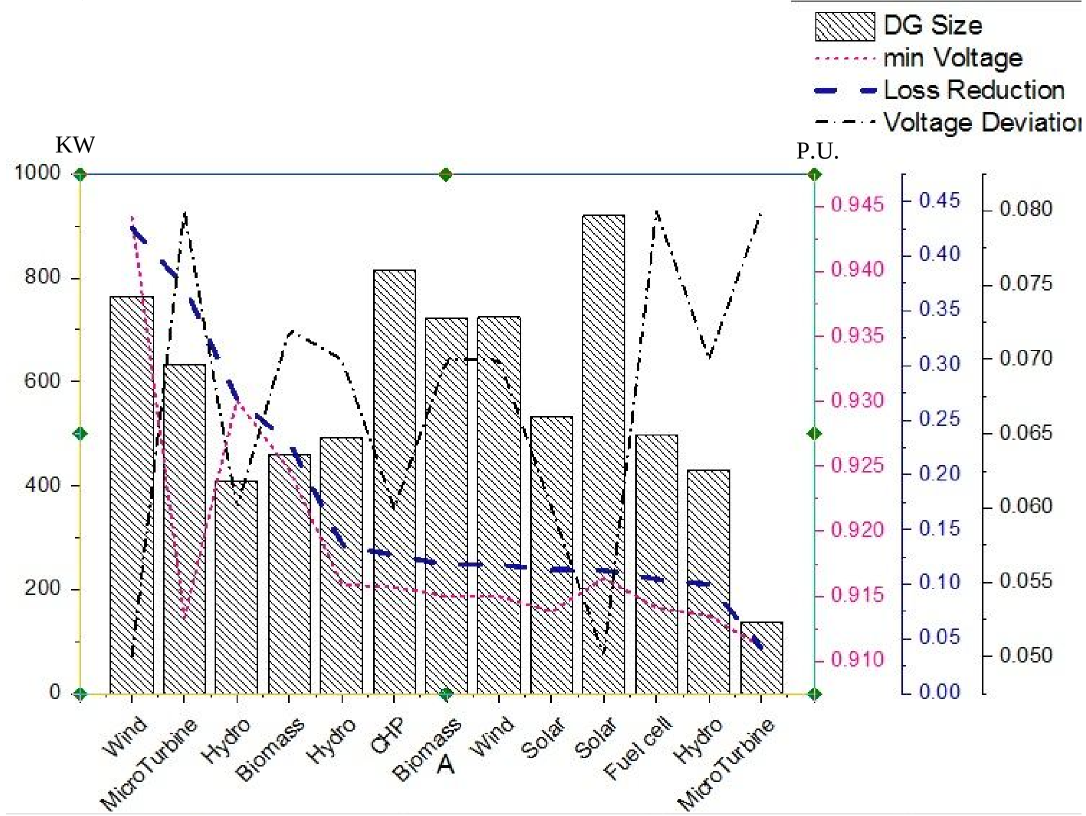

Fig 2: Single DG Size Studied Cases (Losses Reduction Descending) Summary

Table -4 shows the Multi DG Studied Solutions brief. For Multi DG Solution, the Total cost during the study period (5 Years) is varied from 0.4 to 6.3 M$, while the Loss reduction is ranged from 2% to 48%. Voltage Deviation according to eq. (4) is changed from 4% to 9% compared to 9% in the original case. The min voltage is ranged from 0.9107 to 0.95 p.u. compared to 0.9102 p.u. in the original case. Highlighted solution refers to the matching results with the literature survey in Sec. I.

Table -4: Multi DG Studied Solutions Brief

Technology	P loss (KW)	DG Size KW	Location	Loss Reduction	Voltage Deviation	min Voltage	Total Cost M$
Biomass	187	923 349	14 67	17%	5%	0.9187	6.3
Micro Turbine	215	65 89	14 15	4%	8%	0.9113	0.4
Solar	210	880 230	4 21	6%	8%	0.9118	3.8
Wind	191	760 209	10 66	15%	7%	0.9167	2.2
CHP	196	90.4 910	3 19	13%	6%	0.9163	2.4
Fuel cell	122	25 913	26 65	46%	4%	0.95	3.7
Biomass	213	74 95 95	8 9 14	5%	8%	0.9119	1.3
MicroTurbine	219	66 72 64	24 32 46	2%	9%	0.9107	0.5
Solar	157	534 73 78	19 22 40	30%	6%	0.9143	2.3
Wind	220	68 96 23	32 40 62	2%	9%	0.9112	0.4
Hydro	207	87 83 51 61	19 25 52 55	8%	8%	0.9128	1.1
CHP	208	10.7 249.2 42.2	40 56 66	7%	9%	0.9139	0.7
CHP	209	273 358 40	25 31 33	7%	8%	0.9121	1.6
Fuel cell	117	26 841 619	27 55 63	48%	4%	0.946	5.8

Fig. 3 illustrates the DG size (KW) and the corresponding Ploss (KW) , min voltage (P.U.) and the total cost (M$). The presentation depicts the cost values in ascending manner. Fig. 4 depicts all DG studied solutions. It illustrates the DG size (KW) and the corresponding Ploss (KW), min voltage (P.U.) and the total cost (M$). The drawing shows the Ploss values in ascending order.

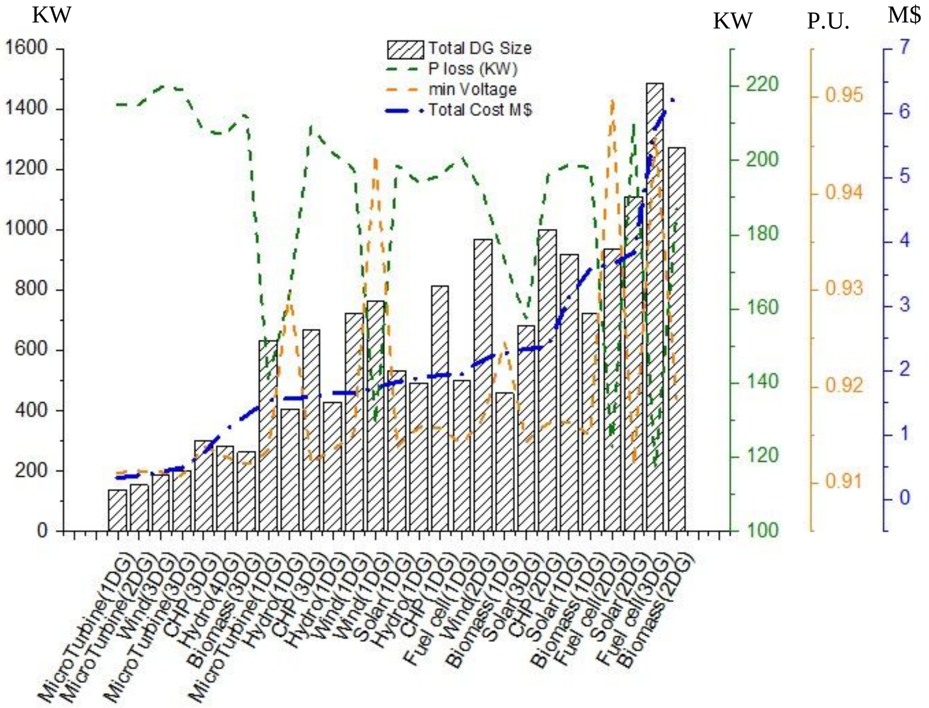

Fig. 3: All Studied Cases Cost Ascending Summary

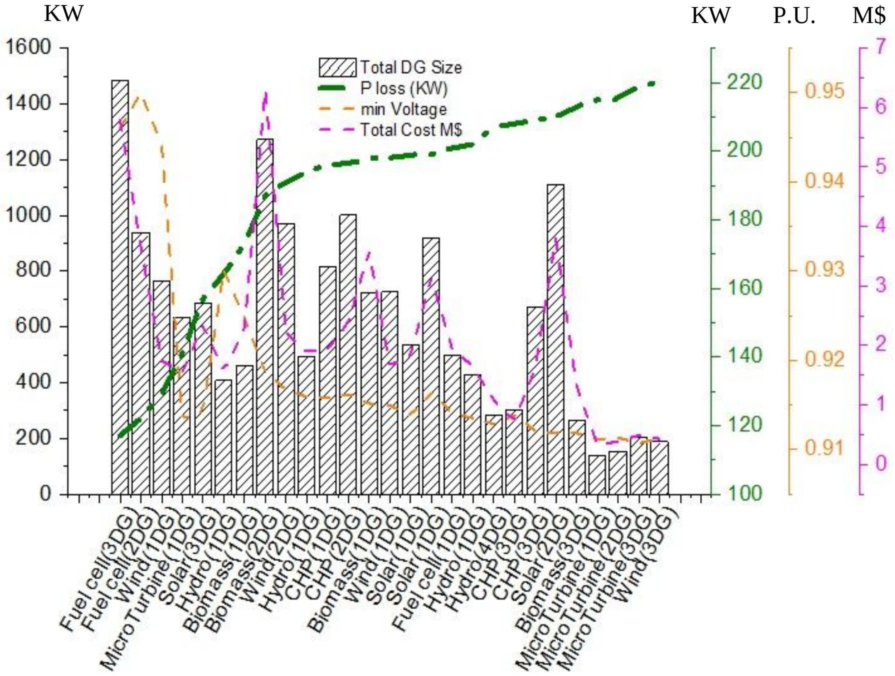

Fig. 4: All Studied Cases (Ploss Ascending) Summary

Compromising Solutions using Fuzzy ranking Method

By applying Fuzzy compromise concept, the compromise solutions are summarized in table -5

Table -5: Compromise Solutions Brief

	DG Size (KW)	Location Bus No.	DG Total (KW)	µ Compromise	Ploss (KW)	Voltage Deviation	Cost (M$)
Biomass	386	60	386	0.0999	173.73	7.30%	1.915332
Micro Turbine	64 820	44 64	884	0.0585	125.18	4.80%	2.15899
Solar	534 73 78 47	19 22 40 52	732	0.0577	193	6.40%	2.50344
Wind	75 250	15 61	325	0.108	185	7.90%	0.741
Hydro	84 816 51	6 58 65	951	0.0671	140.427	5.50%	3.649748
CHP	70.7 249.5 42.2	40 56 66	362.4	0.0683	208	8.70%	0.862621
Fuel Cell	52 471	23 50	523	0.0984	220	9.80%	2.039439

Following are the indicative drawings and summary of the compromise solutions. Fig. 5 shows the system voltage profile for different technologies. Micro turbine solution shows great enhancement in the voltage profile (min value).

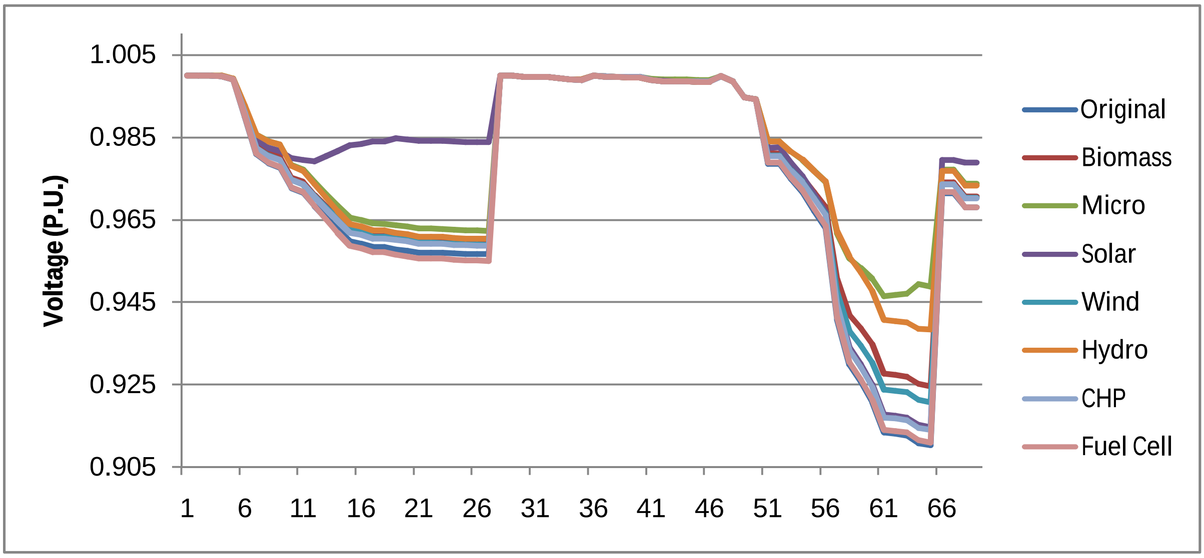

Fig. 5: Voltage Profile Summary of all compromise solutions

DOI: 10.15662/IJAREEIE.2015.0409071

From Table -5 the DG size is ranged from 325 to 951 KW. All cases show good loss reduction except the Fuel Cell solution. The voltage deviation is varied form 4.8% to 9.8%; the total cost is changed from 0.7 to 3.6 M$. Fig. 6 summarizes DG compromise solutions. It illustrates the DG size (KW) and the corresponding Ploss (KW), min voltage (p.u.) and the total cost (M$). The Ploss is illustrated in ascending manner.

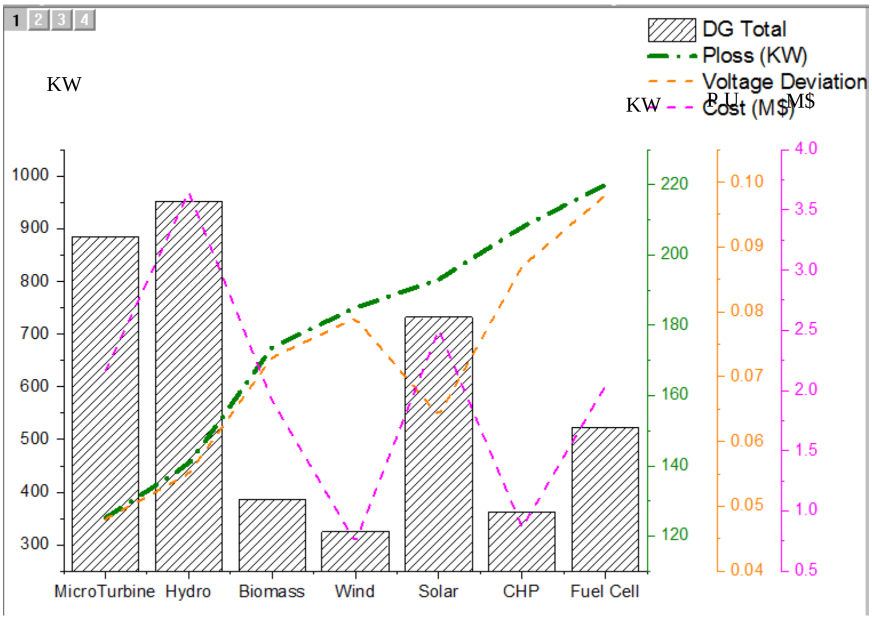

Fig. 6: All compromise solutions - Ploss Ascending Summary

Fig. 7 gives DG compromise solutions. It illustrates the DG size (KW); and the corresponding Ploss (KW); min voltage (p.u.) and the total cost (M$). In that figure the cost is illustrated in ascending values.

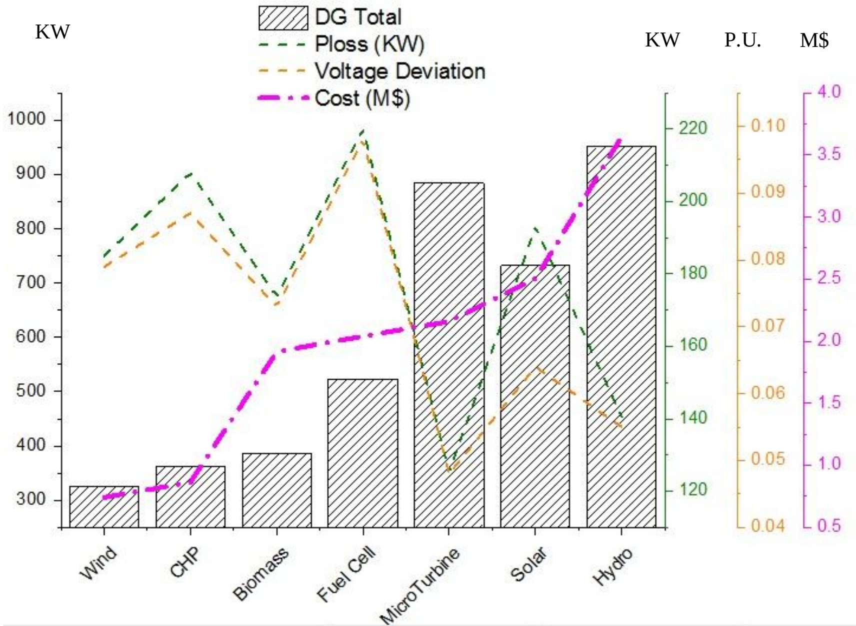

Fig. 7: All compromise solutions - Cost Ascending

Comparing the above results with that given in table -1 that summarizes the results of previous studies on that system (IEEE 69- bus system), however, not taking into account the economical point, but using various objectives and optimization techniques, show that bus 64 is the global solution for the location of DG unit, whose size is ranged from 0.8 MW to 1.2 MW irrespective of the DG technology.

VI. CONCLUSION

Due to the rapid increase of electricity consumption; and to make use of renewable energy generation, distributed generation units are now applied in distribution systems. For realizing technical and economical benefits of them, proper allocation of these units has been studied.

A review of literature indicates that most of the problem of optimal location and sizing of DG has formulated as a mono-objective optimization problem. However, the formulation of DG location and sizing problem as a mono-objective optimization is not quite practical. This paper formulates the problem as multi objectives and presents an algorithm which differentiates between different technologies of DG applications. The objectives are minimization of capital and operation cost of DG units; minimization of system peak loss; and minimization of voltage deviation with respect to nominal bus voltage. The optimization tool is the modified Non-Dominated Sorting Genetic Algorithm NSGA-II. For verification of the proposed algorithm, it is applied on IEEE 69- bus system.

The system has been studied for various generating unit types to trace their effect on changing the optimized size and location of distributed generation units. The results compared to the published works, and it was showing great potential for the proposed algorithm. In addition, the study concludes that certain bus (buses) in the system may be preferable for DG applications irrespective of the considered objectives.

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