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Siting and sizing of dg for maximum cost saving in distribution system with increasing load scenario using fuzzy and water flow-like algorithm

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This paper presents Distribution Generation (DG) placement in distribution systemsbased on cost objective function for a planning period of 10 years. The benefit of DG when connected to the grid mainly depends on the location and size of the same. The real loss index and voltage index were calculated and given as inputs to fuzzy inference system to generate DG location index. The high index values are prioritised in giving for DG locations. Water flow-like algorithm (WFA) is computed for finding the optimal size of DG which will maximise the objective function resulting in the saving for the system. In this paper, interest and inflation rates were taken into consideration to estimate the present cost value of the system. The result analyses are compared for constant load and increasing loadscenarios. It is observed that the invested price on DG is recovered within the planning period. The proposed approach is tested on an IEEE 33-bus system and the results obtained were presented.

Keywords: *Distributed Generation; fuzzy logic approach; IEEE 33-bus system; increasing load scenario, cost analysis of dg, water flow-like algorithm*

1.0 NOMENCLATURE

C_{MS}	-	Cost of Maximum Saving, $
K_{ES}	-	Cost of Energy saving/kW-yr, $
$K_{DG,\ Gen}$	-	Cost of DG power/kW-yr, $
$K_{DG,\ O\&m}$	-	Cost of DG O&M cost/kW-yr, $
$K_{DG,\ Inv}$	-	Cost of DG investment/kW, $
C_{NLR}	-	Cumulative cost of energy saving, $
$C_{DG,\ Gen}$	-	Cumulative cost of DG generated power, $
$C_{DG,\ O\&m}$	-	Cumulative cost of DG O&M, $
$C_{DG,\ Inv}$	-	Cost of DG investment, $
X_{DG}	-	Capacity of DG, kW
NPV	-	Net present value
γ	-	Net present value factor
N_p	-	Planning period
N_B	-	Number of buses
IF	-	Inflation rate
IR	-	Interest rate
RLI	-	Real loss index
VI	-	Voltage index
$DGLI$	-	DG location index
P_{loss}	-	Real loss of the system without DG
$P_{loss,DG}$	-	Real loss of the system with DG
$P^i_{loss,0}$	-	Real loss of the system with no load at i^{th}bus.
N	-	Number of flows
G	-	Generation limit
g	-	Gravitational force
W_i	-	Mass of the water flow *i*
V_i	-	Velocity of the water flow *i*
W_0	-	Initial mass of the flow
n_i	-	Number of *subflow*possible from flow *i*
n_t	-	Maximum number of subflows
t	-	current iteration count
t_p	-	Iteration limit for regular precipitation

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2.0 INTRODUCTION

The IEA defined Distributed Generation (DG) as "a generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltage." The DG with technologies like photovoltaic, wind turbine, etc. has been accepted as environmental friendly, reliable etc. Though DG has a high installation cost, it can play a prominent role in reducing the system losses, improving voltage profile, and maintaining the reliability of the grid. According to [1] one of the key advantages of DG is its close vicinity to the load centres. The author defined DG as "electric power generation within distribution networks or on the customer side of the network."

In literature, there are numerous articles available which discusses on the importance of site and capacity of DG when integrating to the grid. Peter et al [2] review the methods for placing DG so as to improve the installation and interconnection to the classical grid. In [3] the author proposed a simple approach based on the load centroid method for placing DG in radial and mesh network.In [4] Naresh et al examined the effect of size and site of DG with respect to losses of the system.The authors [5] have investigated the problem of multi DG placement for maximum loss reduction.

In paper [6] the author has proposed a comparative study among GA and nonlinear algorithm for placing DG.An analytical method of placing DG is proposed to reduce the real losses with power factor control [7].Vijaykumar et al proposed a simple method for DG placement and sizing to deal with maximum saving and congestion of the system[8].Gandomkar et al [9] proposed an algorithm for allocating DG site based on the level of distribution losses reduced.Authors [10] proposed an augmentedlagrangian genetic algorithm for optimal placing and sizing of renewable DG.Satish et al [11] proposed a simple method for choosing the location and size for capacitor and DG so as to maximize the profit. In [12] shuklaet al have estimated the economic saving of the system, which translated from the technical benefits resulted with multi DG placement. This paper is organized as follows section 3 presents the problem formulation where the objective function for cost maximisation of the system is given. In section 4 the optimal locations of DG were identified using the fuzzy approach. Section 5 deals with the sizing of DG using the water flow-like algorithm. The last section discusses the results and their inferences and finally followed by conclusion and references.

3.0 PROBLEM FORMULATION

In this paper the main objective is to maximise the cost saving of the system when DG integrated to the grid. The DG locations are identified using the fuzzy approach and its size is optimized through WFA. The algorithm optimizes the DG size in the prescribed location such that the saving of the system i.e. objective function is maximized. The mathematical model of the objective function is given in eq. (1).

$$\max(F) = C_{MS} \qquad \text{...(1)}$$

where, ***'F'*** is the objective function of the system.,

$$C_{MS} = \left\{ \underbrace{\sum(NLR \cdot K_{ES})}_{C_{NLR}} + \underbrace{\sum(X_{DG} \cdot K_{DG,gen})}_{C_{DG,gen}} \right\} - \left\{ \underbrace{\sum(X_{DG} \cdot K_{DG,O\&M})}_{C_{DG,O\&M}} + \underbrace{(X_{DG} \cdot K_{DG,Inv})}_{C_{DG,Inv}} \right\} \qquad \text{...(2)}$$

The benefit of the system is the summation of cost of net loss reduction and cost of power generated by DG. The combination of DG investment cost and the summation of its O&M costgives the expenses of the system.

3.1 Net loss reduction

It is difference of the real loss of the system without and with DG placement, which is given in below eq.(3).

$$NLR = P_{loss,\,DG} \qquad \text{...(3)}$$

3.2 Net Present Value [12]

The value of cost changes with time. The value of present cost over a planning period,(N_p) is estimated by calculating the net present value factor, (γ), which includes inflation and Interest rate [7] given in equation (4). This factor is multiplied with respective costs heading to calculate the present cost value.

$$\gamma^t = \sum_{t=1}^{N_p} \left(\frac{1+IF}{1+IR} \right)^t \qquad ...(4)$$

Where, t = $1, 2, 3, \ldots, N_p$;

4.0 DG LOCATION THROUGH FUZZY APPROACH

In this section the optimal locations for DG placement is decided using fuzzy approach [13, 14], where it approximate between the inputs real loss index and voltage index based on rule base designed to generate DG location index. The flow chart for generating the optimal locations is given in figure (1)

TABLE 1
DECISION MATRIX FOR OPTIMAL DG LOCATION [14]

AND		VI				
		L	LN	N	HN	H
RLI	L	LM	LM	L	L	L
	LM	M	LM	LM	L	L
	M	HM	M	LM	L	L
	HM	HM	HM	M	LM	L
	H	H	HM	M	LM	LM

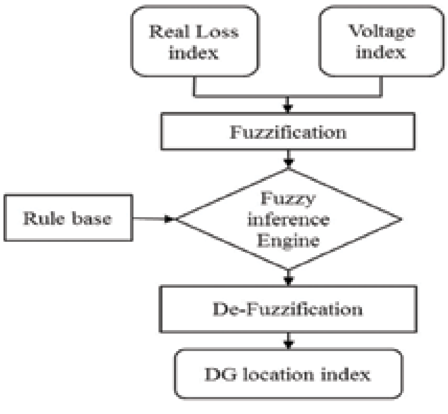

FIG 1: FLOW CHART FOR FINDING OPTIMAL DG LOCATIONS.

4.1 Real loss index

First load flow analysis is performed to find the real loss (P_{loss}). Now the load at i^{th} bus is removed and the load flow is carried out again to find the real loss ($P^i_{loss,0}$) of the system. The difference in loss is captured for that particular bus. Likewise for all buses the process is repeated and their values are noted using eq. (5). These numbers are normalised between 0 to 1. Buses whose values are nearing one are prioritised.

$$RLI = P_{loss} - P^i_{loss,0} \qquad ...(5)$$

Where i=1,2,3,…,NB.

4.2 Voltage Index

For calculating this index, the voltage magnitude of the system is normalised between 0 to 1. The values nearing zero are best choice for selection.

4.3 DG Location Index

Figure (2-4) shows the membership fuctions with Low (L), Low Medium (LM), Medium (M), High Medium (HM), High(H) for the indices framed. The output of fuzzy inference system gives the location index. This index is computed based on the rules base(given in Table(1)) framed.

In Table (2) all the indices are tabulated for top five buses. The bus number 9 has maximum location index value and hence it is taken as optimal location for placing DG. In this location the capacity of DG to be included so has to maximize the objective function is optimized by using the WFA which is discussed in next section.

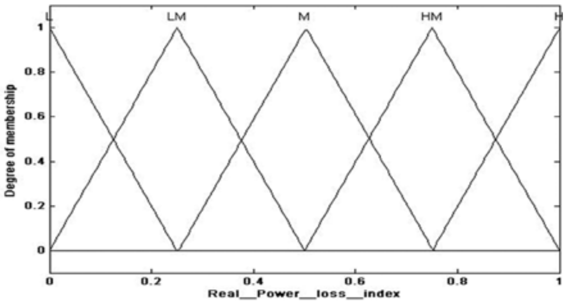

FIG. 2 MEMBERSHIP FUNCTION FOR RPL INDEX

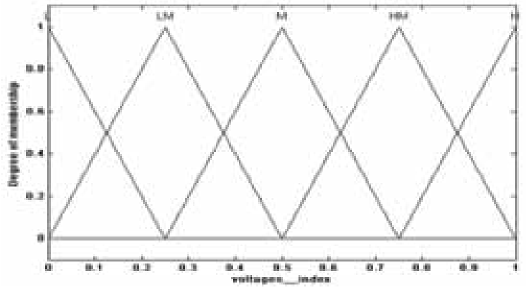

FIG. 3 MEMBERSHIP FUNCTION FOR VI INDEX

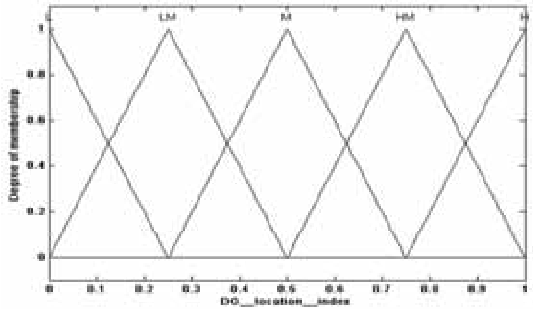

FIG. 4 MEMBERSHIP FUNCTION FOR DGLI INDEX

TABLE 2

OPTIMAL LOCATIONS FOR 33-BUS SYSTEM

Bus no.
9
32
18
14
31

5.0 OVERVIEW OF WATER FLOW-LIKE ALGORITHM

In this paper the sizing of DG is optimized using Water flow-like algorithm [15,16] for maximizing the objective function discussed through equation (1). This algorithm is inspired from the natural flowing of water from higher altitude to lower altitude. The flows are regarded as solution agents, which will traverse the entire solution space (terrain) to find the lowest ground level. The drives of these flows are governed by the gravitational force and the momentum of water. The algorithm starts initially with a single flow and then splits into several *subflows*, while traversing through rough surface. In a similar way the number of *subflows* will merge to form a single flow when reaching a common location. In this way several flow split, moving and merge operation were performed until lowest ground level (optimal solution) is reached.

5.1 Operation of WFA

The computational operation of this algorithm is carried through the following: 1) Flow splitting and moving, 2) Flow merging, 3) Water evaporation, 4) Precipitation.

5.1.1 Flow splitting and moving

The algorithm initially starts with a single flow with assigned mass($\boldsymbol{W_i}$) and velocity($\boldsymbol{V_i}$) which is moved by momentum($\boldsymbol{T}$) and potential energy. While traversing the solution space, the flow is moved with constant steps to identify new and better locations.

When a flow has enough momentum, then the flow can split into several *subflow*. The number of *subflows*is obtained using equation (6). The locations for these *subflows* on the solution space are identified from the neighbouring locations of the original flow. In contrast flows having less momentum will be continued as a single flow to search for better location.

$$n_i = \min\left\{\max\left\{1, \operatorname{int}\left(\frac{W_i V_i}{T}\right)\right\}, n_t\right\} \qquad ....(6)$$

Where $\boldsymbol{n_i}$is the number of *subflow* forked from flow $\boldsymbol{i}$ (where $\boldsymbol{i}$ belongs to 1,2,3,…N flows), $\boldsymbol{n_t}$ is the upper limit to control the number of *subflows*, in general $\boldsymbol{n_t}$is set for 3.The energy conservation law is followed to distribute the mass and velocity of the original flow to its *subflows*.

The mass and velocity of the *subflow k*, forked from flow $\boldsymbol{i}$ is calculated using the below equations(7-8):

$$W_{ik} = \left(\frac{n_i + 1 - k}{\sum_{r=1}^{n_i} r}\right) W_i$$
$$where,\ k = 1,2,\ldots,n_i \qquad ...(7)$$

$$\mu_{ik} = \begin{cases} \sqrt{V_i^2 + 2g\delta_{ik}}, & if\ V_i^2 + 2g\delta_{ik} > 0, \\ 0, & otherwise \end{cases} \qquad ...(8)$$

After this operation the number of flows is updated with newly formed *subflows* and their respective objective function value is recorded.

5.1.2 Flow Merging

The Flow merging operation is performed on two or more flows when moved to a common location on the solution space into a single flow. The mass and velocity of the newly formed single flow is calculated using the below equations (9-10).

$$W_i = W_i + W_j \qquad ...(9)$$

$$V_i = \frac{W_i V_i + W_j V_j}{W_i + W_j} \qquad ...(10)$$

This operation reduces the redundancy of the solution agents having same objective function value. After this the number flows and the related objective values are updated.

5.1.3 Water Evaporation

The flows having zero momentum will stagnate at certain location(assuming reaching local optima). To avoid these circumstances the natural water evaporation technique is employed, where part of the stagnated water is evaporated to the atmosphere. After certain time these flows are completely removed. To observe this operation mass of each flow is trimmed in every iteration through the equation (11) as evaporation process occurs continuously.

$$W_i = \left(1 - \frac{1}{t}\right) W_i, \quad i = 1,2,3,\ldots,N \qquad ...(11)$$

5.1.4 Precipitation Operation

After reaching a certain limit, the accumulated water vapour in the atmosphere will return as precipitation. There are two types of precipitation, Enforced precipitation and regular precipitation.

In enforced precipitation, the number of flows is not changed. All flows are treated equally to evaporation. This method is applied when all the flows finished with zero velocity. When returning to the ground the locations of the flows are randomly placed on the solution surface. The cumulative mass (***W₀***) distributed equally among the flows. The mass of flow ***i*** can be calculated using the below equation (12).

$$W_i^{'} = \left(\frac{W_i}{\sum_{k=1}^{N} W_k} \right) W_0 \qquad ...(12)$$

In regular precipitation, for every t_p iteration the precipitation of water is carried. New locations are created for the returned flows adding to the current number of flows. The mass of the new flows are calculated using the eq. (13). After this operation the flow merging operation is carried out to check the redundancy.

$$W_i^{'} = \frac{W_{t_p}}{\sum_{k=1}^{N} W_k} \left(W_0 + \sum_{k=1}^{N} W_k \right) \qquad ...(13)$$

5.2 Finding DG capacities through Water Flow like Algorithm [17]

Step 1: In the beginning of the run, initialise the parameter of WFA: ***N***=25, ***G***=100;W_0 = 8; V_0=5; ***T***=0.

Step 2: For each flow repeats Steps 3–6.

Step 3: For each flow '***i***', find the number of *subflow* 'n_i' possibly can be forked using the equation (6).

Step 4: Find the best neighbouring locations for each *subflow**k*** of flow ***i*** by traversing with constant steps from the original flow *i*.

Step 5: Maintaining the energy conservation law, distribute the massoforiginal flow ***i***to its *subflows**k*** using equation (7).

Step 6: Evaluate objective function value for each *subflow**k***. Find the value of objective function for each *subflow**k.*** If it is improving then update the number of flows count, else retain the original flow. Update the corresponding velocity of each flow using equation (8).

Step 7: Perform the merge operation for the *subflows*having the same objective value. Using equation (9-10) update the velocity and mass of the newly formed flow.

Step 8: Update the number of *subflows* for each flow *i*.

Step 9: Update the total number of water flow 'N'.

Step 10:Using equation (11),perform the water evaporation operation and update the mass of each flow.

Step 11:Perform Steps 12, 13, and 14 if precipitation condition is reached. Otherwise, go to Step15.

Step 12:Enforced precipitation is performed, if the velocities of all flows are zero. Else regular precipitation is carried on.

Step 13:Check the prescribed iteration limit t_p for regular precipitation. If t_p> 10 go to step 14, else go to step15.

Step 14:Using eq. (13),perform regular precipitation and generate new flows in new locations and update the number of flows count.

Step 15:Update the mass of the new flows based on the precipitation method employed using eq. (12) or (13)

Step 16:Perform the merger operation for the flows having same objective value. Update the velocity and mass of the flows using eq. (9) and (10)

Step 17:If Generation limit G or tolerance limit is reached goto step 16 else increase the iteration count and goto step2.

Step 18:Stop the algorithm.The best flow location gives the optimal DG rating and the corresponding objective value gives the maximum cost saving for the system.

6.0 RESULT AND DISCUSSIONS

In this article, the proposed algorithm is coded and simulated in MATLAB environment using Quad core Pentium processor, 2GB RAM laptop. The algorithm is tested on standard IEEE 33 bus system to observe the effectiveness of the proposed study. The test systemhas 33 buses and 32 branches with real and reactive load of 3755.00 kW and 2330.00 kVARs respectively and the losses of 212.4875kW and 142.2592 kVARs respectively. The type of DG considered is solar PV.The cost details of DG are taken from National Renewable Energy Laboratory (NREL) [18]. The cost of energy saving and cost of DG generated power is taken from [12].

In this simulation study the maximization of cost objective function given in equation (1) is analysed for constant load and increasing load scenario over a planning period of 10 years.

6.1 Constant load scenario

Table (2) shows bus number 9 has maximum location index. WFA optimizes the rating of DG to 1137.2132 kW in the location prescribed to maximize the objective function. The system with DG has 121.3979 kW real losses and 78.8842 kVAR reactive losses. The saving of the system is estimated for a planning period (N_p) of 10 years. In constant load scenario the load values are freeze to base case. However the cost details for the present value is predicted by including the inflation rate of 9% and interest rate of 12.5%. Using equation (3), the present value factor for the entire planning period is calculated and multiplied with respective costs which vary with time.

After the planning period, the cumulative difference of benefits and expenses gives the maximum saving of the system as15.34 M$ which is given Table (7).The cost of DG investment for the optimized rating is 2302.86 K$. From the figure (6) it can be observed the benefit curve crosses the DG investment curve exactly at 6.9 with reference to the abscissa, indicating the time required to recover the investment. Though including the present value factor, the saving of the system in this scenario is computed for a constant load and with constant DG rating, which is not the way possible in practical.

6.2 Increasing load scenario

In this increasing load scenario, the load of the system is assumed to increase 2% every year over the base load of the system.

6.2.1 For first year in planning period

For the first year, the load of the system is initialised with base values. When the DG size is optimized by WFA in the location given by the fuzzy approach i.e. 9th bus, it converges at 1137.2132 kW. With DG placement the saving through energy loss reduction is 39.89 K$ which is given in Table (4). The present value of this cost is estimated by multiplying with the NPV factor (γ) to 38.65 K$ which is mentioned in Table (6). The DG placement cost for the first year is 2302.86 K$. In Table (3) it indicates that with DG the deviation of voltage is reduced from 0.1011 pu to 0.0613pu.

6.2.2 For 10th year in planning period

The load of the system in tenth year is 118% of base case i.e. 4430.90 kW and 2749.4 kVAR. When load flow analysis is carried the real and reactive losses are 304.942 kW and 204.2964 kVAR respectively. WFA optimizes the DG for the present load, in the prescribed location to 1465.6 kW making a loss reduction of 137.978 kW. The investment cost for the optimized rating of DG in the present year is 2967.839 K$. The cost of energy saving with DG is 60.434 K$ and the cost of DG generated power is 439.679 K$ which are mentioned in Table (4). The deviation of voltage with DG is reduced from 0.1213 pu to 0.0710 pu.

From the Table (5) it can be observed that with increase in the load, the rating of DG also increased though optimized to the respective load conditions.

TABLE 3

SYSTEM PARAMETERS OF 33-BUS SYSTEM IN PLANNING PERIOD

Description	First year		10th year #	
	Without DG	With DG	Without DG	With DG
P_{loss}, kW	212.4872	121.3979	304.942	166.964
Q_{loss}, kVAR	142.2592	78.8842	204.2964	108.847
Total loss reduction with DG, kW	N/A	91.0893	N/A	137.978
Min. Voltage, V (p.u)	0.8989 (at Bus 18)	0.9387 (at Bus 33)	0.8787 (at Bus 18)	0.9290 (at Bus 33)
Voltage deviation, V(p.u)	0.1011	0.0613	0.1213	0.0710
DG Location	N/A	Bus 9	N/A	Bus 9
DG Capacity, kW	N/A	1137.2132	N/A	1465.6000

Note: #-With increase of 2% load every year, by 10th year it totals to 118% of base load.

TABLE 4

COST DETAILS OF 33-BUS SYSTEM AFTER ONE YEAR OF PLANNING PERIOD.

Description	First year	10th year
C_{NLR}, (K\$/yr)	39.89	60.434
$C_{DG, Gen}$, (K\$/yr)	341.16	439.679
$C_{DG,O\&M}$, (K\$/yr)	18.19	23.449
$C_{DG, Inv}$, (K\$)	2302.86	2967.839

The penetration level of the DG in the first year of ***Np*** is 30% and is assumed to increase at 2% each year. In Table (6) the DG investment cost column represents the corresponding cost value to the optimized DG rating. But, while computing the saving of the system, the DG investment cost of the 10th year is considered, so as reflect the investment made in the beginning. In Table (7) the comparison of the cost details between the constant load and the increasing load is given. It is clearly results that the saving of the system is maximised with DG for increasing load scenario. In figure (5) it is observed that the time required to recovery of invested amount for increasing load scenario is approximately 7.2 years. It is also observed that w.r.t. increasing load scenario, the benefits from the constant load will return the investment in 9.2 years' time.

TABLE 5 COST DETAILS OF THE SYSTEM AFTER PLANNING PERIOD		
Description	Constant load	Increasing load
$C_{NLR,}$ (M$/yr)	1.94	2.58
$C_{DG,\ Gen,}$ (M$/yr)	16.58	19.72
$C_{DG,O\&M,}$ (M$/yr)	0.88	1.05
$C_{DG,\ Inv,}$ (M$/yr)	2.30	2.97
Benefits, (M$/yr)	18.53	22.29
Expenses, (M$/yr)	3.19	4.02
$C_{MS,}$ (M$/yr)	15.34	18.28

7.0 CONCLUSIONS

The proposed approach is tested on a standard IEEE 33 bus system, for constant load and increasing load scenario over a planning period of 10 years. In this paper, an objective function is framed which gives the maximum saving for the system. The optimal location for DG is obtained using the fuzzy approach which generated bus number 9 as best choice. The WFA algorithm has optimized the DG size, so as to increase the objective value. The saving of the system with DG after planning period, for constant load and increasing load is 15.34 M$ and 18.28 M$ respectively. By taking the DG investment for increasing load as reference, the benefit from constant load will recover the investment in 9.2 years, while for increasing load it is approx. 7.2 years which is given in figure (5). Hence it can be concluded that the placing of DG in radial distribution system with increasing load scenario will definitely results in technical and economic benefits to the system.

TABLE 6

SYSTEM PARAMETERS FOR INCREASE LOADING SCENARIO

Planning Year	Load of the system	Real Load (kW)	Reactive Load (kVAR)	Real Losses (kW)	Reactive Losses (kVAR)	Real losses (kW) with DG	Reactive losses (kVAR) with DG	DG rating (kW)	Penetration Level of DG into the system (%)
1	1.0000	3755.000	2330.000	212.487	142.2592	121.398	78.884	1137.213	30.285
2	1.0200	3830.100	2376.600	221.798	148.5033	126.053	81.936	1173.267	30.633
3	1.0400	3905.200	2423.200	231.342	154.9053	130.809	85.057	1209.427	30.970
4	1.0600	3980.300	2469.800	241.124	161.4670	135.667	88.247	1245.694	31.296
5	1.0800	4055.400	2516.400	251.145	168.1903	140.626	91.506	1282.070	31.614
6	1.1000	4130.500	2563.000	261.409	175.0770	145.688	94.834	1318.554	31.922
7	1.1200	4205.600	2609.600	271.917	182.1290	150.852	98.232	1355.149	32.222
8	1.1400	4280.700	2656.200	282.674	189.3483	156.119	101.700	1391.854	32.515
9	1.1600	4355.800	2702.800	293.681	196.7367	161.490	105.238	1428.671	32.799
10	1.1800	4430.900	2749.400	304.942	204.2964	166.964	108.847	1465.600	33.077

TABLE 7

COST DETAILS FOR INCREASE LOADING SCENARIO

Planning year	NPV Factor	With 2% of load increasing every year	DG rating kW	Cost of Energy saving ($)	Cost of DG generated Power ($)	Cost of DG Operation and Maintenance ($)	Cost of DG Investment ($)
1	0.9689	1.0000	1137.213	38655.999	330550.027	17629.338	2302857.124
2	1.9076	1.0200	1173.267	79998.898	671449.278	35810.629	2375865.222
3	2.8172	1.0400	1209.427	124050.050	1022149.976	54514.674	2449089.163
4	3.6984	1.0600	1245.694	170830.557	1382129.390	73713.557	2522530.630
5	4.5522	1.0800	1282.070	220361.519	1750888.801	93380.751	2596191.269
6	5.3795	1.1000	1318.554	272663.849	2127952.536	113490.791	2670072.733
7	6.1810	1.1200	1355.149	327758.572	2512867.021	134019.439	2744176.665
8	6.9576	1.1400	1391.854	385667.242	2905199.978	154943.974	2818504.794
9	7.7101	1.1600	1428.671	446410.950	3304539.214	176242.063	2893058.592
10	8.4391	1.1800	1465.600	510011.506	3710492.516	197892.835	2967839.974

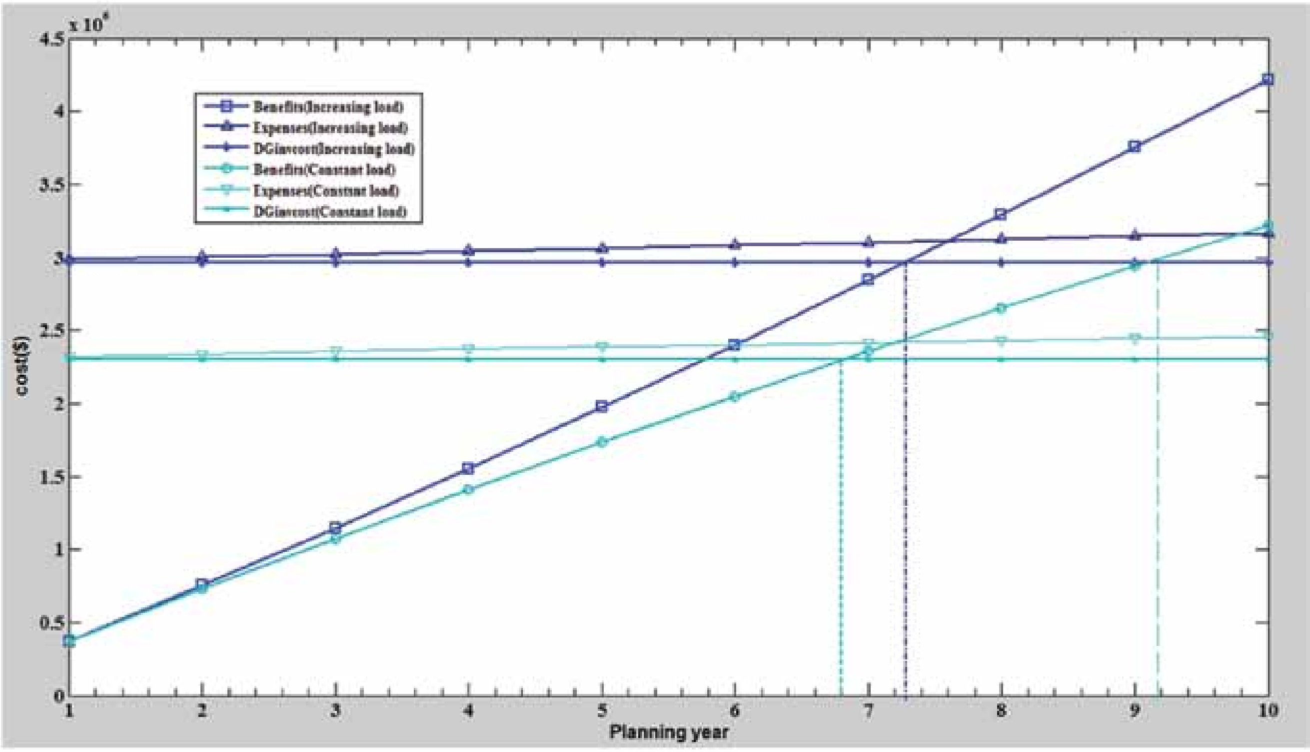

FIG 5: COST GRAPH FOR INCREASING LOAD AND FOR CONSTANT LOAD.

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