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Multi-objective JAYA algorithm based Optimal location and Sizing of Distributed Generation in a Radial Distribution System

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***Abstract*—In this paper, Multi-Objective Decision Making (MODM) algorithm viz. Multi-Objective JAYA (MOJAYA) algorithm has been applied for the first time to optimally locate the Distributed Generations (DG) and to choose the optimal size of DGs in a Radial Distribution System (RDS) for achieving the multiple objectives of reducing power loss, improving voltage profile and stability. In order to maximize the DG owners profits and simultaneously achieve the above cited multiple objectives, Multi-Attributes Decision Making (MADM) methods such as Analytic Hierarchy Process (AHP), and Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS) have been utilized. The proposed MOJAYA algorithm has been applied on IEEE 33 bus RDS and the results thus obtained has resulted in maximizing the profits to the DG owners and achieved the multiple objectives of reducing power loss, improving voltage profile and improving voltage stability of the RDS.**

***Index Terms*—Radial Distribution System, Distributed Generations (DGs), MADM, MODM, DG owners cost, Distribution Company (DISCO) cost.**

I. INTRODUCTION

In recent years due to improvement in technologies it is possible to use the small distributed generation (DG) in distribution system. In general power is transferred from the Generating Station to the Distribution Centre by incurring transmission losses thereby decreasing the voltage profile at the buses. Hence by integrating DGs at the appropriate buses the power loss can be reduced to a significant extent and thereby improves the voltage profile and helps the system to be more robust in terms of voltage stability.

The optimal allocation of DGs and size of DGs plays vital role while integrating DGs in Distribution system. If DGs were not placed at right location in the Distribution system,there will be a adverse impact on stability [1]. In addition to get the technical benefits, size and location are to be optimized at the same time DG owners revenue, payback time and DISCOs cost should be considered. Cost minimization and system technical improvement are the two vital goals of any DG planning study. One can efficiently cut the working costs by increasing the reliability of supply with quality of marketable energy and reducing power and energy losses [2].

Optimal DG placement in Distribution system are continuously studied in order to get the different objectives. Several techniques have been proposed in determining the optimal location of DG. DG allocation to reduce power loss have been explained in [3]–[7] by considering voltage profile improvement and voltage stability as the objective for DG allocation. Author in [8] has explained that DG allocation was done based on DG owners profit and DISCOs cost using multi-objective heuristic optimization algorithm to arrive at the final solution based on different technical operating index. In this paper comparison of two novel multi-objective algorithms MOPSO and MOJAYA algorithm gives multiple solutions to choose the best optimized solution using combined AHP and TOPSIS methods by incorporating Technical index as an attribute for decision making.

This paper is organized in following sequence: Section II deals with the different Objective functions and Constraints. Section III presents about different optimization algorithms. Section IV details about different Operational and Economic indices and MADM techniques. Discussion on analytical study on a test system and results is in Section V and Conclusions are drawn in Section VI.

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II. OBJECTIVE FUCTIONS AND CONSTRAINTS

DG owners considers the size of DG and contract price in between DG owners and DISCOs.

A. DG owners cost and profit

In order to maximize DG owners profit, the objective function [9] that has been formulated is as shown in equation (1)

$$Obj1 = max(DGI - DGIC - DGMC - DGOC) \quad (1)$$

where DGIC is DG Investment Cost in $
DGMC is DG Maintenance Cost in $
DGOC is DG Operational Cost in $
DGI is DG Owner Income in $
The significance of the terms employed in the objective function of equation (1) to arrive at DG Owner Profits are as follows:

1) DG Owners Investment Cost (DGIC): This cost comprises fixed initial costs such as installation, unit construction, land procurement and important equipment cost for each DG.

This DGIC is as shown in equation (2).

$$DGIC = \sum_{i=1}^{N_{DG}} P_{DG,i} * Cost_{inv} \quad (2)$$

where i denotes the number of DGs and P_{DGi} denotes active power generation by i^{th} unit.

2) DG owners Maintenance Cost (DGMC): This cost comprises the cost of repairing, replacing and restoring cost of unit during the planning years. This DGMC is as shown in equation (3).

$$DGMC = \sum_{j=1}^{N_N} \sum_{i=1}^{N_{DG}} CF_i * T_h * P_{DG,i} * Cost_{oper} * R^j \quad (3)$$

where $R = (\frac{1+INFR}{1+INTR})$ gives an idea about interest and inflation rate and N_N denotes the year, CF is capacity factor and T_h is the total number of hours in a year.

3) DG operational Cost (DGOC): This cost comprises of wages to employees, cost of fuel, and generation cost. This DGOC is as shown in equation (4).

$$DGOC = \sum_{j=1}^{N_N} \sum_{i=1}^{N_{DG}} CF_i * T_h * Cost_{oper} * P_{DG,i} * R^j \quad (4)$$

where $Cost_{oper}$ is operational cost based percentage load.

4) DG Owners Income (DGI): The DG owners make profit by selling active power to DISCOs based on contract price. This DGI is as shown in equation (5).

$$DGI = \sum_{j=1}^{N_N} \sum_{i=1}^{N_{DG}} CF_i * T_h * CP_{DG} * P_{DG,i} * R^j \quad (5)$$

where CP_{DG} is Contract price between DG owner and the DISCOs.

B. DISCOs cost

DISCOs need to consider not only for its profit but also technical issues such as power loss, voltage stability voltage profile. So here for calculation of DISCOs cost importance of both size and location will reflect. In order to minimize the DISCOs cost, the objective function [9] that has been formulated is as shown in equation (6).

$$Obj2 = min(CDG + C_{sub} + CIPC) \quad (6)$$

where CDG is Cost of purchasing power from DG owner.
C_{sub} is Cost of purchasing power from substation.
$CIPC$ is Customer Interruption Penalty Cost.

1) Cost of purchasing power from DG owner: This cost include the cost of active power purchase by DISCOs from DG owners based on contract price in between DGs and DISCOs. This cost has already been computed as DGI using equation (5). This cost made strong connection between the two objective functions which yields conflicting objective solutions and so there is a need to apply multi-objective heuristic algorithms.

2) Cost of purchasing power from Substation: The excess power demand which is not fulfilled by DGs has to be brought from substation to meet the supply and demand of load. The excess power from substation is being computed using equations (7), and (8).

$$C_{sub} = \sum_{j=1}^{N_y} \sum_{t=1}^{24} C_{MWh,P} * T_d * P_{sub,t,j} * R^j \quad (7)$$

where

$$P_{sub,t,j} = \sum_{n=1}^{N_b} P_{a,n,t,j} - \sum_{i=1}^{N_{DG}} P_{DG,i} + P_{loss,t,j} \quad (8)$$

$P_{a,n,t,j}$ is active power load connected to n^{th} bus for t time, $C_{MWh,P}$ is Cost of active power brought from Substation, N_b is no. of buses and $P_{loss,t,j}$ refers to the active power loss for t time in j^{th} year which can be calculated using equation (9).

$$P_{loss,t,j} = \sum_{b=1}^{N_{br}} rb * l_{b,t,j}^2 \quad (9)$$

where N_{br} is no. of branches and $l_{b,t,j}$ is the current of b^{th} branch at time t in j^{th} year.

3) Customer Interruption Penalty Cost: DISCOs has a responsibility to supply power continuously to customers. If uninterrupted power is not supplied to customers then DISCOs have to pay penalty to customer for interrupting power. This penalty can be computed using equation (10) based on total load not receiving power supply if fault is there in b^{th} branch.

$$CIPC = \sum_{j=1}^{N_N} \sum_{b=1}^{N_b} \lambda_b * L_b * C_{int} * \sum_{k=1}^{N_{NS}} P_{L,k,j} * R^j \quad (10)$$

where N_{NS} is number of buses not receiving power when fault is at b^{th} branch. λ_b,L_b are fault rate and length of b^{th} branch respectively and $P_{L,k,j}$ is Active power of load connected to k^{th} node in j^{th} year. The objective function that has been formulated is subjected to following constraints:

a. DG owners investment constraint: The amount which can be invested by the DG owner in business is limited by some maximum amount as shown in equation (11).

$$C_{inv} \leq C_{inv}^{max} \quad (11)$$

b. DG power generation constraint: DG has limited capacity to generate active and reactive power as shown in equations (12), and (13).

$$P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max} \quad (12)$$

$$Q_{DG}^{min} \leq Q_{DG} \leq Q_{DG}^{max} \quad (13)$$

c. Bus voltage and line current limit: DG should be placed in a system such that systems voltage and line current limit should not cross the maximum limit as represented in equations (14), and (15).

$$V^{min} \leq V \leq V^{max} \quad (14)$$

$$I^{min} \leq I \leq I^{max} \quad (15)$$

d. Contract price limit : While DG allocation is done on deregulated market there should be some limit on contract price for better business in power market as represented in equation (16).

$$CP^{min} \leq CP \leq CP^{max} \tag{16}$$

III. MULTI-OBJECTIVE OPTIMIZATION ALGORITHMS

The Multi-Objective (MO) format of PSO called MOPSO and MOJAYA are compared in this paper which are suitable in case of minimizing multiple objective functions simultaneously. Multi-objective can be converted into single objective in some cases where both objective functions are not conflicting one another. Conflicting objective function doesnt mean that one is minimization and other is maximization but it means that optimizing one effects adversely other. Here due to strong connection between DISCOs cost and DG owners profit it is not possible to convert these two objective functions into one by weight sum methods and so one need to go for multi-objective optimization technique.

A. Multi-Objective Particle Swarm Optimization

In the proposed MOPSO [10] algorithm, the population has started with n particles and each particle is an m-dimensional vector, where m is the number of variables used in optimization algorithm. The computational flow of the proposed MOPSO technique can be described in the following steps:
Step1: Generate (X) randomly n population with m variables
Step2: Compute the objective function values.
Step3: Apply non dominated sorting to population
Step4: Compute sharing fitness using Euclidean distance and niche count.
Step5: Update population using following formula:

$$\begin{aligned} V(t+1) = w(t) * V(t) + c1 * r1 * (P_{best}(t) - \\ X(t)) + c2 * r2 * (G_{best}(t) - X(t)) \end{aligned} \tag{17}$$

$$X(t+1) = V(t+1) + x(t) \tag{18}$$

where V is the velocity of particle moving toward optimal solution c and r are tuning parameter. P_{bsest} is the positional best and G_{best} is global best.
Step6: Again apply non-dominated sorting and compare with previous solution based on sharing fitness and update the P_{best} and G_{best}.
Step7: Run the algorithm between Step 4 and Step 6 for 100 iterations so as to finally plot the pareto optimal set.

B. Multi-Objective JAYA algorithm

In the proposed MOJAYA algorithm which is extended version of JAYA [11] algorithm for multi-objective purpose, the population has started with n particles and each particle is an m-dimensional vector, where m is the number of variables used in optimization algorithm. The computational flow of the proposed MOJAYA technique can be described in the following steps:
Step1: Generate (X) randomly n population with m variables
Step2: Compute the objective function values.
Step3: Apply non dominated sorting to population
Step4: Compute sharing fitness using Euclidean distance and niche count.
Step5: Update population using equation (19).

$$\begin{aligned} X(t+1) = X(t) + r1 * (X_{best}(t) - |X(t)| \\ -r2 * (X_{worst}(t) - |X(t)| \end{aligned} \tag{19}$$

Step6: Again apply non-dominated sorting and compare with previous solution and update update population based on sharing fitness.
Step7: Run the algorithm between Step 4 and Step 6 for 100 iterations so as to finally plot the pareto optimal set.

IV. OPERATIONAL AND ECONOMIC INDICES

In order to validate the final solution given by heuristic techniques, the ratio of Indices with DG and without DG to indicate the impact of DG placement have been computed and the operating Indices [9] are as follows:

A. Total Voltage Profile Index (TVPI)

This index [9] gives the total deviation of voltages from its rated values over a total period of study and are represented in equations (20), and (21).

$$TVPI_{pu} = TVPI_{withDG}/TVPI_{withoutDG} \tag{20}$$

$$TVPI = \sum_{j=1}^{N_y} \sum_{t=1}^{24} \sum_{n=1}^{N_{Bus}} |V_{rated} - V_{n,j,t}| \tag{21}$$

where $V_{n,j,t}$ refers to voltage of n^{th} bus at t^{th} hour of j^{th}year

B. Total Power Loss Index (TPLI)

Loss minimization of system is one of the important advantage of DG placement. The percentage of loss minimization due to placement of DG is computed as in [9] and same are represented in equations (22), and (23).

$$TPLI_{pu} = TPLI_{withDG}/TPLI_{withoutDG} \tag{22}$$

$$TPLI = \sum_{j=1}^{N_y} \sum_{t=1}^{24} \sum_{b=1}^{N_b} r_b * {I_{j,t,b}}^2 \tag{23}$$

where r_b is the branch resistance and $I_{j,t,b}$ is the current of that branch in j^{th} year.

C. Total Voltage Stability Index (TVSI)

In distributed system where each node is fed by other bus, TVS Index gives good idea about stability of radial distribution system. More this index better is the stability of system. The voltage stability index is computed as in [9] and same are represented in equations (24), and (25).

$$TVSI_{pu} = TVSI_{withDG}/TVSI_{withoutDG} \tag{24}$$

$$TVSI = \sum_{j=1}^{N_y} \sum_{t=1}^{24} \sum_{n=2}^{N} |VSI_{n,j,t}| \tag{25}$$

D. Energy Not Supplied Index (ENSI)

This index gives the information about the amount of load not getting power at the time of maintenance of fault of any line in the system. Lesser is the ENS Index means better is the reluctance to the fault condition.This ENSI [9] mainly depends on the fault rate and are represented in equations (26), and (27).

$$ENSI_{pu} = ENSI_{withDG}/ENSI_{withoutDG} \quad (26)$$

$$ENSI = \sum_{j=1}^{N_y} \sum_{b=1}^{N_b} \lambda_b * L_b * \Delta t_{fault} * \sum_{k=1}^{N_{NS}} P_{L,k,j} \quad (27)$$

where λ_b is the fault rate per year and Δt_{fault} is the repair time for that fault per year.

E. Payback Period (PP)

This index comes under the economic point of view for DG owners. This gives the idea about the present DG placement project is worthy for DG owner or not. The number of years required to recover all investment invested by DG owner is calculated as payback period and is being understood from equation (28).

$$DGI - \sum_{j=1}^{PP} (Cash \quad inflows \quad in \quad ith \quad year) = 0 \quad (28)$$

MADM Techniques:

In order to choose one of the best solution from the multiple solutions obtained my multi-objective heuristic techniques, the MADM techinque [12] has been utilized. Here, the combination of AHP method and TOPSIS method is employed to choose the final optimized solution.

1) Analytic Hierarchy Process (AHP):: AHP is suggested as a tool for implementing a multiple criteria performance scheme. The AHP as developed in [13] is a simple decision-making tool to cope with complex, unstructured and multi-attributed problems. In this case AHP is used to get the weights for different operating indices based on severity of index in distribution system. The relative importance matrix used in AHP for different indices is shown in Table I.

TABLE I: Relative Importance Matrix

ATTRIBUTES	TVPI	TPLI	TVSI	ENSI	PP
TVPI	1	2	3	7	1
TPLI	1/2	1	3	4	1/2
TVSI	1/5	3/7	1	8/5	1/5
ENSI	1/8	3/8	4/7	1	1/8
PP	1	2	3	7	1

The weights derived from the AHP method is shown in Table II.

TABLE II: Weights from AHP method

Attributes	TVPI	TPLI	TVSI	ENSI	PP
Weights	.3356	.1979	.0763	.0546	.3356

2) TOPSIS method:: TOPSIS is a powerful tool in multi-attribute decision making (MADM) technique. TOPSIS is a very useful technique and practical for ranking and selection of best one from multible attributes through distance measures. The TOPSIS method [14] rank the solutions based on the distance calculated from ideal negative and positive solution. i.e.the highest distance from the negative ideal solution. and the best alternative has simultaneously the lowest distance from the ideal solution.

The weights obtained from AHP method is used as the weightage given to different attributes. Here attributes are TVPI, TPLI, TVSI, ENSI and Payback Period. Then TOPSIS method is applied as given in [14] to rank the optimal solution obtained from pareto optimal set.

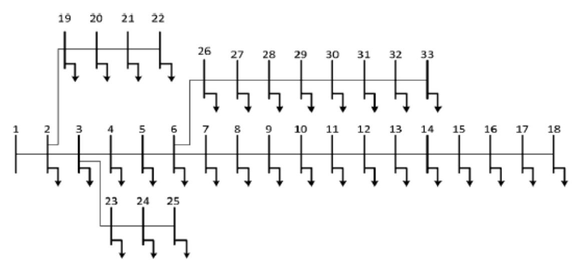

Fig. 1: One Line diagram of IEEE 33-Bus test System [9]

V. Analytical Study

For demonstrating the efficiency of the proposed method, an analytical study has been performed on the IEEE 33-bus distribution test system [9] which is shown in Figure 1. It is considered that the average hourly load of each bus varies with a pattern similar to Figure 2 with an increment of load with rate of 2 percent per year. The standard load pattern at each bus at the peak hour in the first year of the planning period is shown in Figure 3. The cost of power is calculated based on percentage load shown in load curve represented in Figure 2.

It is assumed that there are three price levels for peak, medium and low load levels during a day. The contract price between the DISCO and DG owner considered is in between $US\$$ 0.35$/MWh$ and $US\$$ 0.50$/MWh$. In the Test system three DGs having power in the range of $0.2MW$ to $1MW$ at a 0.9 lagging power factor with a capacity factor of 1 is considered. The commercial information of the DGs [9] is as shown in Table III.

In this analytical study, to calculate reliability indices, it is assumed that the failing rate of transmission lines is $0.12f/km$, year and their repair time is $8hours$. Other equipment of the grid is considered as 100 percent reliable. Here the average failure cost of $US\$$ 20$/kW$is considered for $8hours$

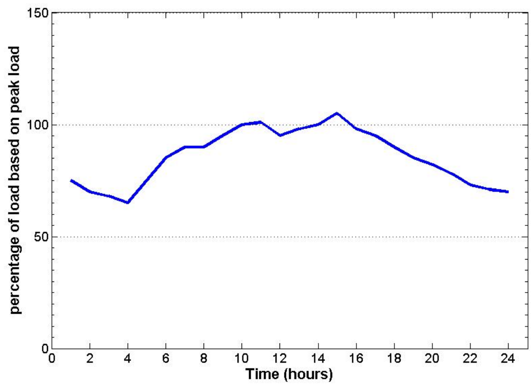

Fig. 2: Hourly percentage load variation curve at each bus based on peak condition [9]

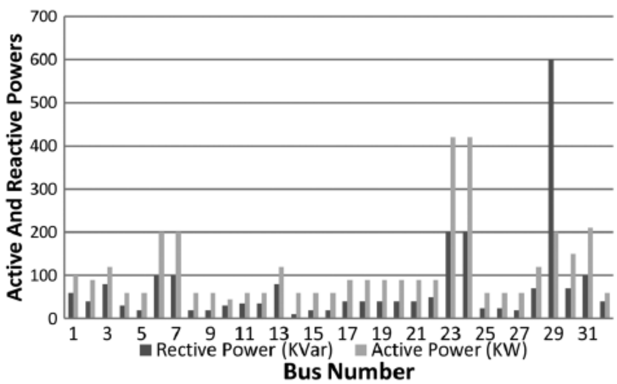

Fig. 3: Load at each bus in a peak hour of the first year [9]

of failure for all loads. the values of used parameters [9] are as shown in Table IV. The proposed MOJAYA algorithm has been applied for the first time under MATLAB environment to obtain multiple solutions that minimizes the DISCOs cost and maximizes DG owners income. The pareto front with MOPSO [10] and MOJAYA is shown in Figure 4. The MADM technique is then applied to multiple solutions obtained by MOPSO [9] and the proposed MOJAYA algorithm. The combination of AHP and TOPSIS method is applied to these set of optimal set of points based on Operational and economic indicies as explained in section V. The final optimal solution arrived at by the proposed MOJAYA algorithm and MOPSO with the application of AHP and TOPSIS is represented in Table VI. From Table VI, It is observed that the amount of TVPI and TPLI indicies by the proposed MOJAYA algorithm decreased in comparison with MOPSO. It is also observed that the TVSI increased in proposed MOJAYA algorithm in comparison with MOPSO. Further, the size of DGs their optimal location and the amount of contract prices are shown in Table VI. In the Table VI, the amount of indicies demonstrates that not only are the economic view points of the two sides of the contract satisfied, but also the operational condition of the power grid have improved considerably. The bus voltage profiles with DGs and without DGs have improved considerably by the proposed MOJAYA algorithm in comparison with MOPSO and this comparison is pictorial shown in Figure 5. The computation time taken by MOPSO and MOJAYA during optimization technique is shown in Table V. The impact of DG placement on Voltage profile of system is shown in Figure 5.

TABLE III: Commercial Information of DGs [9]

Parameter	Unit	Value
DG investment cost	$\$/MW$	31800
DG Operation cost	$\$/MW$	29
DG Maintenance cost	$\$/MW$	7

TABLE IV: Values of the used Parameters [9]

Parameter	Value
Annual growth rate of load	2%
$\lambda_b(f/km.year)$	.12
CF	1
N_{DG}	3
N_y	20
N_{BUS}	33
N_b	32
$C_{int}(\$/kw)$	20
T_h	8760
T_d	365
$INT_R\%$	12.3
$INF_R\%$	9

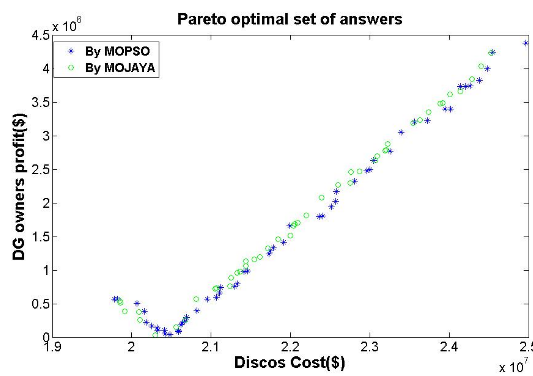

Fig. 4: Pareto optimal set achieved by MOPSO [10] and MOJAYA

TABLE V: Computational Time taken by algorithm

S.No.	MODM algorithm	Time in seconds
1	MOPSO [10]	1608.216745
2	MOJAYA	1213.307644

VI. CONCLUSION

In this paper, the comparison between the MOPSO and MOJAYA is done to find the optimal solution of DG location, sizing and contract price in between DISCOs and DG owners which will motivate the investor to invest in deregulated power market. This paper has shown the effective approach of hybrid MODM and MADM technique to solve the multiobjective

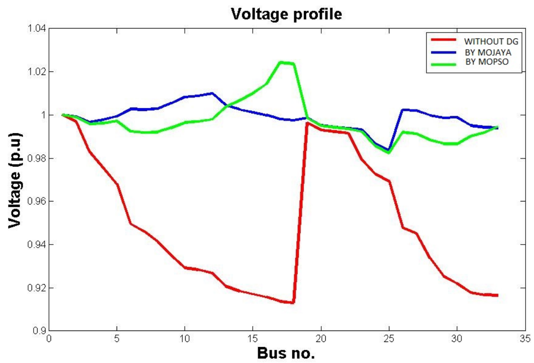

Fig. 5: Comparision of Voltage Profiles for the IEEE 33-Bus Test System with and without DG's employing MOPSO [10] and MOJAYA algorithm

TABLE VI: Best Optimal Points and their relevant operational and economic indices after the application of AHP and TOPSIS methods by the Proposed MOJAYA algorithm

ATTRIBUTES	MOPSO [10]	MOJAYA
location	[5 17 33]	[6 12 30]
size(Mw)	[0.91757 0.91083 0.8228]	[0.98221 0.96066 0.90061]
CP($)	46.654	45.262
TVPI	0.21	0.173
TPLI	0.176	0.109
TVSI	1.221	1.233
ENSI	0.007	0.074
PP(years)	3.626	4.21
DG profit($)	2.7674e+06	2.4623e+06
DISCOs cost($)	2.2363e+07	2.276e+07
DISCOs percentage profit	9.5373	7.9285

problem. This study shows that time taken by MOPSO is greater than MOJAYA as the computational steps in MOJAYA algorithm is less than MOPSO algorithm. Moreover MOPSO algorithm has some tuning parameter which affects the solution while no such parameter is used in MOJAYA algorithm. This approach is not only cost effective but also considered the technical benefits which encourage the DG owners to deploy DGs in distribution system.

To explore further, the impact of DG's on Protection due to the uncertain behaviour of DG's such as Renewable Energy Sources and the cost of protection may be considered in the formulation of the objective function.

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