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Strategic Deployment of Distributed Generators Considering Feeders' Failure Rate and Customers' Load Type

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***Abstract*—This paper presents an optimal planning scheme toward the design of distributed generation (DG) integrated distribution network. The Greedy Search based approach aims to determine the optimal size and location of DG units in order to achieve designated cost curtailment. The cost curtailment includes considerations for investment and maintenance cost of the DGs, active power loss cost and reliability level cost of the distribution network. The deployment strategy consists of adding suitable size of DGs at appropriate site while considering feeders' failure rate and customer load type. Economic factors specifically inflation rate and interest rate are taken into account for present worth evaluation. Also, yearly load growth and hourly and daily variations of the load are considered while planning. Additionally, power losses, risk level and voltage profile are also computed to attest the efficacy of the proposed approach. Furthermore, computations are done to calculate amounts of the detriment due to unreal modeling of the feeders' failure rate and customers' load type. It is proved that the unreal modeling can notably impact the results of the problem as well as the optimal locations of the DGs.**

***Keywords*—Load modelling, Distributed power generation, Power generation economics, Microgrids, Power system planning, Power system reliability.**

NOMENCLATURE

Indexes and Sets

b, S_b	Index and set of branches.
h, S_h	Index and set of hours of a day.
i, j, S_i	Indexes and set of buses.
l, S_l	Index and set of load levels.
m, S_m	Index and set of months of an year.
T	Index of planning period.
x, S_x	Index and set of customers' load types.
y, S_y	Index and set of years of the planning period.

System Parameters and Variables

C^{DG}	Cost for purchasing a DG.
C^M	Cost of yearly maintenance of a DG.
CF_T	Cost function over the planning period
d	Number of days in a month
D_{FLS}	Duration of fault locating and switching.
D_{FR}	Duration of fault repairing.
D_{LL}	Duration of load level.
$Final\ CF_T$	Final value of cost function over the planning period while optimizing.
I_0^a, I^a	Active component of current flowing through branch before and after DG placement.
IFR, ITR	Inflation rate and interest rate.
$InvestC_T$	Cost associated with purchase of DGs.
LNS^{FLS}	Load not supplied of consumers during fault locating and switching.
LNS^{FR}	Load not supplied to consumers during fault repairing.
$\lvert MVA \rvert$	Magnitude of apparent power flowing through branch.
N	Number of installed DGs.
N_B	Number of branches in the test system.
P^{Avg}	Average active power demand.
P^{Sch}, P	Value of nominal active power demand at operating point and current one.
$Power\ Loss_T$	Active power loss over the planning horizon.
$PWLoss_T$	Present worth value of cost associated with energy loss over the entire planning period.
$PWMaintain_T$	Present worth value of cost of maintenance of DGs over the entire planning period.
$PWRisk_T$	Present worth value of cost associated with risk level over the entire planning period.
Q^{Sch}, Q	Value of nominal reactive power demand at operating point and current one.
R	Resistance of branch.
$Risk_T$	Risk Level over the planning horizon
V^{Sch}, V	Value of nominal voltage at operating point and current voltage.
Y	Admittance of line between two buses.
β	Failure rate at load point.
β_0	Failure rate of branch before DG placement.
β_f	Failure rate of branch with no active power flowing through the branch.
δ	Phase angle of voltage.
ε^{ES}	Cost of energy supplied of consumers.
ε^{ENS}	Cost of energy not supplied of consumers.
λ	Length of branch.
ρ, σ	Exponents of different load models.
Θ	Phase angle of Y.

I. INTRODUCTION

Over the past few decades, employment of distributed generation(DG) in distribution networks has gained prominence. Numerous factors have assisted to this phenomenon: remarkable being the need to reduce the cut down on fossil fuels, environmental concerns, cost of transmission and distribution expansion, various advantages of DGs and government subsidies. Strategically placed and sized DG units render various benefits such as power loss minimization[1]-[4], improvement in reliability level[5]-[7], enhancement of voltage profile and loadability[1],[8]-[9], mitigation of harmonics [10], stability and security[11]-[12] and other ancillary benefits particularly network investment deferral[13]. The aforesaid advantages further motivate the boost in DG deployment in distribution networks.

Various authors have investigated DG planning problems with numerous objective functions. Several planning strategies with single as well as mix of different objective criteria have been proposed. In [1], [8], DG placement problem has been studied for improving voltage profile. In [1], DG planning scheme was approached considering both system losses and voltage profile as criteria. Voltage stability margin [9], power stability index [11] and system loadability [12] had also been criteria for DG integration in the distribution system. In [14], dynamic model of DGs in the distribution system was developed wherein eco-friendly features of DGs were reflected. Environmental compensation cost, traditional DG capacity cost, purchased power cost, operation and maintenance cost and network loss cost were optimized using immune algorithm based approach. In [15], stochastic multi-objective structure was developed for microgrids considering economic, technical, reliability and environmental viewpoints.

Of all the advantages of DG integration, power loss minimization and reliability are unquestionably the most fascinating. There is a significant percentage of power loss in distribution networks [16]. This can be attributed to prevalent radial structures of distribution networks and high current to voltage ratio in distribution networks. Reduction in power and energy losses is chiefly dealt in major DG placement problems. Studies in [1]-[4] had examined DG placement problem considering minimum power losses. In [2], DG placement scheme was proposed for optimizing real and reactive power loss using Constriction Factor Particle Swarm Optimization (CFPSO). In [3], DGs were allocated in the system for minimizing real power losses and penalty factor of energy not served. DG placement scheme considering minimum network power losses along with enhancement in network regulation was approached in [4]. In [17]-[18] DG incorporation in distribution network was investigated for minimum energy losses.

Reliability concerns both the service providers as well as customers. It is particularly contended when cost per kW is high. Further, DGs are decentralized, flexible and modular technologies. Their ability to be installed close to the load they serve directly propels the opportunities to furnish reliability-differentiated services. The aforesaid factors have motivated many researchers to develop reliability driven DG planning schemes. Researches in [5]-[7] had evaluated DG placement problem from maximum reliability viewpoint. In [5], placement of reclosers as well as DGs was proposed in order to guarantee power system reliability using Ant Colony System algorithm. In [6], dispatchable and intermittent DG types placement strategy was introduced for maximum reliability specifications. DG planning strategy for minimum electrical losses along with agreeable reliability level and voltage profile was assessed in [7].

In the majority of researches [1]–[15],[17]-[18] done so far, feeder's failure rate has been disregarded while assessing DG placement problem and reliability computations, which means the dependence of feeders' failure rate on current through the feeder is neglected. Further, customers' load type is also not considered in the modeling. In [19]-[21] customer's load models in DG placement problem have been considered. Optimal placement of capacitors while considering customers' load models and feeders' failure rate was approached in [20]. In [21], exponent load models and feeders' failure rate has been considered in DG allocation problem.

In this study, optimal planning solution which involves decision of proper sizing and placement of the DG has been developed with an objective to minimize total cost over the planning span which involves energy loss cost, risk cost of energy not delivered, capital and operating cost. The scheme presented in this paper is distinct from preceding work on DG integration [1]-[19] in that modeling dependence of feeders' failure rate on the current flowing through the feeder is considered while also considering customers' load type. In order to focus on technical aspects such as reliability and power loss viewpoints, economic benefits obtained due to prevalence of price difference between the wholesale and retail markets are not exploited. The problem is simulated within line capacity and voltage limit constraints. For present worth evaluation of the cost involved over the planning span, economic factors namely, interest and inflation rates are also considered. The present worth value computation provides a premise for assessing the suitability of any future financial profits or liabilities. In order to have more accurate analysis, hourly and daily load variations are also accounted.

The remainder of the paper is detailed as follows. Section II, defines the problem statement. The system and load modeling is presented in Section III. Section IV gives the definition of parameters which validate the competence of the proposed solution. The proposed optimization method for solving the problem is presented in Section V. Section VI is describes the test system undertaken. In section VII results for various cases are presents. Section VIII concludes the work.

II. PROBLEM STATEMENT

The paper defines a problem of cost optimal DG arrangement in a distribution system with voltage limits and line capacity as constraints. The problem is stated as follows: *determine the locations, sizes and number DG to be deployed in the distribution network so as to minimize aggregate costs (energy loss cost, risk cost of energy not supplied, capital and* *operating costs) over the entire planning horizon within voltage and line capacity constraints.*

$$CF_T = min\begin{Bmatrix} InvestC_T + PWLoss_T + \\ PWRisk_T + PWMaintain_T \end{Bmatrix} \quad (1)$$

subjected to system security constraints i.e. :

$$|MVA_b| \le \max|MVA_b| \qquad \forall b \in S_b \quad (2)$$

and, $$0.95|V_i^{Sch}| \le |V_i| \le 1.05|V_i^{Sch}| \qquad \forall i \in S_i \quad (3)$$

A. Investment Cost Computation

The cost associated with purchase of DGs at optimal bus locations in accordance with planning scheme for entire planning horizon is given by (4). A DG location matrix (DGLM) is used to identify the number of DGs employed in the planning scheme. DGLM is column matrix with total number of buses as total rows. Any non zero element in DGLM confirms the presence of DG at corresponding bus.

$$InvestC_T = C^{DG} \times (\sum_{i \in S_i} N_i) \quad (4)$$

B. Computation of Present Worth Value of Energy Loss Cost

The present worth value of energy loss cost over the planning period can be computed as shown in (5).

$$PWLoss_T = \sum_{y \in S_y}\left(\sum_{m \in S_m} d\left(\sum_{h \in S_h}\left(\sum_{b \in S_b} \varepsilon_{h,x}^{ES} \times R_b \times |I_{y,m,l,b}|^2\right)\right) \times PWV\right) \quad (5)$$

$$where, PWV = \left(\frac{1+IFR}{1+ITR}\right)^y$$

C. Computation of Present Worth Value of Risk Level Cost

Risk level of the system can be defined as sum of energy not supplied during fault location, switching and fault repair for the planning period. The present worth value of risk level cost over the planning period calculated using (6).

$$PWRisk_T = \sum_{y \in S_y}\left(\left(\sum_{h \in S_h}\frac{D_{LL}}{24}\left(\begin{matrix}\sum_{b \in S_b}\beta_b^{Lin} \times \lambda_b \times \\ \left(\begin{matrix} D_{FLS}\sum_{i \in S_i} LNS_{y,x,i}^{FLS} \times \varepsilon_{h,x}^{ENS} + \\ D_{FR}\sum_{i \in S_i} LNS_{y,x,i}^{FR} \times \varepsilon_{h,x}^{ENS}\end{matrix}\right)\end{matrix}\right)\right) \times PWV\right) \quad (6)$$

D. Computation of Present Worth Value of Maintenance Cost

The present worth value of cost of repairing and maintaining installed DGs over the planning horizon can be evaluated using (7).

$$PWMaintain_T = \sum_{y \in S_y}\left((C^M \times (\sum_{i \in S_i} N_i)) \times PWV\right) \quad (7)$$

III. SYSTEM AND LOAD MODELLING

The modeling of feeders' failure rate, power flow model and modeling time varying loads as well as representation of operating conditions as sourced in this work are briefly elucidated in this section.

A. Modelling of Feeders' Failure Rate

DG units deployed across the distribution system, operating at unity power factor behave as negative active loads, which effectively decreases the load active power demand. As a result, the active component of current flowing through the feeder is reduced which reduces the magnitude of the current. Power losses, which are proportional to square of the current magnitude, also decrease with reduction in current magnitude. The temperature of the feeder is lowered. High temperature has a destructive effect on feeder such as sag in overhead lines and insulation issues in the underground cables [22]. This jeopardizes system stability and reduces the reliability. The temperature effect of current on feeder is moderated after DG placement.

For this work, modelling of feeders' failure rate has been referenced from [20]. Herein, linear relationship between feeders' failure rate and current is assumed. The feeders' failure rate is modelled in accordance with (8).

$$\beta_b = \frac{\beta_{0,b} - \beta_{f,b}}{I_{0,b}^a} \times I_b^a + \beta_{f,b} \quad (8)$$

Since reactive component of the current is still flowing through the branch, it is assumed that completely removing active component of the current flowing through the branch cannot decrease the branch's failure rate more than 90%. In other words,

$$\beta_{f,b} = 0.1 \times \beta_{0,b} \quad (9)$$

B. Modeling of Customers' Load Type

In common power flow problems, the value of reactive and active power demands are specified and constant and values of voltage magnitude and phase voltages are unknown. These values can be determined by using equations (10) and (11).

$$P_i^{Sch} = |V_i|\sum_{k=1}^{n}|V_k||Y_{ik}|\cos(\theta_{ik} + \delta_k - \delta_i) \quad (10)$$

$$Q_i^{Sch} = -|V_i|\sum_{k=1}^{n}|V_k||Y_{ik}|\sin(\theta_{ik} + \delta_k - \delta_i) \quad (11)$$

In real electric power system, the values of reactive and active power demands at various load points have a dependence on their operating voltage profile. Different nature of loads, such as residential, commercial and industrial loads are present and the nature of the loads is such that their reactive and active power loads are dependent on the frequency and voltage of the system. Also, load characteristics have notable impact on the load flow solution and its convergence. Generally, reactive and active powers are expressed in an exponential form or as a polynomial. The exponential load models can be modelled using (12) and (13).

$$P_i = P_i^{Sch}\left|\frac{V_i}{V_i^{Sch}}\right|^{\rho} \quad (12)$$

$$Q_i = Q_i^{Sch}\left|\frac{V_i}{V_i^{Sch}}\right|^{\sigma} \quad (13)$$

where ρ and σ are the exponents for the voltage dependent loads. The values of exponents for different customers' load types are taken from [19].

C. Modeling of Time Varying Loads

In order to have more accurate analysis, variations of load are taken into account in this DG placement and sizing scheme. The hourly and daily load variations are presented in [20]. Yearly load growth has also been incorporated. The system energy loss and energy loss cost calculations are done for every hour of a day whereas hourly variations in loading for month with peak load demand is considered for risk level and risk cost calculations. Price of electricity for different types of consumers and cost of energy not delivered of various consumers at various load levels is presented in Table I [21].

TABLE I. COST OF ENERGY SUPPLIED AND ENERGY NOT DELIVERED TO VARIOUS CONSUMERS AT VARIOUS LOAD LEVELS

Load Type	**Load Level**	**Cost of energy supplied (Cents/kWh)**	**Cost of energy not supplied (Cents/kWh)**
Res.	Light	17.69	17.69
	Medium	22.12	22.12
	Peak	26.54	26.54
Com.	Light	13.84	69.20
	Medium	17.30	86.50
	Peak	20.76	103.80
Ind.	Light	11.22	56.12
	Medium	14.03	70.15
	Peak	16.83	84.18

IV. PERFORMANCE EVALUATION PARAMETERS

Performance of the proposed algorithm can be validated using calculation of its impact on various technical parameters namely, active power losses, risk level and voltage profile. Since the solution proposes a cost based optimization approach, net cost savings due to implementation of the proposed scheme has also been computed.

A. Computation of Active Power Losses

The calculation of total active power losses throughout the planning period can be computed using (14).

$$PowerLoss_T = \sum_{y\in S_y}\left(\sum_{m\in S_m} d\left(\sum_{h\in S_h}\sum_{b\in S_b} R_b * \left|I_{y,m,h,b}\right|^2\right)\right) \quad (14)$$

B. Computation of Risk Level

The calculation of risk level over the planning horizon can be computed using (15).

$$Risk_T = \sum_{y\in S_y}\left(\sum_{h\in S_h}\frac{D_{LL}}{24}\left(\sum_{b\in S_b}\beta_b \times \lambda_b \times \left(\begin{array}{l} D_{FLS}\sum_{i\in S_i} LNS_{y,i}^{FLS} + \\ D_{FR}\sum_{i\in S_i} LNS_{y,i}^{FR}\end{array}\right)\right)\right) \quad (15)$$

C. Computation of Voltage Profile

Voltage profile is a plot which represents the per unit value of voltages at each bus for various load levels. Voltage profile for each load level is sketched corresponding to the highest demand in that load level for the month with highest demand in the first year of planning.

V. PROPOSED OPTIMIZATION ALGORITHM

The flowchart to depict implementation of the algorithm for this planning problem is given in Fig 1.

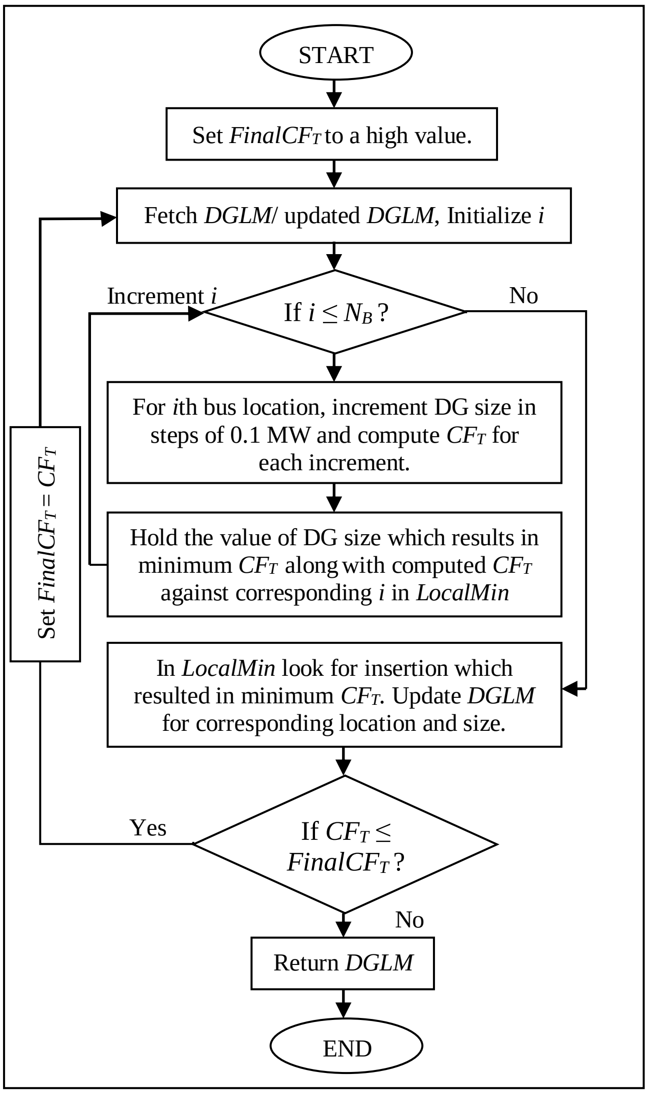

Fig. 1. Flowchart to depict implementation of greedy search algorithm

In this research work, Greedy Search Algorithm has been employed to find optimum placement and sizing of DGs in the distribution system. A greedy search algorithm is an algorithmic scheme that follows the problem solving heuristic of making the locally optimal choice at each stage in order to find a global optimum solution.

VI. TEST SYSTEM

Fig. 2 shows the electrical distribution network undertaken to examine the proposed methodology. It is a 28-bus system with 28 load points and 27 branches and with different consumers including residential, commercial, and industrial. Six normally closed switches are installed.

Also, a normally open switching point at bus 28 is provided for load transmission from feeder F1 onto feeder F2 while a permanent fault is occurred in feeder F1.

The probability that the feeder F2 can convey the transmitted load of the feeder F1 is assumed to be about 60%. In the beginning of the feeder F1, is an installed circuit breaker (CB) which automatically opens if a permanent fault occurs and it cannot be closed until the fault is removed or the faulty part is isolated. The CB is closed only after identifying the fault location and performing one of the actions below:

i. Opening the related switches for isolating the faulty branch;

ii. Repairing the fault branch if the switching action is inefficient for isolating the faulty branch.

Table II indicates initial data for assessment of the given planning problem which includes investment cost for purchasing a DG, size of the DGs, yearly maintenance cost of a DG, inflation and interest rates, load growth, planning horizon, base kV and base MVA and other necessary data for reliability assessment.

The other network data including values of active and reactive demands at each bus, lines' impedances, lines' capacities, customers' load types, and number of customers connected to each bus are presented in [20].

TABLE II. PARAMETERS AND INITIAL DATA FOR ASSESSMENT [21]

Parameters and Initial Data	Unit	Value
Investment Cost of DG	$/DG	80000
Maximum Size of DG	MW	1
Maintenance Cost of DG	$/year	4000
Inflation Rate	% / year	10
Interest Rate	% / year	15
Annual Load Growth	% / year	1
Planning Period	Years	20
Base Voltage	kV	20
Base MVA	MVA	10
Fault Location Period	Hours	1
Switching Time	Hours	0
Fault Repair Time	Hours	3
Length of Each Branch	Km	1
Failure Rate for Each Branch	f/(Km.year)	0.3

VII. RESULTS AND DISCUSSION

The results have been simulated for three different cases:

Case I: DG placement planning when both Feeder's Failure Rate and Customer's Load Type are modeled

Case II: DG placement planning when customer's load type is modelled and feeder's failure rate is considered constant

Case III: DG placement planning when feeder's failure rate is modeled and customer's load type is not modeled.

The results are also compared and error/ detriment has been calculated in order to reflect the importance of feeders' failure rate modeling and customers' load type modeling in DG planning problems where reliability improvement is primary objective.

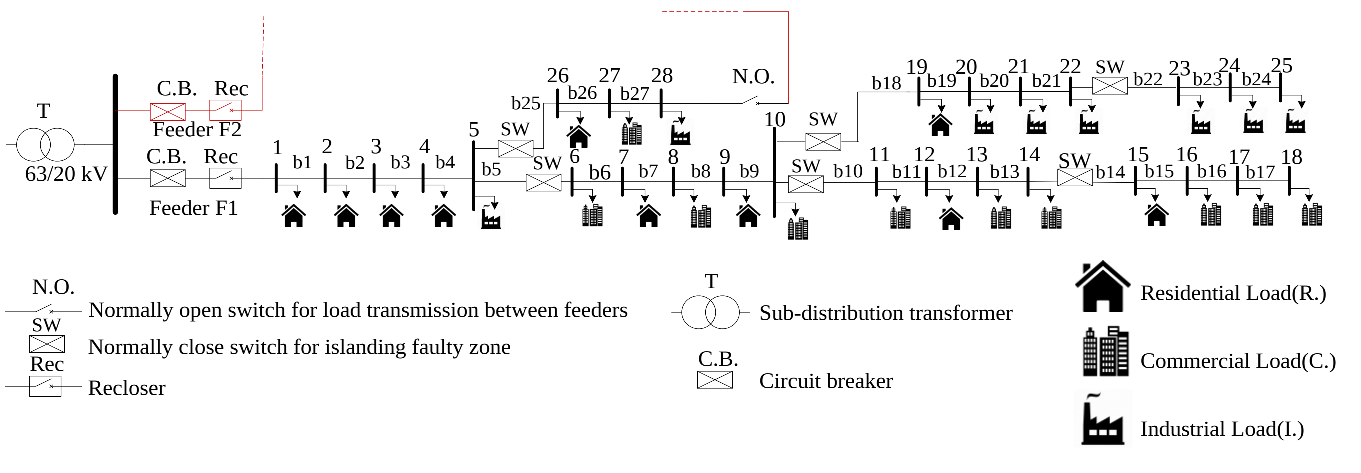

Fig. 2. Electrical distribution network considered for study that includes residential, industrial, and commercial consumers [21].

A. Case I: DG placement planning when both Feeder's Failure Rate and Customer's Load Type are modeled

The simulation results of the planning problem before and after placement of DGs have been presented in Table III. In this case, both feeders' failure rate and customers' load type are regarded as factors which affect DG placement planning.

The results of pre-placement of DGs are found to be comparable to the results from [21] with an error within 0-2%. This sets a fair basis for comparison between the two methodologies. The suggested placement and sizing of DGs for various cases is depicted in Table IV.

Although, the placement strategy for this case adds a total outlay cost of 1.32 million $, the net cost savings from this strategy amount to 3.73 million $. Comparison with results from [21] show that the performance of proposed method overrides the technique in [21] for all economic and technical parameters except total maintenance cost over the planning period. However, the net cost savings using proposed algorithm are more than the one achieved using [21]. Figure 3 gives a comparison of voltage profile before and after integration of DG placement strategy. There is an significant improvement in voltage profile for all of the different load periods.

TABLE III. CASE I SIMULATION RESULTS BEFORE AND AFTER PLANNING

Simulation results for economics of planning (in million $)				
Parameters (over the entire planning period)	***Before planning***		***After planning***	
	Results from proposed scheme	***Results from [21]***	***Results from proposed scheme***	***Results from [21]***
InvestCT	0	0	0.800	0.880
PWMaintainT	0	0	0.518	0.406
PWLossT	4.865	4.917	1.248	1.342
PWRiskT	2.210	2.190	0.776	0.908
Technical impacts of DG planning scheme				
Power Loss (MW)	38229	38926	9697.5	10830
Risk Level (MWh)	5355.5	5380	2098.4	2292

TABLE IV. DG PLACEMENT AND SIZING (IN MW) FOR VARIOUS CASES

Bus No.	**11**	**13**	**14**	**15**	**17**	**18**	**20**	**21**	**23**	**24**	**25**	**28**
Case I	1	1	0	1	1	1	0	1	1	1	1	1
Case II	1	1	1	1	1	1	1	0	1	1	1	0
Case III	1	1	0	1	1	1	0	1	1	1	1	1

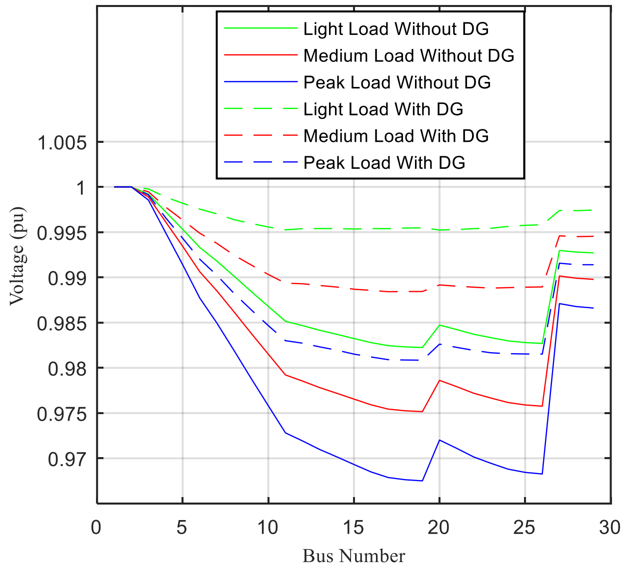

Fig. 3. Voltage Profile Corresponding to Case I

B. Case II: DG placement planning when customer's load type is modelled and feeder's failure rate is considered constant

In this case, the dependence of feeders' failure rate on DG planning problem has been disregarded. The simulation is then carried out for suggested DG allocation and amount of detriment is reported in Table IV. As presented in Table V, the total outlay cost in both Case I and Case II turns out to be the same, however, the detriment in total cost savings, particularly due to cost of risk level is quite significant and amounts to 5.380 hundred thousand $. Similarly, the risk level has risen by 1493.1 MWh. Power losses for case-II are more than case-I. Voltage profile as observed is presented in Fig 4. The DG allocation scheme in Table IV suggests that the DG location, in this case has changed.

TABLE V. VALUES OF THE DETRIMENTS FOR CASE II (WHEN COMPARED TO CASE I)

Simulation results for economics of planning (in thousand $)		
Parameters (over the entire planning period)	***After planning***	
	Detriment for proposed scheme	***Detriment for [21]***
InvestCT	0	-159.92
PWMaintainT	0	-108.35
PWLossT	8.465	500.38
PWRiskT	529.63	201.94
Total Outlay Cost	0	-268.28
Net Cost Savings	-538.09	-235.03
Technical impacts of DG planning scheme		
Power Loss (MW)	132.8	4240
Risk Level (MWh)	1493.1	522

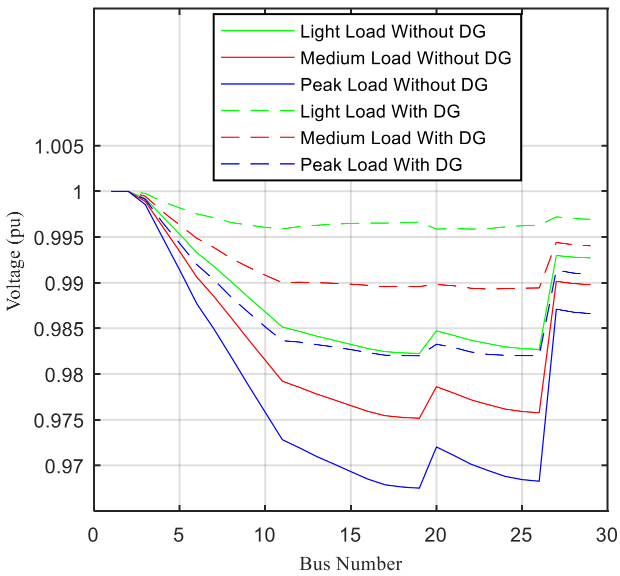

Fig. 4. Voltage Profile Corresponding to Case II

C. *Case III: DG placement planning when feeder's failure rate is modeled and customer's load type is not modeled*

In this case, customers' load type is disregarded in the planning problem, which means simple power flow is applied. As Table IV suggests there are no variations in DG placements when compared to case-I. The errors and detriments in the economic as well technical performance of this case are recorded in table VI.

TABLE VI. VALUES OF THE DETRIMENTS FOR CASE III(WHEN COMPARED TO CASE I)

Simulation results for economics of planning (in thousand $)		
Parameters (over the entire planning period)	***After planning***	
	Detriment for proposed scheme	***Detriment for [21]***
InvestC$_T$	0	80.036
PWMaintain$_T$	0	31.707
PWLoss$_T$	-263.04	-120.979
PWRisk$_T$	6.464	-52.485
Total Outlay Cost	0	111.744
Net Cost Savings	184.23	61.874
Technical impacts of DG planning scheme		
Power Loss (MW)	840.5	-918
Risk Level (MWh)	14.3	-118

Case-III registers the minimum *PWLoss$_T$* among all the three cases when the total power losses for case-III are the maximum. This can be attributed to the fact that the power losses corresponding to case-III mainly consist of industrial losses, with negligible or no residential and commercial losses and the electricity price for industrial consumers is less than residential and commercial consumers in this study. Table VI shows breakdown of total power losses over the planning period according to various customers for case I and case III. The voltage profile as observed is depicted in Fig 5. Case-III, even with better economic performance cannot be called the best case because the results for case-III are system dependent and cannot be generalised for all test systems.

TABLE VII. BREAKDOWN OF TOTAL POWER LOSSES OVER THE PLANNING PERIOD ACCORDING TO VARIOUS CUSTOMERS FOR CASE I AND CASE III

	Case I	**Case III**
Residential Power Losses	5324.2MW	0 MW
Commercial Power Losses	2560.8 MW	0 MW
Industrial Power Losses	1812.5 MW	10538 MW
Total Power Losses	9697.5 MW	10538 MW

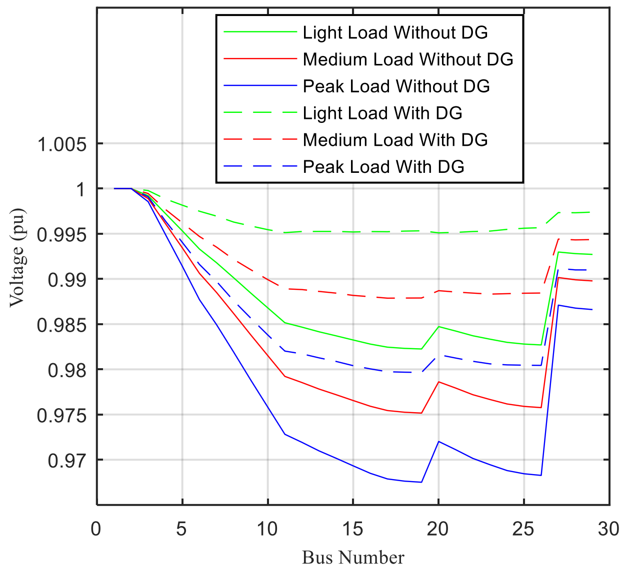

Fig. 5. Voltage Profile Corresponding to Case II

VIII. CONCLUSION

This study was set out to model a distribution system with DGs, to determine the location, sizes and number of DG units to be deployed in distribution system considering reliability and active power losses as criterion and to investigate overall technical and economic performance for the distribution system including DGs. The results were compared to a GA based approach from previous researches. For case-I the proposed methodology performs better than the method proposed in [21] in all parameters other than PWMaintainT. However, the overall improvements in all other parameters make up for poor PWMaintainT for the proposed technique.

Another inference that can be drawn from this research is that feeders' failure rate modelling is significant particularly when risk level is primary concern in DG planning. There is an increased risk level of 1493.1 MWh over the planning period when feeders' failure rate is not modelled.

Of all the three cases, case-I is definitely the best case where both feeders' failure rate and customers' load type are modelled. Case-III, even with better economic performance cannot be called the best case because the results for case-III are system dependent and cannot be generalised for all test systems. It is concluded that to extract maximum benefits of DG installation customers' load type and feeders' failure rate must be essentially modelled.

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