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Evaluation of configuration plans for DGs in developing countries using tradeoff analysis and MADM

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Abstract

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Evaluation of Configuration Plans for DGs in Developing Countries using Tradeoff Analysis and MADM

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***Abstract*--Many developing countries have emphasis on DG technology for their generation expansion planning. The planning considerations and judicious choice of attributes is dictated by the prevailing conditions. With the increased complexities in DG planning options along with multiple attributes to be accounted, more sophisticated techniques are needed to arrive at the correct decisions by decision makers. The Analytical Hierarchy Process (AHP) is proposed to identify the relative significance of the chosen attributes. Proper integration of different attributes can be achieved by linear additive utility function. The uncertainties are accounted using tradeoff analysis by co-relating normalized values of chosen attributes. The superior plans can be identified at the knee set of tradeoff region. The solution space can be further narrowed by the statistical method like interval based Multi-Attribute Decision Making (MADM). The attributes considered are capital costs, energy not served per annum, and profits from injecting power into grid at peak load for all cases. The uncertain futures considered are three possible loading conditions which can be low, medium, and high. The different scenarios (plans) are generated by various combinations of configurations. DGs can be configured as stand alone, hybrid operation, and micro-grid formation, leading to a total of 11 distinct plans. The grid connection is considered optional. The sample system is derived from a practical system in India which is typical representative of a developing country. The results indicate that the proposed decision making technique has an ability to quantify the merits and evaluate plans on a common platform. The assessment of plans is presented and discussed.**

***Index Terms*--Distributed generation, decision support system, hybrid operation, micro-grid, tradeoff analysis**

I. INTRODUCTION

THE developing countries are adopting DG technologies for their generation expansion planning. The wide acceptance of these technologies is for obvious reasons which are well-known. However, the technologies should be candidly assessed on a common platform. The decision maker is confronted with the strategic planning studies with various options for DGs such as grid connection, hybrid systems and now the new option of micro-grid. Micro-grid option has attracted considerable attention of the researchers, and though there are many positive points listed in its favor, they have to be substantiated with the analytical methods which can quantify the benefits. The evaluation of plans can be carried out in three phases. In the first phase, one has to identify the significant attributes, several planning strategies and various futures accounting for uncertainty factors. The relative importance of these attributes can then be evaluated with the help of Analytic Hierarchy Process (AHP). In the second phase, the tradeoff region is generated for various attributes. This information will be useful for deciding the feasible solution space. In third phase, an interval based multi-attribute decision making (MADM) has to be done for the preferential ranking of various feasible planning options and to find out the most viable plan. An elaborative treatment of tradeoff analysis is available in [1], [2]. In [1], tradeoff methodology has been used for strategic resource planning. Different options like coal plant, combined cycle plant, California import, etc., are considered with uncertainties like gas price, load growth, coal plant arrival, etc., so as to find the best way to meet additional firm load of 1000 MW. The design of stand-alone system based on non-conventional energy sources is discussed in [2] with the help of tradeoff analysis.

The MADM approach is most suitable technical aid for strategic planning of electric utilities. It selects the best resource strategy with regard to the chosen attributes [3]. According to [4], MADM will be the appropriate choice for justifying the new technology. Normally, in MADM approach, the information available to the decision maker is often imprecise due to erroneous attribute measurements and imperfect priority judgments. However, the responsible decision maker must balance judgments about uncertainties with his/her preferences for possible consequences or outcomes. To attempt any formal analysis of a complex decision problem requires an articulation of the decision maker's objectives and an identification of attributes useful for indicating the extent to which these objectives are achieved [5].

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Until recently, the viability of DG in a power system was generally justified by cost-benefit analysis, possibility of T&D deferment, reduction in T&D losses, etc. [6, 7]. These all are no doubt important issues but these need not be the only deciding factors. It is very likely that without fulfilling all these requirements, DG may become feasible so as to protect sensitive loads. Studies have predicted that DG may account for up to 20% of the all new generation going online by the year 2010 [8]. This paper reports a novel approach of tradeoff analysis with the help of interval based MADM technique for evaluating the possibilities of various configurations of DGs like hybrid DG source, micro-grid, etc., for typical medium voltage rural distribution system in the State of Maharashtra, India. The comparative assessment of various individual technologies with all possible options can provide executive summary to the decision maker. The use of MADM technique provides a statistical background for comparison of various configuration plans, which gives more precise treatment for addressing tradeoff analysis as compared to approach by [1], [2]. The selection of attributes, various expansion options and the futures representing uncertainty are in context to a typical MV distribution system under consideration.

The paper is organized as follows: Sections II and III review the rural electrification initiatives in the State of Maharashtra in India using DG technology. Section IV elaborates fundamentals of AHP. Next, the tradeoff analysis is covered in section V. The mathematical basis for MADM technique and interpretation of the point estimates are elaborated in section VI. The sample system and results are given in section VII. The comparative assessment of all results is discussed in the concluding section.

II. Rural Electrification Initiatives in the State of Maharashtra

According to Electricity Act 2003 and guidelines from the Ministry of Power (MOP), Government of India, the Maharashtra Electricity Regulatory Commission (MERC) has proposed a comprehensive plan for implementation and facilitation of rural electrification and supply initiatives in the State [9]. It talks about various possible options for 100% electrification in the State. There is a need to explore other models so as to achieve Accessibility, Availability, Reliability, Quality and Affordability (AARQA) goals for rural electrification and supply in the State. Two alternative models are proposed:

A. Generation and Distribution of Electricity through Local Suppliers

Alternative supply arrangements in rural areas in the form of small capacity generation and distribution systems should be encouraged through a facilitative policy and regulatory framework. The development of such a system offers several benefits, some of which are as follows:

- Improvement in the quality and reliability of supply to small rural communities.
- Harnessing the renewable energy and cogeneration potential of the State.
- Village-level employment generation and additional revenue from sale of biomass leading to growth in disposable incomes of the village communities.

The implementation of such systems should be encouraged through some sort of subsidy schemes. It will be useful for minimizing the burden of high initial capital cost and for increasing the affordability for rural communities. It has been proposed that there will be a capital subsidy of around 40% for stand-alone distributed generation systems meant for rural electrification. However, in order to safeguard against such systems being used primarily for the purpose of supply of electricity to industrial consumers located in rural areas, it is recommended that the supply of electricity to industrial consumers from such systems should be restricted to a maximum of 50% of the generating capacity. The import of electricity from the grid in any quarter during the financial year should not exceed 10% of the total generation of electricity by such system, except in case of unforeseen breakdown in the generation system for temporary periods.

B. Rural Distribution and Supply through Local Distribution Entities (LDE)

The preferred model for rural distribution and supply of electricity is through a large number of local suppliers who undertake all the functions of Distribution Licensee in the local area of operations. As per the Electricity Act 2003, these local suppliers may be local authority, *panchayat* institution, user's association, co-operative societies, non-governmental organizations, franchisees, etc. LDE may either choose to set up its own distribution system or it may take over the State Electricity Board (SEB) distribution system for local operations. In case, if the State Government wants to provide subsidy to the customers served by LDE then subsidy may be directly passed to the customers or to the concerned LDE or to the distribution licensee supplying bulk power to LDE.

A performance review and incentives framework is a key element in the institutional framework for rural supply through LDEs as it facilitates improvement in operating efficiency and consumer service. It is recommended that an appropriate performance monitors and incentives framework be introduced for LDEs, which could include the following parameters:

- Specific revenue realisation.
- Percentage of metered sales in total sales.
- Aggregate technical and commercial losses.
- Network costs.
- Distribution transformer failure rate.
- System reliability index.
- Voltage level of consumer at the tail-end of the distribution system.

III. Renewable Energy Technologies in the State

India has got a large potential of renewable energy sources in the country. It is observed that among all these technologies, Wind, Biomass and Bagasse based generation will play a dominating role in near future [10]. In all these technologies, India's position in the world is among the top five countries. In the State of Maharashtra, the installed capacity for wind as well as for bagasse/biomass is expected to be around 1000 MW and 500 MW respectively at the end of year 2007 [11]. In this paper, we have concentrated on wind-solar hybrid scheme, biomass based generation and bagasse based co-generation, which are potential technologies for rural electrification in the State of Maharashtra.

Solar energy is available only during the day time and the availability of wind will be dictated by the atmospheric conditions. Hence, the hybrid combination of wind and solar system can also be used for generating electricity effectively. Such hybrid schemes are already in operation in the western part of Maharashtra.

Huge quantity of biomass in the form of husk, straw, shell of coconut, wild bushes, crop/agro residues, etc., is abundantly available in Maharashtra. Maharashtra is having around 800 MW potential of biomass based power generation. India is one of the largest producers of sugarcane in the world. For bagasse based co-generation, sugar factories have been offered favorable policies from the State as well as the Central Government. Co-generation primarily means production of two or more useful forms of energy such as electrical power and steam. In Maharashtra, there are around 160 sugar factories and the total potential for bagasse based power generation in the State is around 1000 MW. Currently, there are seven co-generation projects with the installed capacity of around 75 MW. Maharashtra is ranked second in the country in terms of power generation from renewables. The total potential and the cumulative achievements as on 31-03-2003 are as shown in table I.

TABLE I
RENEWABLE POWER GENERATION CAPACITY IN MAHARASHTRA [11]

S. No.	Source	Potential in MW	Achievement in MW
1	Wind	3650.00	399.35
2	Small Hydro	600.00	226.57
3	Bagasse Co-generation	1000.00	23.50
4	Biomass	781.00	7.50
5	Municipal Solid Waste	100.00	0.00
6	Industrial Waste	210.00	6.12
Total		6341.00	663.05

It is observed that in some parts of the State there is a possibility to interconnect two or three renewable sources located in the close vicinity of each other. More precisely, these sources can form their own micro-grid which will cater for the local loads in that area. This micro-grid may operate in a stand-alone or grid connected mode.

Usually the micro-sources are located near the sensitive loads and hence during the interruption of grid supply, they may be operated in stand alone mode so as to protect the sensitive loads. Use of multiple sources in the form of a micro-grid, addresses the issue of providing energy especially during outages with a high degree of redundancy. We now build up the background of decision making process in planning studies in phases. The first phase is defining attributes and hierarchy as described in the next section.

IV. ANALYTICAL HIERARCHY PROCESS

The Analytical Hierarchy Process [12] is a general theory of measurements and is most suitable for integrated resource planning. It is used to derive ratio scales from both the discrete and continuous paired comparisons. The pair wise comparisons are elementary in AHP. These comparisons may be taken from actual measurements or from a fundamental scale which reflects the relative scale of preferences and feelings [13]. It is very important to decide the focus of the hierarchy and how the elements in the second level serve to fulfill that focus. The process should continue for each parent element and its descendants. Thus the matrix of pair wise comparisons of the criteria with respect to the overall focus is generated at each level. The next step is to derive the scale of priorities (weights). This scale can be obtained by solving for the principal eigenvector of the matrix and then normalizing the result. This is called local derived scale before weighting by the priority of its parent criterion. After weighting, it is called global derived scale. In this paper, the software package supporting the AHP, known as "expert choice" is used to make these calculations so as to guide the decision maker [14]. AHP may also be used to evaluate the scenario probabilities, criteria weights and uni-dimensional utility function [15]. The hierarchy for the planning process can be typically represented as shown in Fig. 1

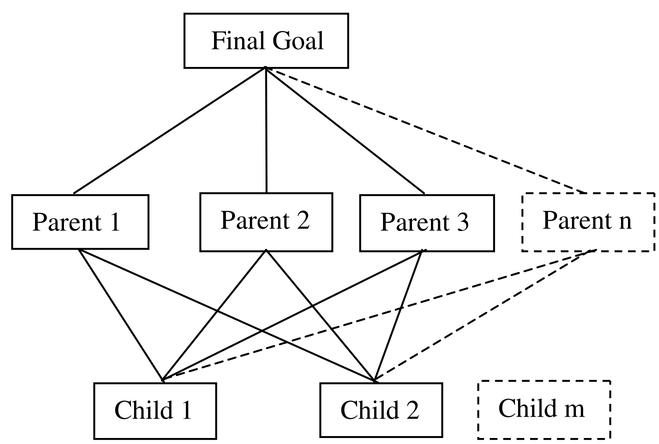

Fig. 1. Hierarchy of the planning process

AHP analysis can be used in conjunction with the scenario analysis so as to account for uncertainty in the system [15]. The decision maker can generate three different scenarios like high risk scenario, medium risk scenario and low risk scenario, and then all the attributes are evaluated for each scenario. This is rather primitive way of incorporating uncertainty and hence interval based MADM approach with the additive utility function is used here so as to decide the best possible expansion strategy which reflects a risk-neutral attitude of the decision maker [3]. The next section deals with the additive utility function and MADM philosophy.

V. Tradeoff Analysis

The tradeoff analysis was developed for finding the best possible solution to the problems with multiple conflicting objectives and uncertainties. It is an organized way of evaluating relationships between attributes and uncertainties and eliminating many plans that are inferior [1]. This approach is very much useful in electric utility strategic planning for dealing with wide range of resource options, conflicting attributes, and concerns for risk due to uncertainty [3]. The conceptual graph between the normalized values of two attributes A and B as shown in Fig. 2, is the best indicative of tradeoff analysis. The tradeoff region is the set of all feasible plans bounded by the dotted lines. Knee set is a conditional decision set with a set of plans that appear to be better than others on the basis of compromise between the normalized values of given attributes. Since our main aim is to minimize all the attributes, it can be easily inferred that plans in the knee set are more attractive.

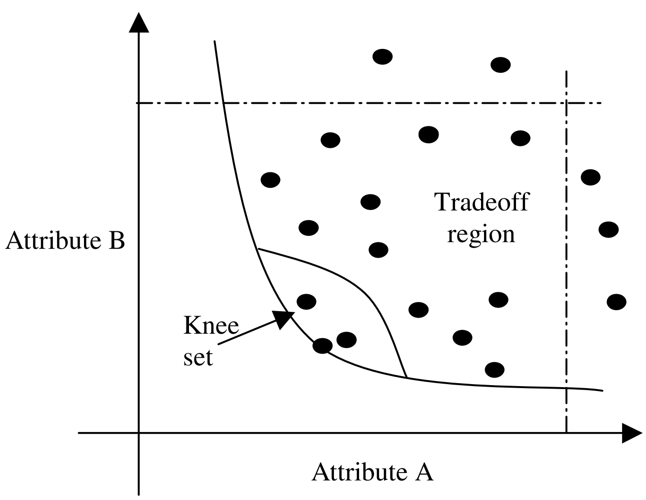

Fig. 2. Conceptual tradeoff curve

This process has to be repeated for examining the performance of each configuration plan under the various features. Hence, number of knee sets will be generated and the robust plan is the one which will appear in all the decision sets. A future is a set of specified uncertainties which can be either modeled by considering the probability distribution for all the uncertainties or by considering the upper and lower bounds on the uncertainties without considering any probability distribution. With no uncertainty, results are conditional on one particular future. The tradeoff curve set can be defined as a set of all plans that are not strictly dominated by any other plan conditional on a particular future. Knee set is a set of all plans that are not significantly dominated by any other plan [1]. The tradeoff region forms the boundary between the sets of possible and unattainable attributes. In tradeoff analysis [1], tolerance limit needs to be specified for each attribute as 'much worse' or 'significantly better', etc., by the decision maker but the use of interval based MADM technique [3] will provide a strong statistical base for finding the superior alternative.

VI. Interval Based MADM Approach [3]

A. *Additive Utility Function:*

Usually most of the MADM problems can be tackled by transforming n-dimensional vector performance into a scalar performance by using multi-attribute utility function (MAUF). The assessment of an appropriate MAUF itself is a big task. MAUF model is comprised of the single utility function and the weighting parameters associated with the chosen attributes. Individual utility functions reflect the decision maker's attitude towards taking a risk, and the weighting parameters reflect the decision maker's priority with regard to different attributes. Conceptually, the composite utility value is a nonlinear function of a single utility function and weighting parameters. One way of analyzing this problem is to decompose MAUF into a series of single attribute assessments. This special form of MAUF model is also known as linear additive form and it can be used only if the contribution of an individual attribute to the composite utility is independent of other attribute values. A general expression of linear additive utility function model can be expressed as:

$$Ut(x) = \sum_{i=1}^{n} w_i \cdot Ut_i(x_i) \tag{1}$$

where,
$Ut(x)$ is the composite utility characterized by the vector of attributes $x = [x_{i,}......., x_n]$,
$Ut_i(x)$ is the single utility function with respect to the i^{th} attribute,
w_i is an appropriate weighting parameter for the i^{th} attribute, representing its relative importance in comparison to other attributes and satisfying $\sum w_i = 1$.

B. *Variance of Composite Distance:*

There are two important terms that are of concern in the construction of linear additive utility model, one is the single utility function and the other is weighting parameter. However, in many MADM applications, the single utility function $Ut_i(x)$ can be represented by the normalized attribute value r_i. If x_i and r_i are the measured and normalized values of the i^{th} attribute, x_i^r is the range of variation of measured attribute values and x_i^* is the optimal value of i^{th} attribute, then the composite distance $Ut_d(x)$ can be represented as:

$$Ut_d(x) = \sum_{i=1}^{n} w_i \cdot \left| \frac{x_i - x_i^*}{x_i^r} \right| = \sum_{i=1}^{n} w_i \cdot r_i \tag{2}$$

For equation (1), the best alternative is the one for which the value of composite utility will be maximum. On the contrary, the most favorite alternative determined by equation (2) represents a minimal distance from an ideal point on the direction preferred by the decision maker and hence the term composite utility is replaced by composite distance.

The influence of inaccurate data on the various planning alternatives can be examined by using a technique of propagation of errors. If there exists a set of numbers and their errors, then the error in some prescribed function involving these numbers can be calculated by using the propagation of errors. For a function y = f (x_1, x_2, ..., x_n), the general expression for propagation of errors can be written as [4]:

$$\sigma_y^2 = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i} \cdot \sigma_{xi} \right)^2 \tag{3}$$

where σ_{xi} is the standard deviation of variable x_i and σ_y is the standard deviation of the prescribed function. Accordingly, the variance of composite distance for linear additive utility function will be:

$$\sigma_d^2 = \sum_{i=1}^{n} \left(\frac{\partial Ut_d}{\partial w_i} \cdot \sigma_{wi} \right)^2 + \sum_{i=1}^{n} \left(\frac{\partial Ut_d}{\partial r_i} \cdot \sigma_{ri} \right)^2 \tag{4}$$

Hence, $$\sigma_d^2 = \sum_{i=1}^{n} \left(r_i^2 \sigma_{wi}^2 + w_i^2 \sigma_{ri}^2 \right) \tag{5}$$

where σ_d is the standard deviation of composite distance values, σ_{ri} and σ_{wi} are the standard deviations, i.e., the error parameters of the normalized i^{th} attribute and its weighting parameter. If p is the number of alternatives to be evaluated, the standard deviation σ_{ri} for a specific alternative, say j, can then be evaluated as:

$$\sigma_{ri}^2 = \frac{1}{\left(x_i^{\max} - x_i^{\min}\right)^4} \cdot \left[\sigma_{x_{ij}}^2 \left(x_i^{\max} - x_i^{\min}\right)^2 + \sigma_{x_i^{\max}}^2 \left(x_{ij} - x_i^{\min}\right)^2 + \sigma_{x_i^{\min}}^2 \left(x_{ij} - x_i^{\max}\right)^2 \right] \tag{6}$$

where,

$x_i^{\min}$ is the minimum of $|x_{ij}|$ for j = 1, 2, ..., p

$x_i^{\max}$ is the maximum of $|x_{ij}|$ for j = 1, 2, ..., p

x_{ij} is the i^{th} attribute for alternative j

The utility function for a single attribute can be approximated by taking the normalization of attribute ratings. Since each attribute possesses various units of measurement, normalization is necessary to obtain a comparable scale which further allows the additivity in equation (1) [4].

VII. Sample System and Results

In this paper, a sample 11 kV distribution feeder from a typical medium voltage rural distribution system from the State of Maharshtra, India, is considered. Three independent attributes and three uncertain futures are considered and the value of each attribute is calculated for various possible configuration plans under consideration. AHP is used for deciding the priorities among all the attributes. By using a tradeoff analysis, the viable sets of plans are short listed for all the uncertain futures. Finally, with the help of additive utility function and MADM approach, the variance of composite distance is evaluated for all the short listed plans. The planning option, which will appear in the conditional decision set for all the futures with minimum value of variance, will be the best option.

A. Details of the Sample System under Study

The small portion of a sample system under consideration is as shown in Fig. 3. It covers around 25 ckm of a realistic 11 kV feeder as a small part of the MV distribution system.

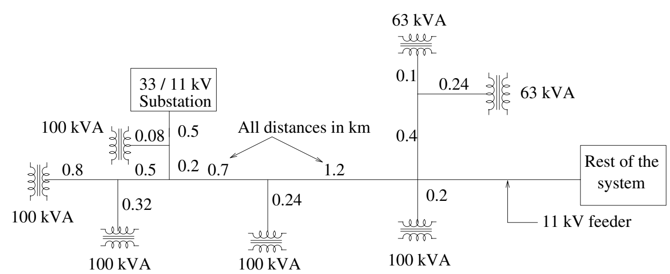

Fig. 3. Sample system under study

This is a typical radial feeder serving a mix of consumers, viz. residential, commercial, industrial, agricultural, etc. It has only one source and hence redundancy of the system is very poor. Nevertheless, it can be improved by ring feeding at some of the strategic locations.

Three uncertain futures are considered with different loading conditions for residential, commercial, industrial and agricultural sectors as shown in table II.

TABLE II
Different Loading Patterns

Futures	Residential (kW)	Commercial (kW)	Industrial (kW)	Agricultural (kW)	Total (kW)
F1	247	62	224	1212	1745
F2	353	88	328	1751	2520
F3	122	31	114	607	874

Future 1 represents the base case and apart from this, two separate loading conditions with high and low loads are considered. According to the sector-wise loading pattern, there will be 69.5% of agricultural load, 14% of residential load, 13% of industrial load and 3.5% of commercial load on the sample feeder. For futures 1 and 2, total 26 numbers of 100 kVA transformers, 7 numbers of 63 kVA transformers and 33 numbers of double pole structures are considered for catering the total load. In the case of future 3, there will be a total 9 numbers of 100 kVA and 4 numbers of 63 kVA transformers with 13 numbers of double pole structures. This data is derived from the real life system of Maharashtra State Electricity Board, India. This plan may be considered as one of the expansion strategies for the configuration plans under consideration.

It is also assumed that there will be other DG configuration plans considering stand-alone, Hybrid and micro-grid operation. DG technologies, which are considered for this particular study, are: gas turbine, wind plus solar hybrid, biomass, bagasse, etc. Micro-grid formation is considered by integrating biomass, bagasse and wind-solar technology. All these technologies may or may not be connected with the grid. DG capacities are flexible depending upon the loading conditions. Three totally independent attributes, i.e. energy not served in an annum (MWh), capital cost (billion INR) and profits for injecting power at peak loads are considered.

With the typical problems of a developing country, the vertically integrated State Electricity Boards are unable to supply reliable and quality power to consumers. Currently, there is a routine load shedding of six hours for rural feeders and three hours for cities on daily basis. The first attribute, i.e., energy not served, takes into account this practical real life situation. Recently, the Government [16] has taken some initiatives for promoting distributed energy sources/renewables for rural electrification. They will be awarded a capital subsidy to the extent of up to 40% of the capital cost. This fact has been taken care of in the second attribute, i.e., capital cost.

The new concept of Availability Based Tariff (ABT) [17] has been implemented in India in the mid of year 2002, wherein all the Central Sector generators and beneficiaries (i.e., various States) must declare a schedule for generation and drawal for every 15 minutes one day in advance. Any deviation from the schedule is charged at the rates, which are frequency dependent. The intra-State ABT mechanism is currently under consideration so as to encourage additional amount generation locally near the load centers. According to Time of Day (TOD) tariff for most of the utilities, there will be morning peak (09.00 to 12 hours) and evening peak (18.00 to 22.00 hours) in a day. DGs may be able to inject some power in to the grid in the peak periods and thus they can be benefited by injecting unscheduled power at peak periods under intra-State ABT mechanism. Since the preliminary aim for each DG option is to serve local loads in its close vicinity, the third attribute, i.e., profits for injecting power at peak loads is evaluated by injecting fractional power at average frequency in the peak periods. For the sake of tradeoff analysis, all the three attributes should have common lower the best characteristics. Hence, the last attribute is converted into reciprocal of profit.

The values of various attributes for all the futures are as shown in table III. These values are used for calculating the variance of composite distance for various configuration plans. The option with the minimum value of variance is the best one. As per the tradeoff analysis, the planning option with conventional grid is considered as an inferior plan. The term INF represents the infeasible value of the concerned attribute.

TABLE III
VALUES OF ATTRIBUTES FOR DIFFERENT CONFIGURATION PLANS

Plan no.	Configuration plans	Energy not Served in an annum (attribute 1)			Capital cost (attribute 2)			Reciprocal of profit (attribute 3)		
		F1	F2	F3	F1	F2	F3	F1	F2	F3
1	Conventional grid	1	1	1	0.023	0.01	0.03	--	--	--
2	Gas turbine	0.044	0.044	0.044	0.048	0.043	0.057	1	0.25	0.96
3	Gas turbine + grid	0.34	0.36	0.34	0.058	0.052	0.073	1	INF	0.96
4	Wind + solar	0.019	0.02	0.013	1	1	1	1	0.25	0.96
5	Wind + solar + grid	0.31	0.34	0.32	0.58	0.55	0.67	0.85	INF	0.96
6	Micro-grid with biomass + wind + solar	0	0	0	0.35	0.37	0.48	1	INF	1
7	Micro-grid with bagasse + biomass	0	0	0	0.075	0.064	0.089	1	INF	0.96
8	Micro-grid with biomass + wind + solar + bagasse	0	0	0	0.35	0.37	0.53	1	1	1
9	Bagasse + grid	0.34	0.36	0.34	0.058	0.048	0.069	1	INF	0.96
10	Micro-grid with biomass + wind + solar + grid	0	0	0	0.35	0.37	0.48	1	INF	1
11	Micro-grid with bagasse + biomass + grid	0	0	0	0.075	0.064	0.089	1	INF	0.96
12	Micro-grid with biomass + wind + solar + bagasse + grid	0	0	0	0.35	0.37	0.53	1	1	1

B. Use of AHP for the proposed approach

According to the hierarchy of the proposed planning process as shown in Fig. 4, the values of different weights for all the attributes are calculated by using the software package known as “Expert Choice”. In this particular software the decision maker has to decide the priority of one attribute over the other, i.e., suppose, earlier discussed (previous subsection) three attributes are to be compared from customer point of view then the preference of each attribute has to be decided from the customer’s perspective. Intuitively, the energy not served per annum should have the highest priority among all the three attributes. Accordingly, with respect to utility, the energy not served per annum and the peak load payments are having the same importance. For hybrid DG / micro-grid, the capital cost investment is on top priority.

The values of weights for different attributes will decide the overall importance of each attribute for achieving the goal. In this case, the energy not served per annum will have the highest priority (w_1 = 0.539) as compared to capital cost (w_2 = 0.302) and peak load payments (w_3 = 0.159). The overall maximum inconsistency for the whole AHP process will be 0.10.

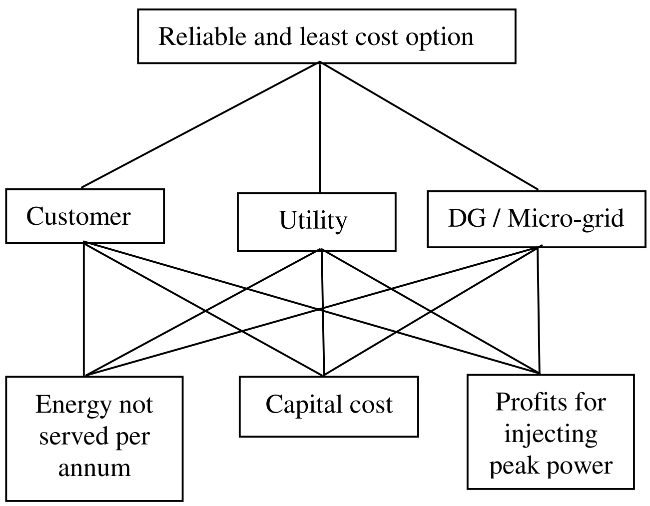

Fig. 4. Hierarchy of the proposed planning process

C. Tradeoff Analysis

Initially, with the help of various attribute values for different futures as shown in table II, the tradeoff region is generated by eliminating all infeasible plans. The infeasible plan is the one with unacceptable value of one or more attributes. As shown in table III, some plans have infeasible values of various attributes. Accordingly these plans are summarily rejected. Thus in case of 3 attributes and 3 futures, total 9 tradeoff surfaces can be plotted. One representative tradeoff plot between attribute 1 and attribute 2 for future 1 is as shown in Fig. 5. Since some plans are overlapping over each other, with a careful observation of the tradeoff curve the decision maker will be able to locate the robust plans. In this particular case, plans 2, 7 and 11 are the most viable plans (knee set) for future 1. This process has to be repeated for all the uncertain futures.

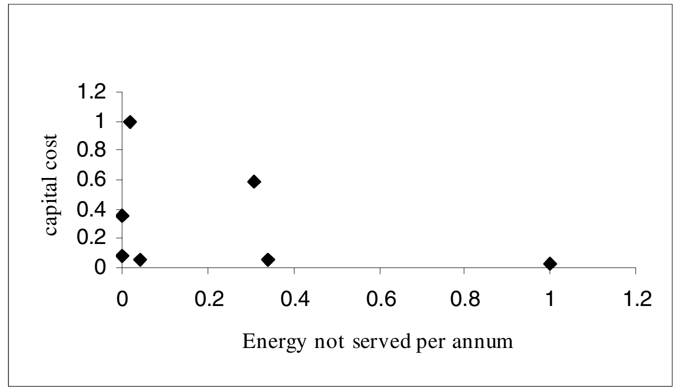

Fig 5. Tradeoff region for future 1

D. Implementation of MADM for Evaluating the Variance of Composite Distance

The variance of composite distance is calculated for each plan contained in the tradeoff surface. Since, in this study the limited number of plans/scenarios are considered, one can intuitively make out the best plan with the help of tradeoff curves. But the implementation of MADM helps the decision maker for preferential ranking of various configuration plans.

TABLE IV
VARIANCE OF COMPOSITE DISTANCE

Plan no.	Variance of composite distance (preferential ranking is shown in the bracket)		
	F1	F2	F3
2	0.0711 (3)	0.3215 (12)	0.0506 (1)
3	0.3837 (17)	--	0.3625 (15)
4	0.1663 (11)	0.1214 (8)	0.1243 (9)
5	0.3365 (14)	--	0.3266 (13)
6	0.0854 (4)	--	0.117 (6)
7	0.0883 (5)	--	0.0668 (2)
8	0.0854 (4)	0.1304 (10)	0.1199 (7)
9	0.3837 (17)	--	0.3628 (16)
10	0.0854 (4)	--	0.117 (6)
11	0.0883 (5)	--	0.0668 (2)
12	0.0854 (4)	0.1304 (10)	0.1199 (7)

According to the MADM analysis, plans 2, 4, 8 and 12 are the robust plans. They appear in the feasible set of all the futures. Plan 2, i.e., stand-alone gas turbine system, plan 8, i.e., micro-grid (bagasse plus biomass plus wind-solar) without any grid connection and plan 12, i.e., micro-grid (bagasse plus biomass plus wind-solar) connected with the conventional grid are some of the plans with high preferential ranking in supporting futures as shown in table IV. Since we have not considered the effect of operating cost in this analysis, it may be possible that there is an edge to the gas turbine technology. The operating costs for conventional DG technologies (for e.g. gas turbine, reciprocating engine, diesel generator, etc.) are quite considerable as compared to the renewable energy technologies. Accordingly, we have incorporated operating cost in addition to the capital cost as one of our attributes and interval based MADM technique is applied to all the robust plans, i.e., plans 2, 4, 8 and 10. It is assumed that the operating costs for a typical gas turbine are

25.5 % of the capital cost on annual basis. For renewables, the average operating costs are in the range of 11% [6]. The values for variance of composite distance for three uncertain futures are as shown in table V.

TABLE V
VARIANCE OF COMPOSITE DISTANCE BY CONSIDERING OPERATING COST

Plan no.	Variance of composite distance (preferential ranking is shown in the bracket)		
	F1	F2	F3
2	0.3109 (7)	0.3211 (8)	0.3653 (9)
4	0.1091 (3)	0.1219 (5)	0.0893 (2)
8	0.0854 (1)	0.1304 (6)	0.1149 (4)
12	0.0854 (1)	0.1304 (6)	0.1149 (4)

The results are quite indicative of the fact that the conventional DG technologies can be compared with renewable energy technology with proper consideration of operating cost along with the capital investments. It is observed that with the inclusion of operating cost parameter in the attribute of capital cost, the wind plus solar system and micro grid options are becoming more viable.

X. CONCLUSIONS

Various configuration plans of DGs for Indian system are evaluated using tradeoff analysis and MADM. The attributes considered represent the typical characteristic of a developing country. The proposed method minimizes the effect of subjectivity and biases by seeking relative significance of attribute values from all stakeholders participating in AHP. The feasible plans are identified by tradeoff analysis, and knee set provides options with lowest attributes values. The results of the tradeoff analysis need further refinement and confirmation, which can be obtained by the preferential ranking using MADM. Total 11 DG configuration plans are considered for low, medium and high loading conditions. From Fig. 5 one can observe that the points in the knee set correspond to plan numbers 2, 7, and 11 obtained by tradeoff analysis. However, this is valid for co-relation between attributes one and two under future 1. When all the attributes under all the futures are considered the overall result show that plans 2, 4, 8, 12 are superior. It can be seen that plan 2 performs well for low and medium loads and plan 4 for high load. Initially, the operating costs are not considered in chosen attributes. These costs need not be considered if all plans involve only renewable energy sources. If the plans contain heterogeneous sources, like renewable and conventional, one should consider the operating costs, which leads to micro-grid with renewables as a better option. The results show that plans 8 and 12 are the two robust plans. Utility of the tool is thus illustrated for the decision maker.

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