Optimal Planning of Microgrid Using Multi Criteria Decision Analysis

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***Abstract*—Today, intelligent buildings have received more attention, as well as, microgrids will have the significant role in future smart power distribution system. Smart building integrated with microgrid can provide much comfort, quality, safety and high energy efficiency for the users. Microgrids can integrate the conventional and renewable energy power generation systems, energy storage systems and controllable loads. Microgrid planning is a complex problem with technical, economic, and environmental attributes that should be considered. In this paper, Multi Criteria Decision Making (MCDM) approach is suggested for the selection among various microgrid planning options. Different plans are generated by various combinations of conventional and renewable energy resources. Five attributes namely, profits from injecting power into grid at peak load, capital costs, cost of energy (COE), total emissions, and energy not served are considered. The Analytical Hierarchy Process (AHP) method is used for weighting the importance of the different criteria, and MULTIMOORA method is proposed for prioritizing of different plans. The final ranking of the plans is obtained considering uncertainty in demand. Three loading conditions are considered as high, medium and low. The proposed procedure is applied to a sample system and numerical results are presented.**

***Keywords*– Distributed Generation, MCDM and Microgrid**

I. INTRODUCTION

Today power system planning is affected by technical, Economic and environmental issues. Centralized power systems are reforming to local scale distributed generations [1]. In future, microgrids will undertake the dominant role in power distribution system [2], [3]. Microgrid is a small power system consisting of one or more distributed generation units that can operated independently from the bulk power system. Energy planning using multi criteria analysis has attracted the attention of researchers for a long time. During the 1970s, dealing with energy problems by single criterion approaches which aimed at finding the most efficient energy supply options at a low cost was popular. However, in the 1980s, growing environmental awareness modified the above decision approach. The need to incorporate environmental considerations in energy planning resulted in the increasing usage of multi criteria methods [4]-[7].

In recent years many researches have been conducted in order to find optimal design and sizing of hybrid energy systems for residential application [8]-[12]. Microgrid planning process should include engineering, financial and environmental aspects to find an optimum solution. Multiple criteria decision-making (MCDM) is an operational evaluation and decision support approach suitable for addressing complex problems featuring high uncertainty, conflicting objectives, multi interests and perspectives. MCDM methodologies are capable of providing solutions to a wide range of energy management and planning problems [13]-[15]. MCDM techniques have been applied to different energy planning problems. References [6], [15] reviewed the MCDM methods application in sustainable energy planning. The authors in [16] used two MCDM algorithms to choose the best prime mover for a micro-CCHP system, to be used in a residential building. In [17] the authors applied the fuzzy MCDM model to select the best cool storage system in buildings. Reference [18] presented a review of multi-criteria decision-making methods for bioenergy systems.

Reference [19] solved the problem of evaluation and selection of an optimum thermal power plant using Multi Attribute Decision Making methodology. Reference [20] developed the multi-criteria decision support framework for finding the most sustainable electricity production technologies. Application of MCDM to Prioritizing of demand response (DR) programs was addressed in [21]. The role of MCDM in load estimation, load management, congestion management, expansion planning, distributed generation planning, unit commitment problem, multi-microgrid concept was presented in [22]-[30]. In this paper, planning of a grid-connected micogrid is considered. Various possible combinations of energy resources are evaluated for this microgrid using HOMER software [31], [32]. The different attributes namely, profits from injecting power into grid at peak load, capital costs, cost of energy (COE), total emissions, and energy not served are considered. The plans are prioritized according to the attributes by using MADM techniques considering uncertainty in demand. The remaining of this paper is organized as follows. In section 2 the problem description is illustrated. Section 3 describes the MCDM methods and the algorithm for the proposed approach. The sample system and results are presented in section 4. Finally, Section 5 concludes the paper.

II. PROBLEM DESCRIPTION

Simultaneously with the advent of the smart grid concept, as well as increasing concerns about the harmful effects of greenhouse gases, environmental and technical issues in addition to economic issues in the power system planning need to be considered more than ever before. The microgrid is an emerging technical solution to deal with these problems. Decision maker (DM) has to evaluate all possible plans for the microgrid including renewable and conventional energy resources. Because of the conflicting nature of the aforementioned attributes, it is a complex problem to find the optimum selection of the energy resources with regard to these attributes. The plans can be prioritized using advanced planning techniques presented in the next section. The proposed approach can help the decision maker to find the perfect solution for the planning problem considering the concerned issues.

III. THE PLANS PRIORITIZING PROCEDURE

In this section, procedure of planning with respect to various technical, economic and environmental attributes are considered. Five attributes are namely, profits from injecting power into grid at peak load, capital costs, cost of energy, energy not served and total emissions. First, HOMER software is utilized to generate the several planning options. All possible combinations of DERs are evaluated by HOMER with respect to the components installation and replacement costs, fuel price, and regional environmental data. And HOMER can calculate the values of the attributes for each plan too. A three-layer hierarchy shown in Figure 1 is used for the assessment of planning options.

The aim is in the first layer, attributes are in the second layer and the planning options (alternatives) are located in the third layer. The aim is to prioritizing the planning options and selection of the optimized plans based on these attributes. In the proposed planning process the attributes are weighted by Analytical Hierarchy Process (AHP) technique. Then, the decision maker sorts the plans (alternatives) by means of MULTIMOORA method.

Then, five best plans are selected, and sensitivity analysis is applied to these selected plans. Finally the best plan is suggested according to uncertainty in future load.

A. AHP Method

AHP method builds on the pair-wise comparison model for specifying the relative importance of all the attributes. AHP was proposed primarily by Saaty [33]. AHP is done according to the hierarchy of the planning process. The attributes constituting the hierarchy are allowed to rate each other, and finally the weight of attributes is determined.

In order to find the relative importance from different attributes with regards to the alternative, a comparison matrix among pairs using a relative importance scale is build. The judgments are entered taking into account the fundamental scale of the AHP. An attribute compared with itself will always have the value 1, thus the main diagonal entries of the matrix will be all one. The numbers 3, 5, 7, and 9 correspond to the verbal judgments. "moderate importance", "strong importance", "very strong importance", and "absolute importance" (with 2, 4, 6, and 8 for compromise between the previous values).

Considering n attributes, the comparison between pairs of i attributes with j attributes generates Anxn matrix where aij denotes the comparative importance of i attribute regarding to j attribute. In the matrix, aij=1when i=j and aji=1/aij. To obtain the attributes weights (wj) from matrix A, first the normalized matrix A is built and then wj is calculated as the average of the entries in row j of normalized matrix A [34].

B. The MULTIMOORA Method

Brauers and Zavadskas introduced the MULTIMOORA method firstly as MOORA standing for Multi-Objective Optimization by Ratio Analysis. Then they extended the method making it more robust as MULTIMOORA (MOORA plus the full multiplicative form) [35], [36]. The MULTIMOORA method begins with a decision matrix D where its elements xij denote the performance of the i-th alternative regarding j-th attribute as following:

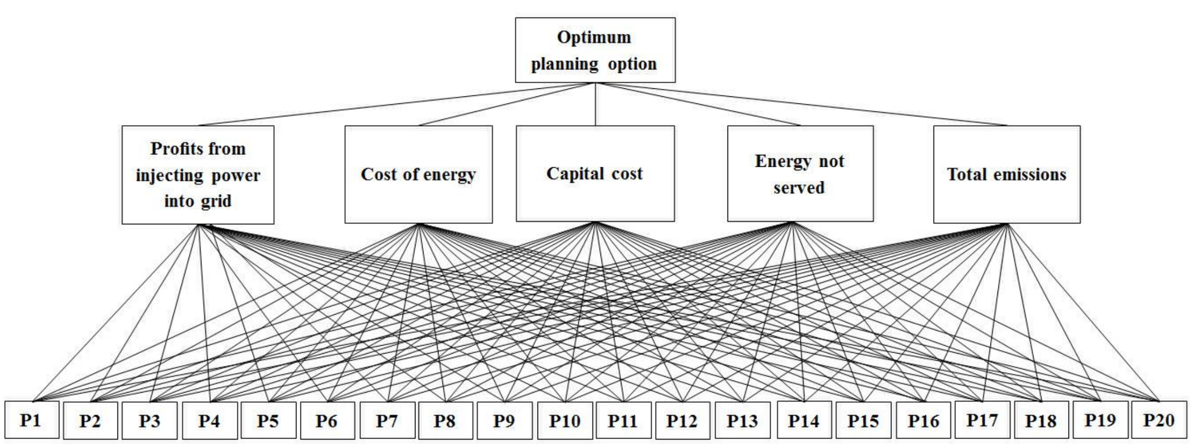

Figure 1. The three-layer hierarchy for the proposed planning process

$$D = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \quad (1)$$

The method includes three parts namely, the Ratio System, the Reference Point approach, and the Full Multiplicative Form.

The Ratio System of MOORA: Ratio system utilizes the vector data normalization by comparing alternative of an attribute to all values of the attribute:

$$r_{ij} = w_j \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad 0 \le w_j \le 1 \ , 0 \le r_{ij} \le 1 \quad (2)$$

Where x_{ij} denotes the performance of the i-th alternative regarding j-th attribute and w_j is weight of the j-th attribute, $\sum_j w_j = 1$. These Indexes are subtracted (if desirable value of indicator is minimum) or added (if desirable value of indicator is maximum). So, the summarizing indicator of each alternative is derived as following:

$$c_i = \sum_{j=1}^{g} r_{ij} - \sum_{j=g+1}^{n} r_{ij} \quad (3)$$

Where g = 1, 2, ..., n denotes number of attributes to be maximized, so the rest of attributes to be minimized. Ranking of the alternatives is based on the C_i value. The higher C_i coefficient is the better alternative (plan).

The Reference Point of MOORA: The Maximal attribute Reference Point (vector) is found with respect to ratios obtaining from Eq. (2). The j-th element of this vector can be defined as $y_i = \max r_{ij}$ in case of maximization. Every member of the reference point represents maximum or minimum of certain attribute. Then every element of the normalized decision matrix is recalculated and final rank is determined according to deviation from the reference point and the normalized values as below:

$$\min|_i [\max|_j (y_i - r_{ij})] \quad (4)$$

The Full Multiplicative Form and MULTIMOORA: Brauers and Zavadskas [26] improved MOORA by Full Multiplicative, comprising maximization and also minimization of purely multiplicative utility function. The i-th alternative utility is declared as:

$$U_i = \frac{A_i}{B_i} \quad (5)$$

$A_i = \prod_{j=1}^{g} (x_{ij})^{w_j}$: The product of attributes of the i-th alternative to be maximized.

$B_i = \prod_{j=g+1}^{n} (x_{ij})^{w_j}$: The product of attributes of the i-th alternative to be minimized.

Where j = 1,...,g are the numbers of attributes to be maximized and j= g+1,…,n are the numbers of attributes to be minimized [15], [20].

Figure 2 shows the flowchart of the proposed planning options sorting algorithm.

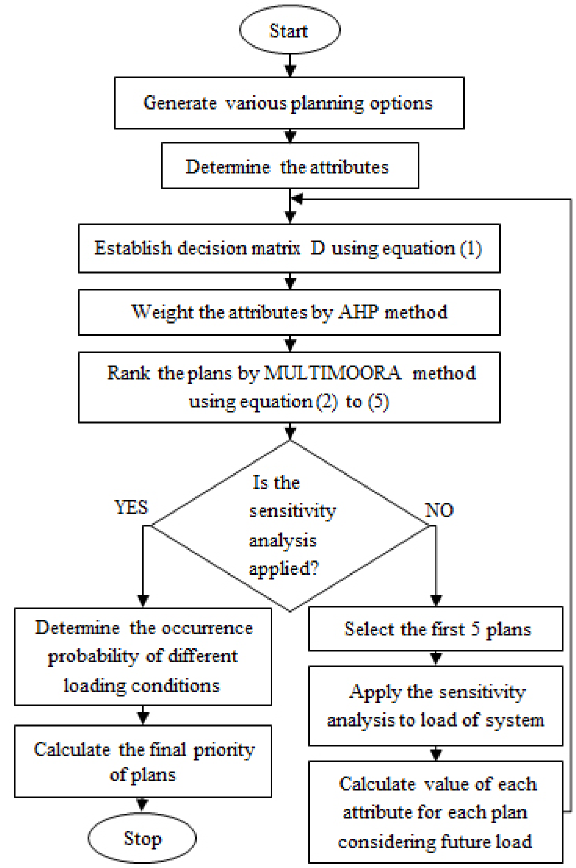

Figure 2. Flowchart of the proposed planning options sorting algorithm

IV. SAMPLE SYSTEM AND RESULTS

The MADM techniques developed in section 2 are applied to the sample system using the proposed procedure and results of the methodology are presented in this section. In this research, a grid-connected microgrid is considered. The annual load average of case study is 1000 kwh/d, with 93 kw peak load and load factor of 0.45 which has ability to exchange electrical energy with power grid. And also supplies thermal load with annual load average of 100 kwh/d, 9 kw peak load and load factor of 0.53. All possible combinations of electricity production technologies, namely, microturbine, wind power generation unit, PV solar unit, diesel power generation unit, biomass combustion power generation unit and a set of storage batteries are considered supplying power to the microgrid. The system includes a converter, a boiler, AC and DC buses and other essential components of the microgrid. The schematic diagram of the proposed system in this research is shown in Figure 3.

The first attribute namely profits from injecting power into grid at peak load should be maximized and while four

TABLE I
NORMALIZED VALUES OF ATTRIBUTES FOR VARIOUS CONFIGURATION PLANS

Plan no.	Configuration Plans	Profit Received	COE	Capital Cost	Energy not served	Total emissions
1	Grid+DSL+MT+Battery	0.000017	0.03168	0.047519	0	0.040133
2	Grid+BIO+MT	0.000104	0.039565	0.059348	0	0.037502
3	Grid+PV+DSL+MT+Battery	0	0.0355	0.053249	0	0.04007
4	Grid+DSL+BIO+MT	0.000104	0.045432	0.068148	0	0.037502
5	Grid+PV+BIO+MT+Battery	0	0.046005	0.069007	0	0.038381
6	Grid+DSL+BIO+MT+Battery	0.000104	0.046414	0.069621	0	0.039599
7	Grid+PV+DSL+BIO+MT+Battery	0	0.051871	0.077807	0	0.038381
8	Grid+PV+Wind+DSL+MT+Battery	0.000156	0.050234	0.075351	0	0.039507
9	Grid+Wind+BIO+MT+Battery	0.000104	0.056919	0.085379	0	0.038104
10	Grid+PV+Wind+BIO+MT	0.000400	0.05812	0.08718	0	0.036703
11	Grid+MT	0.054097	0.033198	0.049797	0.136753	0.03982
12	Grid+PV+MT	0.055332	0.037018	0.055528	0.136753	0.039728
13	Grid+DSL+MT+Battery	0.038506	0.050552	0.075829	0.082052	0.039826
14	Grid+PV+Wind+MT+Battery	0.038820	0.054373	0.081559	0.082052	0.039731
15	Grid+DSL+BIO+Battery	0	0.033044	0.049566	0	0.028275
16	Grid+PV+DSL+BIO+Battery	0	0.036864	0.055296	0	0.028404
17	Grid+PV+DSL+BIO	0	0.034244	0.051367	0	0.026662
18	Grid+Wind+DSL+BIO+Battery	0	0.047778	0.071668	0	0.028043
19	Grid+PV+Wind+DSL+BIO+Battery	0	0.051599	0.077398	0	0.028075
20	Grid+BIO+Battery	0.031964	0.038092	0.057138	0.082052	0.021828

TABLE II
ATTRIBUTES WEIGHTING BY AHP METHOD

	Profit Received	COE	Capital cost	Energy not served	Total emissions	Weight
Profit Received	1	0.33	0.33	0.5	0.5	0.1
COE	3	1	0.5	1	1	0.2
Capital cost	3	2	1	1	2	0.3
Energy not served	2	1	1	1	2	0.24
Total emissions	2	1	0.5	0.5	1	0.16

attributes namely capital costs, cost of energy (COE), energy not served, and total emissions should be minimized. The value of each attribute for different possible configuration plans is calculated and the normalized values (r_{ij}) of this attributes are as shown in Table 1. The decision matrix D is established using Eq. (1) with the results obtained from Table I. The decision matrix D expresses the values of each attribute for each plan.

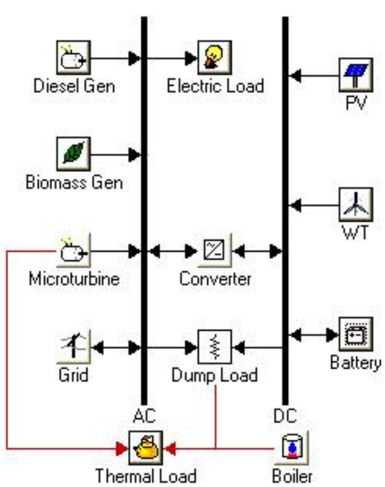

Figure 3. Schematic of microgrid system configuration

Table II shows the weights of attributes obtaining by AHP method.

Now by using the MULTIMOORA method the ranking of planning options can be calculated using Eqs. (2)-(5), and the results are shown in Table III. As seen from Table III, five best plans are 10,2,4,8 and 6 plans. Then the uncertainty in future load is considered in these selected plans. 3 Uncertain futures namely, future 1 (F1), future 2 (F2) and future 3 (F3).F1 represents the base load, F2 high load and F3 low load with annual load average of 1000, 1200 and 800, respectively.

TABLE III
PRIORITY OF PLANNING OPTIONS

Priority	Plan no.	Priority	Plan no.
1	Plan 10	11	Plan 13
2	Plan 2	12	Plan 14
3	Plan 4	13	Plan 3
4	Plan 8	14	Plan 5
5	Plan 6	15	Plan 7
6	Plan 9	16	Plan 15
7	Plan 1	17	Plan 16
8	Plan 20	18	Plan 17
9	Plan 11	19	Plan 18
10	Plan 12	20	Plan 19

TABLE IV
NORMALIZED VALUES OF ATTRIBUTES FOR SELECTED PLANS CONSIDERING UNCERTAIN FUTURES

Plan No.	Future	Profit Received	COE	Capital cost	Energy not served	Total emissions
10	Future 1	0.008659	0.181482	0.091688	0	0.039529
	Future 2	0.001506	0.183117	0.091688	0.122059	0.043239
	Future 3	0.068142	0.183117	0.091688	0	0.035523
2	Future 1	0.002259	0.170037	0.062417	0	0.04039
	Future 2	0.000376	0.174942	0.062417	0.146471	0.044227
	Future 3	0.031624	0.170037	0.062417	0	0.036527
4	Future 1	0.002259	0.173307	0.071672	0	0.04039
	Future 2	0.000376	0.178212	0.071672	0	0.044252
	Future 3	0.031624	0.173307	0.071672	0	0.036527
8	Future 1	0.003388	0.178212	0.079248	0	0.042549
	Future 2	0.000376	0.186387	0.079248	0.103072	0.049058
	Future 3	0.040283	0.178212	0.079248	0	0.036237
6	Future 1	0.003388	0.178212	0.079248	0	0.042549
	Future 2	0.000376	0.186387	0.079248	0.103072	0.049058
	Future 3	0.040283	0.178212	0.079248	0	0.036237

The value of each attribute for selected plans considering uncertain futures is calculated and the normalized values of this attributes are as shown in Table IV. Then the proposed procedure for prioritizing of the plans is applied to the selected plans again considering various futures. Table V demonstrates the preferential ranking of plans regarding uncertain futures by using the AHP and MULTIMOORA methods.

TABLE V
PRIORITY OF SELECTED PLANS CONSIDERING UNCERTAINTY IN FUTURE LOAD

Priority	Plan no.	Priority	Plan no.
1	Plan 2(3)	9	Plan 8(1)
2	Plan 4(3)	10	Plan 6(1)
3	Plan 10(3)	11	Plan 4(2)
4	Plan 8(3)	12	Plan 10(2)
5	Plan 6(3)	13	Plan 2(2)
6	Plan 10(1)	14	Plan 8(2)
7	Plan 2(1)	15	Plan 6(2)
8	Plan 4(1)		

Now probability of each uncertain future is determined which is depicted in Table VI. Finally in order for find the effect of uncertain future loads to plans, final ranking of plans is determined according to probability of each uncertain future load. Table VII shows the final priority of plans.

As it is seen from Table IV, Plan 4 has the highest rank and plan 6 has lowest rank. Plan 4 includes microturbine, diesel generator and biomass combustion power generator that can better meet all considered attributes under different future loads.

TABLE VI
PROBABILITY OF FUTURE LOADING CONDITIONS

Loading condition	Probability
Future 1	0.5
Future 2	0.2
Future 3	0.3

TABLE VII
FINAL PRIORITY OF PLANS

Priority	Plans
1	plan4
2	plan2
3	plan10
4	plan8
5	plan6

According to the Table IV, plan 4 is the only plan with zero value of energy not served for all future loads, indicating the high reliability of this plan. It has also acceptable values for remaining attributes comparing with other plans. The notable point is that all five plans include the microturbine, thus the microturbine technology can be an appropriate choice in microgrid planning process.

V. CONCLUSION

In this paper, a MCDM approach was proposed to solve microgrid planning problem for buildings. Distributed energy resources considered for microgrid are microturbine, wind turbine, photovoltaic panels, biomass combustion power generator and diesel engine. The microgrid has the ability to exchange electrical energy with bulk power grid. Economic, technical and environmental attributes were identified, and weighting process of all the attributes was performed using AHP method.

The proposed method was applied to a sample building. The prioritizing of all possible plans was done using MULTIMOORA method. Three loading conditions were considered as high, medium and low. The final ranking of the plans is obtained considering uncertainty in future load, In order to assess performance of selected plans. The best plan was introduced as plan with better performance in different loading conditions. It should be noted that the proposed approach is a proper method in field of intelligent building planning to find the optimum plan for microgrid.

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