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Distributed Generation Planning Using the R Method

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Abstract. Nowadays micro-grids are employed to improve the resilience and stability of power systems. The supervised operation of several distributed generation (DG) in a distribution system will give customers enough options to select the better solution under various priorities. Strategic planning studies with a variety of options are presented to the decision-maker. Major problems faced by decision-makers are assigning weights to the attributes, using attribute data for various alternatives, and making final decisions. These problems can be effectively managed in the multi-attribute decision-making approach. It deals with choosing the best option from a large but finite number of options while taking into account how each option performs concerning several attributes. In this paper optimal planning of a DG using the R method considering various configurations such as hybrid DG, Micro-grid, and the grid is presented. Three attributes such as reliability, incremental cost, and T&D losses are considered in this paper. The results are compared with the Analytical Hierarchy Process approach. The R method is a relatively simple and efficient as it requires less time, limited attention of the decision maker, and a high capacity for processing the information. This research paper will help to develop a control algorithm using fuzzy for strategic planning of DGs.

Keywords: sensor, detecting diode, terahertz radiation, 3D model, resonance frequency, HFSS, conversion efficiency, reflection losses, directivity

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Планирование распределенной генерации с использованием метода R

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Реферат. В настоящее время микросети используются для повышения устойчивости и стабильности энергосистем. Контролируемая эксплуатация нескольких установок распреде-

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ленной генерации (DG) в системе распределения предоставит клиентам достаточно возможностей для выбора лучшего решения с учетом различных приоритетов. Лицу, принимающему решение, предоставляются исследования стратегического планирования с различными вариантами. Основными проблемами, с которыми сталкиваются лица, принимающие решения, являются присвоение весовых коэффициентов атрибутам, использование данных атрибутов для различных альтернатив и принятие окончательных решений. Эти проблемы можно эффективно решить, используя многоатрибутивный подход к принятию решений. Данный подход позволяет осуществлять выбор наилучшего варианта из большого, но конечного числа вариантов с учетом того, как каждый вариант способен выполнять несколько атрибутов. В данной статье представлено оптимальное планирование распределенной генерации с использованием метода R, учитывающего различные конфигурации, такие как гибридная распределенная генерация, микросеть и сетка. Данная статья рассматривает три характеристики: надежность, дополнительные затраты и потери при передаче и распределении. Результаты сравниваются с подходом аналитического иерархического процесса. Метод R относительно прост и эффективен, поскольку требует меньше времени, ограниченного внимания лица, принимающего решения, и высокой производительности для обработки информации. Данная исследовательская работа позволит разработать алгоритм управления с использованием нечеткой логики стратегического планирования работы распределительных групп.

Ключевые слова: чувствительный элемент, детекторный диод, терагерцовое излучение, трехмерная модель, резонансная частота, HFSS, эффективность преобразования, потери на отражение, коэффициент направленного действия

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Introduction

Nowadays in developing countries like India Distributed generation (DG) has become a important part of the power system network. It has various advantages like minimum generation cost and transmission cost, minimum transmission and distribution losses, less pollution, and improved reliability of the system [1, 2]. In India government is motivated to utilize decentralized clean energy resources like solar PV, Wind and Biogas, etc. generation to provide electricity in rural areas where it is not served by centralized transmission and distribution infrastructure of electrical energy. This results in transmission cost savings and a reduction in fossil fuel emissions. Micro-grids are employed to increase the resilience and stability of power systems [3]. The Micro-grid comprises a collection of electrically distinct linked loads and DGs.

There are two modes of operation of the Micro-grid: 1. Grid-connected and 2. Islanded mode. As per the availability of electricity, a Micro-grid can be switched ON and OFF from the grid and acts as an independently controlled structure concerning the grid [4].

Fig. 1 represents the basic structure of a Micro-grid which includes various types of loads, and DG resources including an energy storage system (ESS), main controller, smart meters and switching systems, protection equipment, communication systems as well as automated control system [3]. It provides lots of benefits such as low cost, less emission, minimum transmission losses with improved reliability of the system, and is more flexible than a backup generating unit. It consists of dispatchable and non-dispatchable DGs. Renewable energy sources (RES) are non-dispatchable units because they produce unpredictable and irregular output power [5]. Because of the intermittency and volatility of the output, it is necessary to support ESS. The ESS plays a vital role in coordinating with the DGs to ensure appropriate generation from Micro-grids during the islanded as well as grid-connected modes of operation [6]. It can also be used for energy management during low-price hours the energy can be stored in ESS and can be used to supply load during peak hours [7]. Protective equipment and smart switches regulate the connection between loads and DGs. The function of the master controller is to connect or disconnect a Micro-grid from the utility grid according to economic and security issues. The smooth functioning of control operations and guarantee of uninterrupted, efficient, and reliable interaction amongst Micro-grid components is achieved with the help of advanced automation technologies for communications, and control. Islanded mode of operation is the most distinguishing feature of Micro-grid.

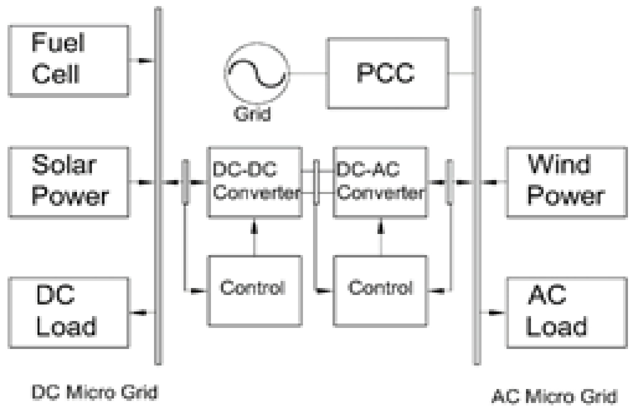

Fig. 1. Basic Structure of Micro Grid

The study of Micro-grids has grown considerably during the past few years in light of the growing interest in their application. Challenges faced while integrating the Micro-grids with the utility grid and the solutions to overcome these challenges are elaborated in [8]. The status of Micro-grids in India is presented in [9]. To address the constraints and difficulties of the distribution network, such as the optimum size and placement of a distribution substation and DGs, a multi-dimensional framework for optimal active distribution network planning is introduced in [10, 11]. In the distribution system planning problem, the planning horizon is split into various subperiods and is solved by considering the investment and operating costs [12]. Mathematical models for the analysis of the economic benefits of DGs are presented in [13]. Based on the equal incremental rate of non-renewable fuel consumption, the economical dispatching and optimal power flow computation for Micro-grid integrated systems were developed by [14]. A power flow algorithm for a distribution network with DGs was proposed in [15]. Using load flow analysis and optimization techniques the optimum location and size of DGs were determined for a Micro-grid [16]. The cost of generation of DGs and non-renewable energy sources is determined and is used for long-term planning. Multi-objective optimization model of isolated Micro-grids was proposed by [17]. Ant colony optimization technique was used to reduce pollution and minimize the cost of generation.

From the literature review, it is concluded that the deployment of some recent innovations in distribution systems, such as Micro-grids, and the supervised controlled operation of several DGs will give enough options to select better solutions under various priorities to the users. The strategic planning studies provide a variety of options to the decision-maker, including grid connection, hybrid systems, and the newest option, micro-grid. The Micro-grid option has received a lot of attention from researchers, and while there are numerous advantages claimed for it, they must be supported by analytical techniques that can quantify the advantages. In old techniques, the significant aspects and relationships between the system's elements are established in the initial phase. An additive utility function with appropriate weights is developed in the second phase. With these features for special attributes, comparing multiple options is simple. The results, however, may be distorted by the adequacy and quality of the supplied data. This problem can be effectively managed using the multi-attribute decision-making (MADM) approach.

The MADM problems deal with choosing the best option from a large but finite number of options while taking into account how each option performs concerning several attributes. Assigning weights to the attributes, use of attribute data for various alternatives, dealing with qualitative attributes or incomplete information, and making final decisions are the major problems faced by the decision-maker. Several MADM methods like Analytical Hierarchy Process (AHP), Analytical Network Process, Preference Ranking Organization Method for Enrichment Evaluations, Decision-making Trial and Evaluation Laboratory, Best-Worst Method, etc. are available in the literature. These methods are used by many researchers however these have demerits like requiring lengthy calculations and with the increased number of alternatives and attributes the method become more complex. Different methods used for normalization of data may change the rankings of alternatives and make the calculation procedure complex. The AHP method was implemented by [18, 19] for optimal DG planning. The AHP approach generates numerous comparison matrices by comparing attributes and alternatives. The dimension of these comparison matrices is completely depended upon the number of alternatives and attributes. Additionally, the ranks of the alternatives will differ depending on the weights assigned to the attributes using the arithmetic mean, geometric mean, etc.

Strategic resource planning for conventional resources was done using the MADM methodology. Moreover, cost-benefit analysis, the potential for deferring T and D, a decrease in T and D losses, etc. were typically used to support the viability of DG in a power system. These are all significant issues, but they cannot be the only ones used to make decisions. In this paper optimal planning of a distribution system using the R method considering various configurations of Micro-grids such as hybrid DG, Micro-grid, and the grid is presented.

This paper contributes to providing a detailed discussion on:

1. R method for strategic Planning studies based on the MADM approach.
2. Implementation of the R method for DG planning in the distribution system.
3. Analysis of the strategic planning of DG using the R method for various loading conditions and expansion strategies.

Rest of the paper is structured as follows: Section 2 covers the fundamentals of the R method. Implementation of the R-method for strategic planning of distributed generation is presented in Section 3. Results and discussion are elaborated in Section 4 and the paper is concluded in Section 5.

The R Method

From the literature review of the MADM techniques, it is concluded that the weights of the attributes are derived either by objective or subjective approach. In the objective approach, there is no role of the decision maker in deciding the preference. On the other hand, in the subjective approach, the weights are assigned by the ranking method. There is a need for the development of a simple and efficient technique to solve complex decision-making problems having many attributes and solutions. In 2021, V Rao proposes the R method for strategic planning which is based on the alternatives and attribute ranking [20].

Decision table in MADM approaches contains alternateves, attributes, attribute weights, and performance metrics for the alternatives. The prime goal of the decision maker is to identify the best alternative by ranking all alternatives from the decision table as per the decision-making methodology. Fig. 2 shows the flow chart of step-by-step procedure of the R method.

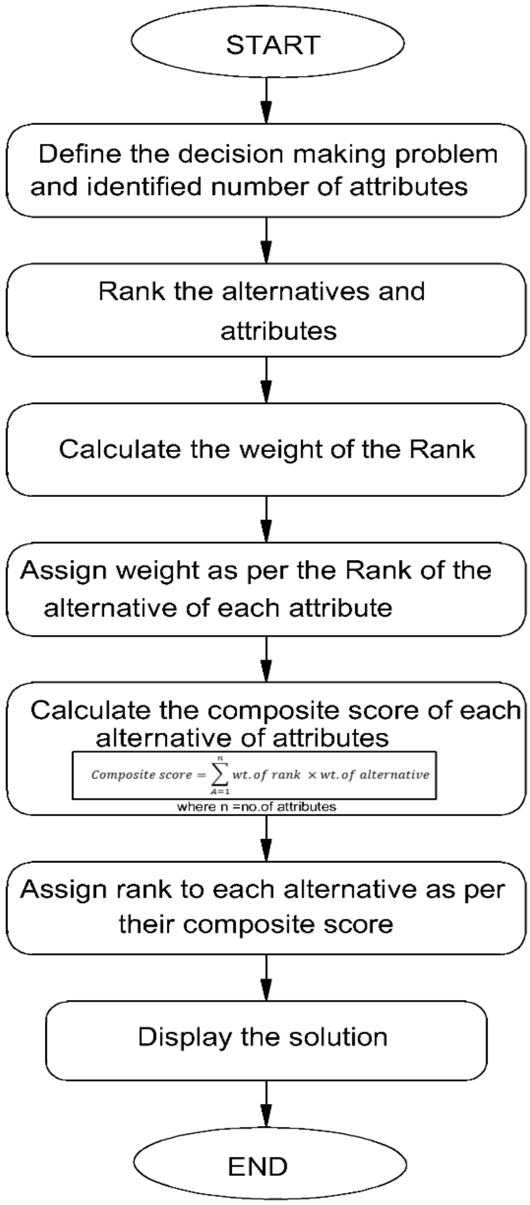

Fig. 2. Flow Chart of R Method

Implementation of the R Method for Strategic Planning of Distributed Generation

For most developing nations worldwide, the main issues are the growing demand for energy, 100 % rural electrification, and the limited supply of conventional generation resources. In India, these problems are overcome by increasing the use of renewable energy sources such as solar, wind fuel cells, etc. As of Feb. 2023, the installed capacity of renewable resources is almost 130 GW. Electricity generation by renewable resources has increased by 109 % since 2014.

Problem Formulation. In India, for the electrification of rural areas, micro-grid is the most appropriate option. It is also observed that there is the possibility of interconnecting two or more renewable resources such as solar, wind bio-gas, etc. The main advantage of micro-grids is the increased reliability and security of the system. However, finding a suitable combination of sources of energy to supply load demand is the biggest challenge in micro-grid operation. Social/technical/political issues make the decision-making process complicated. There are various options such as stand-alone, hybrid, and micro-grid are available to the decision-maker. The stakeholders' perceptions of various competing attributes must also be taken into account. Therefore, the problem is simply to evaluate the various options and find the ranking of the same as per the attributes by using any of the effective MADM techniques.

Implementation of R Method. In this paper strategic planning for DG using the R method is presented. Various loading conditions such as light load, and high load of medium voltage distribution system were considered for the same. Various types of loads for respective loading conditions are given in Table 1 [19]. The analysis is carried out for three different attributes such as:

Attribute 1: Incremental Cost.

Attribute 2: Transmission and distribution (T&D) losses.

Attribute 3: % time duration for which the load remains unserved for a month.

Table 1

Various types of Loading Conditions

Load	High Load (kW)	Low Load (kW)
Residential Load	353	122
Commercial Load	88	31
Industrial Load	328	114
Agriculture Load	1751	607
Total Load	**2520**	**874**

The values of each attribute for different expansion strategies for various loading conditions given in Table 2 are taken from [21].

Table 2

Values of each attribute for different expansion strategies [21]

Expansion Strategies	Attribute 1	Attribute 2	Attribute 3
Low Load condition			
Grid Mode	0.004	0.71428	1
Hybrid Mode	0.0433	0	0.1249
Micro-grid Mode	0.06105	0	0.0416
High Load condition			
Grid Mode	1	1	0.7498
Hybrid Mode	0.9035	0	0.2499
Micro-grid Mode	0.7465	0	0.0166

Following is the step-by-step procedure of the R method.

Step 1: Formulate the problem of DG planning and frame the attributes required.

Step 2: Run the R Method algorithm and prepare the decision table with performance indicators of the alternatives corresponding to the attributes.

Step 3: Rank the attributes as per the various cases considered for study.

Step 4: Rank the alternatives as per the performance indicator. It may be quantitative or qualitative.

Step 5: Calculate the corresponding weights using the ranks that were given to the attributes and alternatives.

Step 6: Calculate the composite score of the alternatives by adding the product of the weights of attributes and the corresponding weights of alternatives.

Step 7: Arrange the alternatives in descending order. An alternative with the highest composite score will be the best choice.

Results and Discussion

In the MATLAB environment, the R-method algorithm is written. For the analysis, various loading conditions and expansion strategies with different priorities of attributes are considered.

For each expansion strategy, the highest priority attribute will be different. For the customer, reliability is the highest priority however for the utility *T* and *D* losses and the cost are important for micro-grids. To prove the efficacy of the R method for strategic planning of DGs the program is run for various cases with different load conditions such as Low Load, High Load, and Combined Load conditions for various attributes priorities.

The result analysis is carried out for three cases considering each attribute at the highest priority. The three cases considered are as follows.

Case 1: Attribute 3 i. e. reliability of supply is at the highest priority.

Case 2: Attribute 2 i. e. efficiency (*T* & *D* Losses) of the system is considered the highest priority.

Case 3: Attribute 1 i. e. Incremental Cost is at the highest priority.

The decision table which consists of the weight of the attributes, composite score, and composite rank for different priorities of attributes with high and low loading conditions for various expansion strategies are given below from Table 3 to Table 11. The results of the R-method are compared with the results of the AHP method presented in [21].

Table 3

Decision Table

Expansion Strategy	Attri-bute 1	Attri-bute 2	Attri-bute 3	Compo-site score	Compo-site Rank	Variance of com-posite distance (Results of ref. [21])
Grid + High load	0.10510	0.10510	0.11163	0.07160	6	0.690
Grid + Low load	0.29955	0.11163	0.10510	0.10272	4	0.804
Hybrid + High load	0.11163	0.15766	0.12062	0.08586	5	0.186
Hybrid + Low load	0.19970	0.15766	0.13413	0.10429	3	0.097
Microgrid + High load	0.12062	0.15766	0.29955	0.14092	1	0.162
Microgrid + Low load	0.13413	0.15766	0.19970	0.11322	2	0.102
Rank of Attribute	0.16339	0.19970	0.29955			
	3	**2**	**1**			

Table 4

Decision Table Case 1: Low Load Condition

Expansion Strategy	Attri-bute 1	Attri-bute 2	Attri-bute 3	Composite score	Composite Rank
Grid	0.45205	0.24658	0.24658	0.29724	2
Hybrid Mode	0.30137	0.27123	0.30137	0.29229	3
Microgrid	0.24658	0.27123	0.45205	0.34689	1
Rank of Attribute	0.24658	0.30137	0.45205		
	3	**2**	**1**		

Table 5

Decision Table Case 1: High Load Condition

Expansion Strategy	Attri-bute 1	Attri-bute 2	Attri-bute 3	Composite score	Composite Rank
Grid	0.24658	0.24658	0.24658	0.24658	3
Hybrid Mode	0.30137	0.27123	0.30137	0.29229	2
Microgrid	0.45205	0.27123	0.45205	0.39756	1
Rank of Attribute	0.24658	0.30137	0.45205		
	3	**2**	**1**		

Case 1: Reliability of supply is at the highest priority.

The program is run for all loading conditions with reliability as the highest priority. The results are presented in Table 3 to Table 5 for combined load, low, and high load conditions respectively. From the output results it is concluded that the Micro-grid option is the most reliable option for any load condition.

In [21] the variance of the composite distance is minimum for hybrid mode with low load and micro-grid with low load conditions so these are selected as the best planning option. However, the load is variable and for high-load conditions, the AHP method is not performing well. On the other hand, in this paper, from the output results of the R method used for DG planning, it is observed that the composite rank of micro-grid options for high as well as low load is rank 1 and rank 2 respectively hence as per the load condition best planning option can be selected.

Case 2: Efficiency of the system is at the highest priority.

In this case 2 the program is run considering T and D losses at the highest priority for all loading conditions. The results are tabulated in Table 6 to Table 8 for Low, high, and combined load conditions respectively. In this case, also the micro-grid option is found to be the most efficient option in the distribution system for any load condition.

Table 6

Decision Table Case 2: Low Load Condition

Expansion Strategy	Attribute 1	Attribute 2	Attribute 3	Composite score	Composite Rank
Grid	0.45205	0.24658	0.24658	0.29724	2
Hybrid Mode	0.30137	0.27123	0.30137	0.28775	3
Microgrid	0.24658	0.27123	0.45205	0.31965	1
Rank of Attribute	0.24658	0.45205	0.30137		
	3	**1**	**2**		

Table 7

Decision Table Case 2: High Load Condition

Expansion Strategy	Attribute 1	Attribute 2	Attribute 3	Composite score	Composite Rank
Grid	0.24658	0.24658	0.24658	0.24658	3
Hybrid Mode	0.30137	0.27123	0.30137	0.28775	2
Microgrid	0.45205	0.27123	0.45205	0.37031	1
Rank of Attribute	0.24658	0.45205	0.30137		
	3	**1**	**2**		

Table 8

Decision Table Case 2: Combined Load Condition

Expansion Strategy	Attribute 1	Attribute 2	Attribute 3	Composite score	Composite Rank
Grid + High load	0.10510	0.10510	0.11163	0.07095	6
Grid + Low load	0.29955	0.11163	0.10510	0.10337	4
Hybrid + High load	0.11163	0.15766	0.12062	0.08955	5
Hybrid + Low load	0.19970	0.15766	0.13413	0.10664	3
Microgrid + High load	0.12062	0.15766	0.29955	0.12675	1
Microgrid + Low load	0.13413	0.15766	0.19970	0.10902	2
Rank of Attribute	0.16339	0.29955	0.19970		
	3	**1**	**2**		

Table 9

Decision Table Case 3: Low Load Condition

Expansion Strategy	Attribute 1	Attribute 2	Attribute 3	Composite score	Composite Rank
Grid	0.45205	0.24658	0.24658	0.33946	1
Hybrid Mode	0.30137	0.27123	0.30137	0.29394	3
Microgrid	0.24658	0.27123	0.45205	0.31458	2
Rank of Attribute	0.45205	0.24658	0.30137		
	1	**3**	**2**		

Table 10

Decision Table Case 3: High Load Condition

Expansion Strategy	Attribute 1	Attribute 2	Attribute 3	Composite score	Composite Rank
Grid	0.24658	0.24658	0.24658	0.24658	3
Hybrid Mode	0.30137	0.27123	0.30137	0.29394	2
Microgrid	0.45205	0.27123	0.45205	0.40747	1
Rank of Attribute	0.45205	0.24658	0.30137		
	1	**3**	**2**		

Table 11

Decision Table Case 3: Combined Load Condition

Expansion Strategy	Attribute 1	Attribute 2	Attribute 3	Composite score	Composite Rank
Grid + High load	0.10510	0.10510	0.11163	0.07095	6
Grid + Low load	0.29955	0.11163	0.10510	0.12896	1
Hybrid + High load	0.11163	0.15766	0.12062	0.08329	5
Hybrid + Low load	0.19970	0.15766	0.13413	0.11236	3
Microgrid + High load	0.12062	0.15766	0.29955	0.12171	2
Microgrid + Low load	0.13413	0.15766	0.19970	0.10582	4
Rank of Attribute	0.29955	0.16339	0.19970		
	1	**3**	**2**		

Case 3: Incremental cost is at the highest priority.

To test the proposed algorithm for economic operation Attribute 1 i.e. incremental cost is kept at the highest priority. From the output result (refer to Table 9 to Table 11) it is found that for economical operation of the distribution system during low and combined load conditions grid option is the most suitable whereas during high load conditions micro grid option is at rank 1.

The composite rank for different expansion strategies for combined load is shown in Fig. 3. From Fig. 3 it is clear that from a supply reliability and system efficiency point of view, the Microgrid strategy is most suitable for high as well as low load conditions. However, for incremental cost at top priority, the grid option during low load and the Microgrid option during high load conditions is found suitable. The ranking for various expansion strategies for reliable supply and efficient operation of the system is the same.

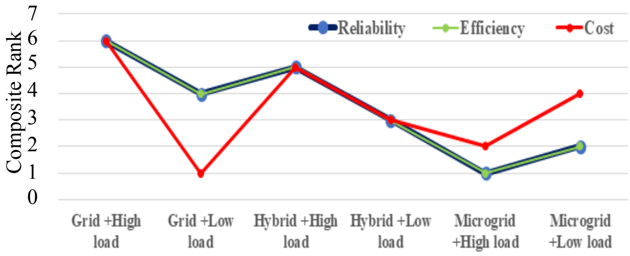

Fig. 3. Composite Rank for different expansion strategies with various attributes

Fig. 4 shows the graphical representation of the composite score for all the attributes of various expansion strategies. From Fig. 4 also it is clear that the composite score is the maximum for microgrid options with high as well as low load conditions for all cases. On the other hand, the difference in a composite score of first and second rank is very small i. e. 0.00725, and the third and fourth rank is 0.00654 is also very negligible for incremental cost at the highest priority.

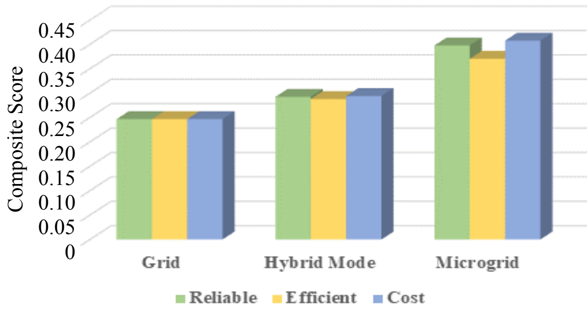

Fig. 4. Composite Score for different expansion strategies with various attributes

Fig. 5 and Fig.6 present the composite score for the grid, hybrid mode, and Microgrid strategies for reliable supply, efficiency of the system, and incremental cost as the highest priority during high and low load conditions respectively.

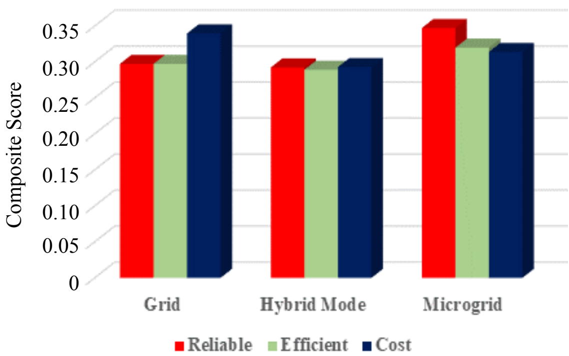

Fig. 5. Composite Score for different expansion strategies with various attributes
during High Load Condition

From Fig.6, it is clear that during high load conditions Microgrid option is the most suitable for all three attributes i.e. reliability of supply, efficiency of the system, and incremental cost considered at highest priority.

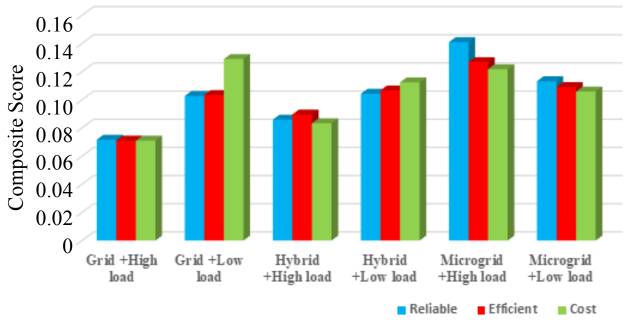

Fig. 6. Composite Score for different expansion strategies with various attributes during Low Load Condition

During low-load conditions for reliable supply and efficient system operation, the Microgrid option is most suitable however for incremental cost Grid option is most suitable.

Conclusion

Micro-grid is a small-scale power system having lots of benefits such as low cost, less emission, minimum transmission losses with improved reliability of the system, and more flexibility in operation. Smart switches and protective devices manage the connection between loads utility and DGs. The islanded mode of operation is the most salient feature of the Micro-grid. Micro-grid, and the supervised operation of several DGs in a distribution system, provide customers with enough options to select the better solution under various priorities. The MADM approach is most suitable to solve this problem. R-method is simple and easy to implement as compared to other MADM techniques. It also requires less time, limited attention of the decision maker, and a high capacity for processing the information. From the output results it is concluded that for the reliable supply, efficient system, and incremental cost Micro-grid option is most suitable during all loading conditions. This research paper can be extended by incorporating fuzzy with the R-method for developing the control algorithm for strategic planning of DGs.

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