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MULTIMOORA Decision Making Algorithm for Expansion of HVDC and EHVAC in Developing Countries (A Case Study)

Ali Aranizadeh[1] ,Mehrzad Kazemi[1], Homayoun Barahmandpour[1] and Mirpouya Mirmozaffari[2*]

[1]Niroo Research Institute (NRI), Tehran, Iran
[2]PhD Fellow, Dept. of Industrial Engineering and Engineering Management, Western New England University, USA

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Abstract

These days, as the residents of urban areas grow, the requirement for consumption rises too. This quantity of consumption needs power generation cores with large volume utilizing that it needs to be big enough which guides technology in the direction of wholesale power transmission systems. Consequently, two kinds of power transmission systems including HVDC and EHVAC can be considered. However, since none of the aforementioned technologies has been used in developing countries, a decision should be made to present and progress any of these technologies. Applying both of these technologies concurrently would not be economic. Therefore, this paper studies deciding on the introduction and development of HVDC and EHVAC in a developing country, Iran. A decision-making development needs the principles of conflicting purposes for alternatives and the selection of the best alternative based on the needs of decision-makers. Multi-objective optimization methods may well provide a solution for this selection. To this end, measures of this selection are described in more specifics and then, MULTIMOORA, one of the recognized MCDM approaches, is used to make the ultimate result.

Keywords:
Bulk power transmission, Development of future infrastructures, MCDM, Direct current system, MULTIMOORA

*** Correspondence E_mail**: m.mirmozaffari@gmail.com

INTRODUCTION

Technology growth and development of urban life have formed high national consumption points. With the intention of recompense this load, large volume generation centers are compulsory which are usually far from load points. Generation points and consumption points being distant necessitates bulk power transmission technology (Aranizadeh et al., 2019). However, since there are a few studies regarding experiences on construction or operation of these systems compared to lower voltage systems and given technical, economic and environmental constraints of such systems, several studies are being done in this framework. Countries which intention to enter this area frequently start with pilot projects and wide developing research.

Bulk power transmission can be divided into two groups of high voltage direct current and extra-high voltage alternative current (HVDC, EHVAC). These technologies are generally used in various countries all over the world like the USA, China, India, Brazil, South Africa, and most European countries. To explain more, most developed countries of the world formulate their transmission network development roadmap according to these technologies.

Bulk power transmission technology has not been used in Iran yet, but Iran has features like massiveness, high and focused electric energy consumption in big cities, electricity generation with primary carriers in large volume and an exclusive strategic location in the area for electric power transition. These pieces of evidence make it a good candidate for using the bulk power transmission system for future developments.

Employing bulk power transmission technologies needs comparison studies, particular decisions about introducing, the progress of the technology, considering challenges of designing, applying and operating this technology earlier. Consequently, it is required that our country customs the practical knowledge and skills attained in the context to employ this technology in the future. The finest way to get familiar with various areas of design and operation of these technologies is to evaluate them in pilot form and small scale before consuming them effectually in the network. The pilot form is introduced to the electric industry progressively through basic scheduling for using bulk power transmission corridors, its design and operation challenges are recognized to gain the required experience for employing this technology in the electric industry.

Thus, section II defines the AHP algorithm. Section III explains the measures used to decide about HVDC and EHVAC technologies. Section IV presents the AHP algorithm on the aforementioned two technologies considering the decision-maker measures and final analysis is made to choose the technology of interests.

MULTIMOORA DECISION MAKING ALGORITHM

As a useful tool to achieve the optimal answer and ranking priorities in different decision- making issues, Multi Criteria Decision Making techniques are divided into two general categories: Multi-Objective Decision Making and Multi-Attribute Decision Making. So far, decision-making methods have been studied to evaluating alternatives, allocating attributes to alternatives, and prioritizing alternatives by several researchers. There are a large number of MADM methods available, such as Data Envelopment Analysis (DEA). Although DEA has a strong link to production theory in economics, the method is also used for benchmarking in operations management, where a set of measures is designated to benchmark the performance of manufacturing such as cement companies (Mirmozaffari., 2018) and service operations in healthcare such as evaluation of hospital efficiency (Mirmozaffari et al., 2017).

The MULTIMOORA method is introduced and implemented in this paper as a multi-objective decision-making technique and one of the most updated and appropriate decision-making methods. The MOORA technique, which stands for Multi-Objective Optimization based on Ratio Analysis, was first proposed by Brauerz and Zavadescas (Brauerz et al., 2010) and then developed in a more general version of MULTIMOORA (Brauerz et al., 2010). Many studies have used this technique to date. For example, it has been used by Balzentis et al., (Balzentis et al, 2012) to select personnel in fuzzy conditions. A fuzzy concept such as an expert system plays an important role in many fields of study such as engineering and healthcare (Mirmozaffari., 2019). In a recent work (Gashteroodkhani et al., 2019), fuzzy logic is used for energy recovery in water distribution systems using a hydropower generator. The method can maximize the generator efficiency and provide constant pressure for customers. In a study (Brauerz et al., 2011), this technique was used to make a loan decision to invest. The MULTIMOORA approach in fuzzy conditions has been used by Balezentis group to select a unit manager in a telecommunications company (Balezentis et al., 2013). The concept of MULTIMOORA using interval gray numbers has been developed by other group (Datta et al., 2013) to prioritize industrial robots. Three parts of the MULTIMOORA method are the Ratio System Approach, the Reference Point Approach, and the Full Multiplicative Form. In the Ratio System Approach, after normalizing the decision matrix and multiplying the relevant weights, the sum of the attributes options value that is costly is deducted from the sum of the values of profit attribute options. The best alternative with the highest score is selected. In the reference point approach, an alternative with the least distance to the reference point wins the highest priority.

In the Full Multiplicative Form, the normalized values reach the power of their weights, and an alternative is chosen after calculating the profit-to-cost ratio, to obtain the maximum value. Finally, the best alternative is selected using the Dominance Theory.

Accordingly, taking into account the different aspects of alternatives and attributes and their multidimensional nature can be considered as the advantage of the MULTIMOORA method compared to other existing decision making methods such as SAW, TOPSIS, and AHP. It makes it possible to make more correct decisions considering the unpredictable and high uncertainty conditions of decision making.

Although the MOORA method consists of two approaches, namely the Ratio System Approach and the Reference Point Approach, it has been updated as MULTIMOORA and includes three parts namely the Ratio System Approach, the Reference Point Approach, and the Multiplicative method. A decision matrix X is considered for this method like other decision-making approaches.

The decision matrix arrays of x_{ij} show the value of the Ai alternative for the aj index, where i = 1,2, ..., m and j = 1,2, ..., n.

$$X = \lfloor x_{ij} \rfloor_{m*n} \tag{1}$$

Subsequently, the decision matrix should be normalized to make its arrays dimensionless and comparable and is represented by x^*_{ij}. Normalization is generally a comparison between the alternative ratio and a given attribute. Brauers and Zavadskas (Brauers et al., 2006) has used the relation (2) to normalize this method:

$$x_{ij}^* = x_{ij} \Big/ \left[\sum_{i=1}^{m} x_{ij}^2 \right]^{1/2} \tag{2}$$

Also, weights sum are equals to one:

$$\sum_{j=1}^{n} w_j = 1 \tag{3}$$

Ratio system

The normalized matrix values are first multiplied by their respective weights in this method according to relation (4). Then, the resulting values are added together, and the sum of the cost indices is deducted from the sum of the profit values:

$$y_i = \sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j x_{ij}^* \tag{4}$$

In this respect, it indicates the number of profit attributes and the number of cost attributes. In the ratio system, the alternative with the highest numerical value is the optimal solution (Balezentis et al., 2013):

$$A_{RS}^* = \{ A_i | \max x_i\, y_i \} \tag{5}$$

Reference point method

This method is based on the concepts of "Maximal Attribute Reference Point (MORP)" and "Tchebycheff Distance". The coordinates of the

J vector of the Maximal Attribute Reference Point are calculated as follows. In this respect, there are also several profit attributes (Brauers et al., 2011).

$$r_j = \begin{cases} \max_i x_{ij}^*, & j \le g, \\ \min_i x_{ij}^*, & j > g, \end{cases} \quad (6)$$

The deviation of the normalized matrix values from the reference point is calculated using the following relation:

$$d_{ij} = \left| r_j - x_{ij}^* \right| \quad (7)$$

The estimated values are calculated by the reference point method using the relation (8).

$$z_i = \max_j w_j d_{ij} \quad (8)$$

In this method, the solution with the lowest numerical value is the optimal solution:

$$A_{RP}^* = \left\{ A_i \middle| \min_i z_i \right\} \quad (9)$$

Full multiplicative form

The third part of the multivariate algorithm includes the Full Multiplicative Form. In this approach, instead of multiplying weights in the normalized matrix values, weights are used to achieve these values (Brauers et al., 2012). The relation (10) is used to estimate the values in this method:

$$u_i = \prod_{j=1}^{g} (x_{ij})^{w_j} \Big/ \prod_{j=g+1}^{n} (x_{ij})^{w_j} \quad (10)$$

Again, in this relation, some of the attributes are considered profit type and, like the ration system, the optimal solution is selected from the available alternatives with the maximum value:

$$A_{MF}^* = \left\{ A_i \middle| \max_i u_i \right\} \quad (11)$$

An integrated approach is needed to do ranking based on the three above mentioned paragraphs, in the last stage, the final ranking is by the MULTIMOORA method. It also uses, dominance theory, which is structured based on theories of domination, transience, and competence. See reference (Datta et al., 2012) for more detail on these theories.

MULTIMOORA decision making model with entropy weighting

The MULTIMOORA model, introduced in this study, achieved a new development using the entropy weighting method in the research conducted by group (Hafezalkotob et al., 2016). In this development, the basic algorithm of the MULTIMOORA technique has not changed and only the entropy weighting is replaced by the simple weighting.

The entropy weighting method, used in a wide range of research, was developed as a mathematical theory for the relationships between the system components by Claude Shannon in 1948. Because of measuring the contradiction between the data specified in a decision matrix and the transparency of the internal data values, this method can be used effectively in weighting various methods (Shannon., 1948) and (Amin-Nejad et al., 2018). By knowing the decision matrix, instead of using the decision maker's pairwise comparisons according to the Saaty method, the weighting of the attributes can be directly calculated. If we assume the decision matrix D in this method, we have:

$$D = \begin{bmatrix} X_{11} & X_{12} & \ldots & X_{1n} \\ X_{21} & X_{22} & \ldots & X_{2n} \\ . & . & \ldots & . \\ . & . & \ldots & . \\ X_{m1} & X_{m2} & \ldots & X_{mn} \end{bmatrix} \quad (12)$$

The element x_{ij} value that is normalized using the following relation is called P_{ij} as follows:

$$P_{ij} = x_{ij} \Big/ \sum_{i=1}^{m} x_{ij} \quad (13)$$

The entropy value of the J attribute is calculated as follows:

$$E_j = -k \sum_{i=1}^{m} P_{ij} \ln P_{ij} \qquad k = 1/\ln m \quad (14)$$

Using Ej, we calculate the value of dj for the attribute:

$$d_j = 1 - E_j \quad (15)$$

Finally, the characteristic weight j is calculated from the following relation:

$$w_j = d_j \Big/ \sum_{j=1}^{n} d_j \qquad (16)$$

DECISION-MAKING CRITERIA FOR HVDC AND EHVAC TECHNOLOGIES

Decision-making criteria for choosing HVDC and EHVAC considered in this paper are as follows (Aranizadeh et al., 2017):

The justifiability of developing the technology
Ability to develop the technology
Technology requirement

In the following sections, the sub-criteria which affect the justifiability of HVDC and EHVAC technologies are reflected.

The justifiability of developing the technology

Examining the nearby location is an appropriate strategic tool for identifying a large image of the environment in which the technology of interest is being applied (Gashteroodkhani et al, 2018) and (Brauers et al., 2011). Sub-criteria of justifiability in developing the technology are as follows:

Future studies of the technology
The life cycle of the technology
Technology market
The strategic position of the technology

In the following sections, the sub-criteria which affect the justifiability of HVDC and EHVAC technologies are considered.

Future studies of the technology

Future studies are significant tools to attain the aptitude of technology. These studies distinguish the most possible future novelties of human and technological development. Future studies employ a wide range of approaches for a systematic estimation related to the future of knowledge (Brauers et al., 2012).

The design of the DC system has reached an appropriate development. On the other hand, there are more parts compared to the AC systems that need to be studied. Mainly, these power lines are required for long paths with a higher power which affects the future of this technology.

Technology lifecycle

Altering operative features of the technology and reaching technical development through time defines the technology lifespan. Technology lifespan is an idea that shows expansion in the performance of technology throughout time. In other words, the position of technology in the lifecycle is affected by the lifecycle curves of the dependent methods. This curve has four steps including introduction, growth, maturity, and decline.

At this time, transmission lines between 400 to 765KV are in the development phase; indeed, studies on this voltage level are completed and developed to an appropriate magnitude. But voltage levels higher than 765kV up to 1500kV are still in the growth phase and the technology has space for the development.

Allowing for the studies performed on HVDC, it is clear that extra high voltage transmission technology has passed the introduction phase and it is being used in many countries. Considering the increasing trend of development and the increasing number of extra high voltage transmission units in the world, this technology is in the growth phase and it has not entered the development phase yet.

Technology market

Many of the scientists have engaged the lifecycle-market as a tool to recognize strategies and rules to present an item for consumption to the market. This cycle also has 4 phases including introduction, growth, maturity, and decline. Vending a product in the introduction phase is very slow. In the growth phase, it reaches an early peak and demand might grow slowly before declining. Accompanied by these changes, some changes are also detected in the real development of the competitive condition for the strategies and performance.

Strategic position of the technology

Based on the strategic position, technologies can be considered as the key or strategic and conservative technologies. “Key or Strategic” technologies are the technologies that play a significant role in comprehending strategic goals. It is clear that if the strategic goal changes, key technologies also change accordingly.

In bulk power transmission technologies, HVDC plays a more strategic role compared to EHVAC since it can develop other technologies involving HVDC like wind turbine converters, solar converters, and FACTS devices.

Ability to develop the technology

One of the most vital and key decision-making criteria is the capability to develop the technology. There are different sections to study this criterion:

Possibility of cooperation with technology owners

Technology complexity

Technology proportionality

The above criteria which affect the ability to develop HVDC and EHVAC technologies are studied in the following sections.

Possibility of cooperation with technology owners

Making an allowance for political and economic associations of Iran, countries which possess HVDC technology is more complicated to collaborate in compared with those owning EHVAC. EHVAC exists in countries like Korea and Ukraine with which Iran has positive political relationships. Consequently, Iran can collaborate with these countries to simplify the development of these technologies in the country.

Technology complexity

The word "advanced technology" refers to technologies with the following characteristics (Shannon., 1948):

- High complexity
- Science oriented
- Short lifecycle
- A large share of technology in the finished price of the product/service
- The high cost of research and development

In high voltage DC transmission lines, technologies used to design and construct converters (which is the most significant part of the system) are very difficult, thus this technology is high.

As a whole, accomplishing an HVDC power transmission system needs a high technical knowledge and taking practical steps in this context requires creating the design, experimental centers and enhancing technical knowledge of the research centers. Thus, technical knowledge plays a more important role compared to experience.

Technology proportionality

Appropriate technology refers to the technologies which have maximum flexibility with the recognized necessities on one side and existing sources (including technological sources) on the other hand. As a result, appropriate technology is not essentially an advanced technology. The efficient and effective use of advanced technology is conceivable when required substructures and human skills exist previously. One of the challenges in developing countries is that it is presumed that decreasing or removing the difference in technology level with the developed countries is possible only through transmitting advanced technologies.

Since there is accurate experience at the highest available voltage level (400Kv), previous experiences can be used to construct and develop EHVAC lines caused by the existence of technical substructures and scientific knowledge. Design, construction, and installation of EHVAC devices like switches and transformers are possible in Iran. But the condition of HVDC is different.

Technology requirement

In this section, the technologies required in the country are studied. This study is implemented between HVDC and EHVAC which has the following characteristics:

External Corridors

Internal Corridors

In the following, the sub-criteria affecting requirement to HVDC and EHVAC technologies are studied.

External corridors

One of the applications of the bulk power transmission system is linking the electricity network of Iran to the electricity network of neighboring countries. Typically, it is essential to separate networks of two countries for the desired operation by connecting the two countries. Also, since the power exchanged between two neighboring countries is controlled, HVDC is superior to EHVAC. Another method is an economic measure.

In some contents, EHVAC and HVDC are compared in terms of cost for constructing the line, building the station, operating the line in both technologies for the three suggested corridors. The results of this study show that the designated technology in terms of economy and line frontage in the three corridors is HVDC.

Internal corridors

An alternative perspective is a requirement to GW corridors along long paths inside Iran for connecting points with the relative advantage of generation compared to the points with excess consumption potential points. In (Aranizadeh et al., 2017), the cost of building the station, cost of building the line, operation cost, consistency and line frontage are calculated to obtain the designated technology among the proposed corridors. From the results among 5 proposed corridors, HVDC is selected in three corridors and EHVAC is selected in 2 corridors.

IMPLEMENTING THE DECISION -MAKING ALGORITHM FOR SELECTING HVDC AND EHVAC

Data collection in this research was performed using a questionnaire and a survey of industry experts. The initial results are presented in Table 1 under the following name:

Decision matrix of advantage assessment of two types under HVDC and EHVAC systems technologies.

Now, considering the algorithms introduced in the scientific research literature, we first normalize the introduced decision matrix. Then, we calculate the sub-attributes of weights using the Shannon algorithm. Finally, by collecting the basic data according to the method's algorithm, we analyze the data in Table 2. ARS in this table is the optimal value of the ratio system, ARP is the optimal value of the reference point method and AMF is the optimal value of the full multiplicative method.

Table 1: Advantage assessment decision matrix of two types under HVDC and EHVAC technologies

technology	**Attributes and sub-attributes of technology selection**								
	technology development feasibility				Technology development ability			Need for technology	
	Technology future studies	Technology life cycle	Technology market	Technology strategic position	Collaboration with technology owners	Technology complexity	Technology fit	Offshore corridors	Internal corridors
EHVAC	2	3	2	1	6	7	7	2	3
HVDC	7	8	8	7	2	2	3	8	7

Table 2: determined values and MULTIMOORA ranking with Entropy weighting

technology	**Ranking criteria in MULTIMOORA algorithm with entropy weighting**						Final ranking by dominance theory
	Obtained values of MULTIMOORA entropy			specified rankings of MULTIMOORA entropy			
	ARS*	ARP*	A*MF	ARS*	ARP*	A*MF	
EHVAC	-0.07	0.19	0.34	2	2	2	2
HVDC	0.63	0.08	1.33	1	1	1	1

According to the results obtained from the specified rankings of MULTIMOORA entropy, HVDC technology outperforms EHVAC technology in all three-ratio systems, reference points, and full multiplicative methods, and thus, the final rank of HVDC is in priority. Finally, along with the dominance theory, this technology is selected.

CONCLUSION

Decision making about the introduction and development of HVDC and EHVAC technologies for future substructures of the country is studied in this paper. So, three criteria including justifiability of the technology development, ability to develop the technology and technology requirement are considered. Each criterion contains sub-criteria such as future studies of the technology, technology lifecycle, technology market, strategic position of the technology, cooperation with technology owners, technology complexity, technology proportionality, external connections, and internal connections. After normalizing the introduced decision matrix, sub-attributes of weights with the Shannon algorithm was applied. At the next step, by collecting the basic data according to the method's algorithm, we analyze the data using MULTIMOORA, the final decision regarding selecting one of these two technologies and introducing it to Iran's network is made. In doing so, HVDC technology outperforms EHVAC technology in all three-ratio systems, reference points, and full multiplicative methods. Finally, HVDC is selected to be introduced and developed in Iran's network. In the future, it is suggested to compare the results of other new and widely used methods of the MCDM techniques such as AHP.

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