# OPTIMUM SELECTION OF STORAGE BATTERY FOR ELECTRIC VEHICLES USING MULTI CRITERIA DECISION MAKING TECHNIQUES

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**CERTIFICATE**

This is to certify that the Project report titled **"OPTIMUM SELECTION OF STORAGE BATTERY FOR ELECTRIC VEHICLES USING MULTI CRITERIA DECISION MAKING TECHNIQUES"** Submitted by **Anandu A, Aswanth Lal, Muhammed Sinan Iqbal, and Nihal Rashid** to the APJ Abdul Kalam Technological University in partial fulfilment of the requirement for the award of degree of **Bachelor of Technology** in **Mechanical Engineering**, is a bonafide record of the project report carried out under our supervision and guidance.

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# ABSTRACT

In this modern era the fossil fuel energy production, the environmental damage is very high. This is where the electric vehicles (EV) comes into the frame. EV's are dominating the automotive market than the traditional internal combustion engines (IC). EV's consist of many parts for its working but the most important part of it is the storage battery for transmission power production. So, an optimum selection of these EV batteries from a variety of battery alternative will improve the functional characteristics of an EV undertaking certain battery parameters or criteria. Now these criteria for battery selection can be given priority manually or by aid with the use of multi criteria decision making (MCDM) methods or tools. AHP, CRITIC are some MCDM tools used for criteria weightage. For the final selection of EV batteries from its variety of alternatives MCDM techniques is once again used. MCDM tools like TOPSIS, MOORA, EDAS are examples for such tools. So by the MCDM techniques we can find the best option of battery for an EV from a wide range of battery alternatives with the help of various battery criteria.



Keywords: MCDM, EV, Battery

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# CHAPTER 1

## INTRODUCTION

An electric vehicle (EV) is a mode of transport which is powered by electricity. Unlike conventional vehicles that use a gasoline (petrol) or diesel-powered engine, electric cars and trucks use an electric motor powered by electricity from batteries or a fuel cell. A key advantage of EVs over other forms of transport is that they hold the potential to significantly reduce pollution by having zero exhaust emissions. EVs have an electric motor instead of an internal combustion engine (ICE). The vehicle uses a large traction battery pack to power the motor and must be plugged in to a charging station or wall outlet to charge. Most EVs use lithium-ion batteries, which have higher energy density, longer life span and higher power than most other practical batteries.

There are three main types of EVs. Hybrid EVs (HEVs) and plug-in hybrid EVs are both powered by petrol and electricity. The former generates energy through the car's own braking system to recharge the battery, while the latter can recharge through any external source of electricity. Meanwhile, battery EVs (BEVs) are fully electric, meaning that the vehicle emits no emissions from the exhaust and does not contain the typical liquid fuel components, such as a fuel pump, fuel line, or fuel tank.

### 1.1 History of EV

Electric motive power started in 1827, when Hungarian priest Ányos Jedlik built the first crude but viable electric motor, which used a stator, rotor, and commutator; and the next year he used it to power a small car. In 1835, professor Sibrandus Stratingh of the University of Groningen, in the Netherlands, built a small-scale electric car, and sometime between 1832 and 1839, Robert Anderson of Scotland invented the first crude electric carriage, powered by non-rechargeable primary cells. American blacksmith and inventor Thomas Davenport built a toy electric locomotive, powered by a primitive electric motor, in 1835. In 1838, a Scotsman named Robert Davidson built an electric locomotive that attained a speed of four miles per hour (6 km/h). In England a patent was granted in 1840 for the use of rails as conductors of electric current, and similar American patents were issued to Lilley and Colten in 1847.

The first mass-produced electric vehicles appeared in America in the early 1900s. In 1902, the Studebaker Automobile Company entered the automotive business with electric vehicles, though it also entered the gasoline vehicles market in 1904. However, with the advent of cheap assembly line cars by Ford Motor Company, the popularity of electric cars declined significantly. Due to lack of electricity grids and the limitations of storage batteries at that time, electric cars did not gain much popularity; however, electric trains gained immense popularity due to their economies and achievable speeds. By the 20th century, electric rail transport became commonplace due to advances in the development of electric locomotives. Over time their general-purpose commercial use reduced to specialist roles as platform trucks, forklift trucks, ambulances, tow tractors, and urban delivery vehicles, such as the iconic British milk float. For most of the 20th century, the UK was the world's largest user of electric road vehicles.

Electrified trains were used for coal transport, as the motors did not use the valuable oxygen in the mines. Switzerland's lack of natural fossil resources forced the rapid electrification of their rail network. One of the earliest rechargeable batteries – the nickel-iron battery – was favored by Edison for use in electric cars.

### 1.2 Benefits of EV

EVs are an environmentally friendly alternative to petrol or diesel cars as they generate much less air pollution, releasing no exhaust air pollutants. From wheel to wheel, EVS emit approximately 66% less carbon dioxide ($CO_2$) compared with ICE-powered vehicles. The emissions associated with the electric drivetrain of EVs come from power plants generating electricity to charge the batteries – emissions can therefore be further reduced if renewable energy is used to recharged an EV. Noise pollution is also cut out due to the fact that an EV is nearly silent. Running costs for fuel, maintenance and car tax are much lower for EVs. As company cars tend to travel further on a daily basis, the payback on the original purchase price is faster, making EVs particularly attractive for fleets. One of the biggest benefits of introducing EVs to a business is the reduced refueling costs, with electricity being far cheaper than fuel at the pump. Indeed, fuel costs can be as low as 2p per mile. For an annual mileage of around 10,000 miles per year, switching from a conventional to an electric car or van could save around £800 in fuel costs alone.

EVs are also a lot cheaper to maintain, mainly because they have a lot less moving parts than a conventional fossil-fuel powered car. For instance, there is relatively little servicing and no expensive exhaust systems, starter motors, fuel injection systems or radiators. Recent research has shown that several EV features can improve safety – EVs tend to have a lower center of gravity that makes them less likely to roll over, for instance. EV owners can gain additional monetary value from an EV through the implementation of vehicle-to-grid (V2G) technology, which provides demand-response services to the power grid. EVs can feed electricity into the grid when not in use through batteries during peak hours, and do most of their charging at night when there is unused generating capacity.

### 1.3 Parts of an EV

These are the important parts of an EV: -

- Traction battery pack: Traction battery pack is also known as Electric vehicle battery (EVB). It powers the electric motors of an electric vehicle. The battery acts as an electrical storage system. It stores energy in the form DC.
- DC-DC convertor: The DC-DC convertor distributes the output power that is coming from the battery to a required level. It also provides the voltage required to charge the auxiliary battery.
- Electric traction motor: Electric traction. Charge Porton motor converts the electrical energy into kinetic energy. This energy rotates the wheels. Electric motor is the main component that differentiates an electric car from conventional cars.
- Power Inverter: Power Inverter coverts DC power from the batteries to AC power. It also converts the AC current generated during regenerative braking into DC current. This is further used to recharge the batteries.
- Charge Port: The charge port connects the electric vehicle to an external supply. It charges the battery pack.
- Onboard charger: Onboard charger is used to convert the AC supply received from the charge port to DC supply. The on-board charger is located and installed inside the car. It monitors various battery characteristics and controls the current flowing inside the battery pack.
- Controller: Power electronics controller determines the working of an electric car. It performs the regulation of electrical energy from the batteries to the electric motors. The pedal set by the driver determines the speed of the car and frequency of variation of voltage that is input to the motor. It also controls the torque produced.
- Auxiliary batteries: Auxiliary batteries are the source of electrical energy for the accessories in electric vehicles. In the absence of the main battery, the auxiliary batteries will continue to charge the car. It prevents the voltage drop, produced during engine start from affecting the electrical system

- Thermal system: The thermal management system is responsible for maintaining an operating temperature for the main components of an electric vehicle such as, electric motor, controller etc. It functions during charging as well to obtain maximum performance. It uses a combination of thermoelectric cooling, forced air cooling, and liquid cooling.
- Transmission: It is used to transfer the mechanical power from the electric motor to the wheels, through a gearbox.

### 1.4 EV Battery

Batteries as they are designed to give power over sustained periods of time and are deep-cycle batteries. Batteries for electric vehicles are characterized by their relatively high power-to-weight ratio, specific energy and energy density; smaller, lighter batteries are desirable because they reduce the weight of the vehicle and therefore improve its performance. Compared to liquid fuels, most current battery technologies have much lower specific energy, and this often impacts the maximum all-electric range of the vehicles.

### 1.5 Project Objective

Selection of a best storage battery for EV from its alternatives improve the performance characteristics of an EV. This may be according to already set criteria and parameters regarding an EV battery. So the main objective of this project is the optimum selection of EV storage battery.

### 1.6 Project Description

Initially the EV storage battery is studied thoroughly and different alternatives of EV batteries are identified. Criteria or parameters regarding these EV batteries are also studied and are taken for consideration.

Now the MCDM method is used for the selection of best battery alternative from the list of total alternatives. For this the main factor of selection will be the EV battery criteria. The criteria priority or weightage can be given in this project manually or by using the same MCDM tools. Then with these prioritized criteria list we come to the conclusion of best selected battery for an EV using MCDM tools.

# CHAPTER 2

## LIERATURE REVIEW

A broad review on different multi criteria decision making methods and different types of batteries used in electric vehicles have been carries out which is given below.

### 2.1 Multi Criteria Decision Making (MCDM)

**Socaciu et al. (2016)**

This paper deals with the selection of phase change materials (PCM) using analytic hierarchy process (AHP) to maintain the thermal comfort of vehicle occupants. Thermal comfort of the vehicular occupants is gaining more importance due to the rising attention towards comfortable mobility. Also due to the growing time that people spent in vehicles. vehicular climate control contributes to a more secure driving in many ways. PCM is a substance with a higher heat of fusion it can have various composition different properties and different application fields. Phase change properties do not make all these materials viable for a specific application. Here a set of PCM s which can be used to maintain the thermal comfort of vehicle occupants was analyzed using AHP method considering certain criteria’s and 10 commercial PCM s where ranked. The systemic evolution of AHP method can increase the efficiency of the system and decrease the hazardous selection of material. These studies try to correlate the scientific and engineering goals for maintaining the thermal comfort of the vehicle occupants.

**Yang et.al (2018)**

This paper deals with the selection of proper PCM to meet the needed requirements based on MCDM methods. The selection of optimum phase change material from a wide Verity of alternatives is of great importance. Furthermore, material selection plays a major role in functionality ' performance and security of a given application. PCM selection should consider a variety of factors according to the actual situation and the ideal option cannot be discovered because of the conflicting tradeoffs among various selection factors. Here by summarizing the application of the MCDM methods in the PCM selection a comprehensive appraisal index model and a new MCDM method is put forwarded which is employed to select Optimal PCM for ground source heat pump (GSHP) system. This model can promote the process of the PCM selection to get more reasonable conclusion for a given application and this method can avoid unreasonable results caused by the inconsistent of subjective and objective weight.

**Anilkumar et.al (2021)**

Here the optimum PCM is selected for the efficient solar cooker considering various thermal energy storage materials. For this they use the MCDM technique for the optimal section of PCM’s. MCDM technique is used to select the best of a set of alternatives by evaluating them with reference to different attributes. MCDM’s are used both for evaluation of each criteria weightage in final section and also for the final optimal selection of alternatives. AHP is a MCDM method for evaluation each criteria weightage; other examples are CRITIC, ENTROPY etc. This paper also gives details on MCDM programs used for final selection of optimum alternatives for example Technique for order preference by similarity to ideal solution (TOPSIS); other MCDM methods in this category are CODAS, MOORA, etc. So here initially the criteria are selected for different alternatives of PCM’s and their different data’s are collected. Then the criteria are given certain weightage by using MCDM methods (AHP, CRITIC, ENTROPY) and finally the optimum selection done by different MCDM techniques and erythritol is found out to be the best PCM for solar cooker considering various thermal energy storage materials.

**Emovon et.al (2020)**

Here in this paper, we are discussing about the material selection process using the MCDM method. As material selection is a tedious and thought-provoking procedure when it's done manually; it is best and optimally done by using MCDM technique. There are various MCDM tools for this, some of them are TOPSIS, PROMETHEE, AHP, ELECTRE, VIKOR, CORPAS, MAUA etc. Some of these tools are used for determining criteria weightage and most of them are used for optimal selection of alternatives from the list of total alternatives. From this paper we can find that the best MCDM tool is hybrid MCDM i.e. the combination of two or more MCDM's for selection procedure. Also found out that the most used criteria is cost of materials. We can also see that the country with most usage of MCDM technique in production and manufacturing field is India.

**Kumar et.al (2017)**

This paper discusses energy planning for renewable electrical energy for different areas. Considering the multiple sustainability scenario and factors, MCDM method models are best suited for such revolutionary objectives. In order to achieve the best solution overcoming all the environmental and local issues in real time application, MCDM technique models have to be utilized on multiple criteria involving multiple scenarios. This paper discusses the essential aspects of MCDM techniques; energy based MCDM method models and outlines various performance indicators which can be utilized to address the core issues for achieving the goals of sustainability in developing nations especially at rural levels. Here we have three types of MCDM models namely Value measurement models, Goal, aspiration and reference level models and Outranking Models. These models have been used in combination as well. These models are basically utility based models and include methods like MAUT, AHP, Weighted Sum Method, and Weighted Product Method. These are mostly preferred for ranking energy technologies like application of energy storage devices in the field of renewable energy. A suitable renewable source of energy planning can be selected based on the alternatives sorted out and can be implemented accordingly.

**Rathod et.al (2011)**

This paper discusses about the selection of PCM for the development of a latent heat thermal energy storage system. Criteria for selection of ideal phase change material to be used for latent heat storage are: high sensitive heat capacity and heat of fusion; high density and heat conductivity; chemically inert; non-toxic, non-flammable and non-hazardous; reasonable and inexpensive. A PCM is selected based on achieving the desired properties at minimal cost. Here two Multiple Attribute Decision-Making (MADM) methods to solve PCM selection problem. These two methods are TOPSIS method and fuzzy TOPSIS method that uses linguistic variable presentation and fuzzy operation. Both the methods use an AHP method to determine weights of the criteria. TOPSIS and fuzzy TOPSIS methods are used to obtain final ranking. The methodology used here provides a systematic approach to narrow down the number of alternatives. Ideal material can be selected from these alternatives based on the use of the system.

**Lee et.al (2018)**

This paper discusses on the use of decision-making system of the energy selection various fields for optimal output. Because energy selection issues entail several and frequently at odds criteria, MCDM techniques are growing in popularity. The WSM, VIKOR, TOPSIS, and ELECTRE MCDM approaches are used in this work to give a comparative analysis of ranking renewable energy sources (RES) for power generation in Taiwan. The Shannon entropy weight technique is employed to evaluate the significance of each factor in RES rating. The remaining RE choices are then ranked using four MCDM approaches for quantitative evaluation. Efficiency is given top priority in all evaluation categories, followed by job creation, operation, and maintenance costs, according to the weights estimation results. This study's objectives are to prioritize various RES and make suggestions for Taiwan's RE development.

### 2.2 Electric Vehicle (EV) Battery

#### Iclodean et.al (2017)

In this era the fossil fuel dependency in the international market on the process of energy production is being reduced, also with it the environmental problems caused with the usage of Internal Combustion (IC) engines, we can see an encouraged use of EV’s in the transportation field. In the EV’s the battery of the vehicle is considered the heart as it gives the power for transmission. Various kinds of battery’s are used in EV’s for ex: Lithium – Ion, Nickel Metal Hydride (NMH), Lithium Polymer, Molten Salt ($Na\text{-}NiCl_2$) etc. Here these batteries are considered having same electric energy storage. After comparative studies are done considering same parameter for batteries $Na\text{-}NiCl_2$ are proven to be best choice for energy consumption, low price, increased lifecycle etc. One disadvantage of these batteries is the increased operating temperature, which solidifies the battery electrolyte when the vehicle is not used. A solution for this is the usage of external battery temperature operating system. Also found in the study that the highest energy consumption is accompanied by the Li-S batteries. For high energy storage capacity devices Li-S batteries are used because of its low price, increased energy storage capacity and low weight.

#### Miao et.al (2019)

This paper presents and compares key components of Li-ion batteries and describes associated battery management systems, as well as approaches to improve the overall battery efficiency, capacity, and lifespan. Different materials for positive and negative electrodes, various types of electrolytes and the physical implementation of Li-ion batteries are presented and compared, and components of battery management systems are described. The performance of existing lithium batteries is heavily dependent on material and thermal characteristics. Most of the heat from the battery is generated at the electrodes and additional research in various cooling methods and electrode design criteria is needed to reduce or compensate for the heat, therefore, improving the battery life and capacity. As EV batteries reach the end of their useful life, different approaches are taken to repurpose them as a supplement to the existing power grid or recycle the battery materials when they are no longer viable.

**Chen et.al (2018)**

This paper reviews recent Research and development of Lithium-ion battery used in EV's. Among many kinds of batteries, Lithium-Ion batteries have become the focus of research interest for EV. Li-Ion batteries must be operated in a safe and reliable operating area, which is affected by the charge rate, temperature and voltage range. Li-Ion batteries are sorted using with different methods to improve the use efficiency of the batteries and prolong their service life. Charge estimation due to electrode potential and material limitations, the voltage and capacity of each battery cell cannot fully meet the requirements of the voltage level of EVs. Estimation of the driving range of EV depends on the accuracy of the SOC data. In this paper it also says about second used batteries. The batteries must be retired when they drop to 80% of the primary capacity. And all Li-Ion batteries are reusable. The primary research topics in lithium-ion batteries are outlined in this paper, including estimation of battery capacity, battery sorting, remaining battery life, battery circuit model, and SOC methods. A new technique and model for categorizing retired batteries and calculating SOC are presented, along with the RUL of the retired battery. This increases retired battery uniformity, decreases retired battery degradation, and increases battery cycle life. Future experiments will be done to confirm the effectiveness of this strategy.

**Somanatha et.al (2019)**

This paper deals with electric vehicle charging and battery management system. Battery powered electric vehicles are gaining popularity worldwide. This trend is driven by several factors including the need to reduce air and noise pollution, and dependence on fossil fuels. As per the report made by international energy outlook the transportation sector will increase its oil consumption share on the world market up to 55 percent. Recently, EV’s have grown rapidly as demanded green energy from the world. development is going on in Battery Electric Vehicles (BEV), Plug-in Hybrid Electric Vehicles (PHEV), in its different configurations and Fuel-Cell Electric Vehicles (FCEV). Considering the range of this EVs charging station is required as a gas station. There are three important issues for a charging station: quick charge (less than 30 minutes), long battery lifetime (low temperature rise during charge), and standardization (all vehicle providers can be used). Constant current (CC) and constant voltage (CV) method are normally used for a battery charger. CC provides shorter time for charging a battery with higher temperature rise; whereas, CV offers low temperature rise with longer charging time. With the limit of voltage per cell (V /I cell) and maximum charging current

(Imax) from battery providers. Future trends in electric vehicle charging are mostly fast charging, contactless charging, and charging from renewable or sustainable energies. Fast pulse charging is an important issue in commercialization of electric vehicle in order to reduce charge time to a reasonable amount. When the battery gets fast charging and are overcharged, it will lead to overheating, performance weakening and damage to battery. The BMS lends a hand to battery life improvement, lessen damage rate, and capitalize on capacity, efficacy, durability and reliability in battery stacks.

### 2.3 Summary

In this modern age the usage of fossil fuels is being largely reduced due the environmental damage factors. In this scenario the utilization of electric vehicle (EV) are more encouraged. Now in the case of EV, the most important part is its battery source or simply battery of an EV. Now the best selection of the battery for an EV will improve its performance and range of the distance travelled by the vehicle; so, we can say that the optimal selection of batteries in EV is an important procedure.

As per literature review, different alternatives for EV batteries are identifies as given below: -

i. Lithium-Ion Battery
ii. Lithium Polymer
iii. Nickel Metal Hydride (NiMH)
iv. Sodium - Sulphur
v. Molten Salt ($Na\text{-}NiCl_2$) etc.

Also, different criteria for the selection of battery for EV's are also identified as: -

Battery Capacity, Open circuit voltage, Terminal voltage, Practical capacity, Discharge rate, State of charge, State of Discharge, Depth of charge, Battery energy, Specific energy, Battery power, Specific power, Ragone Plots, Cost, Shelf life etc.

According to the literature study on MCDM methods, AHP, CRITIC, ENTROPY techniques are identified as best tools for criteria weightage calculations. Similarly, MCDM techniques like TOPSIS, EDAS, MOORA, MAUA are chosen for the optimum selection of EV battery from different alternatives.

**Scope**

Each individual has different demands in the selection of Electric Vehicles (EV), so EV batterycriteria is given under the priority of the individual. Optimum selection of battery alternativesis a major factor in the efficient performance of EV in demanded conditions. MCDM is usefulin finding the best suited battery for each demand. So use of MCDM technique for selection of EV batteries improves the overall user experience.

# CHAPTER 3

# METHODOLOGY

The optimum selection of batteries for EV's can be accomplished by calculating criteria weights and ranking the alternatives using different MCDM techniques. Firstly, the weightage of criteria are found by using AHP, ENTROPY, and CRITIC methods. Finally, batteries are ranked by TOPSIS, EDAS, and MOORA methods.

## 3.1 AHP method for computing weightage

Saaty in 1970 developed AHP method to compute the subjective weights for solving multi criteria problems. The optimal solution is obtained with regard to the significance of various criteria and alter- natives. The main drawback is that, as the number of criteria and alternatives increases, this approach would be more complicated. The procedures to be followed in AHP method are given below:

Step 1: Form the hierarchical structure based on the EV battery criteria or attributes and alternatives.

Step 2: Formulate the pair-wise comparison matrix with reference to Saaty's scale of relative importance.

Step 3: Form the normalized pair-wise matrix and compute all criteria weights (Wj,AHP).

Step 4: Form the weighted matrix and check for consistency by finding consistency values, index and ratio.

Consistency values are the product of weighted index and each criteria weights.

Consistency index (CI) is calculated by,

$$\text{Consistency Index (C. I)} = \frac{\lambda max\ - n}{n-1}$$

Where, $\lambda_{max}$ is the average of consistency values and n is the number of criteria.

Consistency ratio (CR) is computed by,

Consistency ratio = Consistency Index(C.I)/Random Index(RI)

Random index (RI) with respect to the number of criteria is obtained according to earlier work. Finally, to check the consistency of weights, obtained CR is compared with the accepted upper bound of 0.1.

### 3.2 ENTROPY method for computing weightage

Shannon's ENTROPY method is one of the prominent methods for finding the objective weights in multi- criteria problem. This method makes use of the initial decision matrix to calculate the criteria weights. The procedures to be followed in this method are as follows:

Step 1: Prepare decision matrix.

Step 2: Normalize the decision matrix by using:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$$

Where n is the number of alternatives and m is the number of criteria and $X_{ij}$ is the performance index of $i^{th}$ alternative on $j^{th}$ attribute.

Step 3: Compute the entropy value ($e_j$) by using the equation

$$e_j = -h \sum_{i=1}^{m} r_{ij} ln(r_{ij}) \qquad \{j = 1,2,3, \dots, n\}$$

$$h = \frac{1}{ln(m)}$$

Step 4: Calculate the degree of diversification (dj) as:

$d_j = 1 — e_j$

Step 5: Calculate the criteria weight (Wj,ENT) as:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)}$$

### 3.3 CRITIC method for computing objective weights

CRITIC technique is used to find the objective weights of relative importance in MCDM problems. In the contest of decision-making framework of the problem, this approach involves both the severity of the contrast and the conflict. The standard deviation of the normalized criterion values by columns and the correlation coefficients of all pairs of columns are used to evaluate the criteria-contrast. In order to assess the information in the attributes under which alternatives are evaluated, this method relies on an empirical analysis of the decision matrix. The step-by-step procedure to be followed is given below:

$$\overline{X_{ij}} = \frac{X_{ij} - X_j^{worst}}{X_j^{best} - X_j^{worst}}$$

Where, $x^{best}$ j and $x^{worst}$ j are respectively the maximum and minimum values for beneficial and minimum and maximum for non-beneficial attributes in the decision matrix. For beneficial criteria, larger values are preferred whereas for non-beneficial, smaller values are preferred.

Step 2: Compute the standard deviation (σj) for each criterion.

Step 3: Form a matrix of order m x m by finding the elements ($Z_{jk}$) as linear correlation between $Z_j$ and $Z_k$.

Step 4: Find the measure of conflict made by criterion j with respect to the decision condition defined by remaining criteria as,

$$\sum_{k=1}^{m} (1 - r_{jk})$$

Step 5: Find the quantity of information for each criterion as:

$$C_j = \sigma_j \times \sum_{k=1}^{m} (1 - r_{jk})$$

Step 6: Calculate the weights as,

$$w_j = \frac{C_j}{\sum_{k=1}^{m} C_j}$$

### 3.4 TOPSIS method

The TOPSIS method is based on the selection of the optimum alternative at the shortest distance from the ideal positive and longest distance from the ideal negative solution. The ideal positive solution maximizes the benefit and minimizes non-beneficial criteria. Whereas, the negative ideal solution minimizes the benefits and maximizes non-beneficial criteria. The procedure to reach optimum solution is as follows:

Step 1: Formulate the decision matrix

Step 2: Normalize the decision matrix by using eq:

$$\overline{X_{ij}} = \frac{X_{ij}}{\sqrt{\sum_{j=i}^{n} X_{ij}^{2}}}$$

Step 3: Calculate the weighted normalized decision matrix as:

Yij = Wj *Zij

Where, Yij is the weighted normalized value.

Step 4: Find the ideal positive (best) and negative (worst) value. Ideal best solution ($Y_j^+$) will be the maximum value for the benefit and the minimum value for the non-beneficial criteria in the weighted normalized matrix. Similarly, ideal worst solution ($Y_j^-$) is the minimum value for the benefit and the maximum for non-beneficial criteria.

Step 5: Compute Euclidean distance from ideal best and worst solution as:

$$S_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2\right]^{0.5}$$

$$S_j^- = \left[\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2\right]^{0.5}$$

Step 6: Calculate the value of relative closeness (RC) to the perfect solution as:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

Step 7: Rank the alternatives based on the value of RC.

### 3.5 EDAS method

EDAS is one of the important MCDM techniques for selecting best alternative based on various attributes. In this method, the best alternative will be corresponding to the distance from the average solution. Here, in the first step, positive distance (PDA) and the negative distance from the average (NDA) are to be calculated which indicates the difference between each alternative and average solution. Higher PDA and lower NDA values would therefore imply optimum solution. The procedure to obtain optimum solution is given below:

Step 1: Determining the average solution.

Step 2: Calculate the positive distance from average.

Step 3: Calculate the negative distance from average.

Step 4: Weighted sum of PDA.

$$SP_i = \sum_{j=1}^{m} w_j PDA_{ij}$$

Step 5: Weighted sum of NDA.

$$SN_i = \sum_{j=1}^{m} w_j NDA_{ij}$$

Step 6: Normalize values of SP and SN.

$$NSP_i = \frac{SP_i}{max_i(SP_i)}$$

$$NSN_i = 1 - \frac{SN_i}{max_i(SN_i)}$$

Step 7: Normalize the values of NSN and NSP.

$$AS_I = \frac{1}{2}(NSP_I + NSN_I)$$

**3.6 MOORA method**

The MOORA method was developed by Brauers in 2006 to solve different complex decision-making problems in the manufacturing sector. The procedure to be followed in solving the problem is as follows:

Step 1: Prepare the decision matrix.

Step 2: Normalize the decision matrix by using eq:

$$x_{ij}^{*} = x_{ij} / \left[ \sum_{i=1}^{m} x_{ij}^{2} \right]^{1/2} \quad (j = 1,2, \dots, n)$$

Step 2: Estimation of assessment values.

$$y_{i} = \sum_{j=1}^{g} w_{j} x_{ij}^{*} - \sum_{j-g+1}^{n} w_{j} x_{ij}^{*} \; (j = 1,2, \dots, n)$$

# CHAPTER 4
# RESULTS AND DISCUSSION

## 4.1 Criteria for optimum selection

The specific energy, energy density, nominal voltage, specific power, energy efficiency, life cycle, working temperature, production cost are identified criteria's for optimum selection. Here the working temperature and production cost is taken as the non-beneficial criteria whereas the others are taken as behavioral criteria.

Here all other criteria except the production cost is taken in the quantitative form, whereas the production cost is taken as a linguistic term . This is then converted into quantitative fuzzy scores using eleven-point scale.

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