# A Decision Support System for Ranking the Different Battery Energy Storage Technologies using CRITIC and EDAS Method

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*Abstract*— **Electric Power Distribution Utility Companies (EPDUC) performing in the deregulated energy market always strive to provide a stable as well as steady power supply to its consumers cost competitive price. One of the latest approach to achieve the objective of providing cost-competitive reliable power supply is to integrate Battery Energy Storage Systems (BESS) with grids at both micro and macro level. However, due to involvement of multiple stakeholders in a power business there arises a problem of decision making to choose from a plethora of BESS technologies. An automated condition monitoring system (CMS) of a modern EPDUC deploys a combination of Internet of Things (IoT), Cloud computing, and Big-Data Analytics (BDA) based Decision support system (DSS) to make a choice for most techno-commercially viable BESS suitable as per dynamics of the demand in its network. This paper presents a DSS applying a hybrid approach of two Multi criteria decision making (MCDM) strategies namely CRITIC and EDAS for selecting the most BESS technology available in the network.**

***Keywords— Battery Energy Storage System (BESS), Decision Support System (DSS), Multi-criteria Decision Making (MCDM), Power Distribution System (PDS).***

## I. INTRODUCTION

Modern Electric Power Distribution Utility Companies (EPDUC) has to perform in an environment which is not only competitive on economic front [1], but also challenging on the technical fronts like reliability and quality [2]. The essence of a successful power distribution system (PDS) business is to strike a balance between cost and reliability of supplied power [3]. However, integration of Distributed Energy Resource (DER) based micro-grid in a PDS beyond a limit may not be beneficial; rather over penetration of such DER micro-grids can harm the performance of PDS due to phenomena like Duck-curve [4].

Therefore, EPDUC around the globe are in constant search of tangible solutions which can address the problem effectively. In recent times, one of the most trending solution for addressing the techno-commercial viability problems of PDS business is integration of Battery Energy Storage Systems (BESS) along with DER micro-grids at various levels of PDS grid [5, 6]. The philosophy behind the integration is simple; the BESS will act as a buffer for the customer at the end-user level whenever there occur an unfavorable change in the dynamics of PDS.

However, one of the prime decision making problem faced by operator of EPDUC is to choose from a pallet of different BESS technologies integrated into the system by different companies. For example, owner of one micro-grid may integrate Lead Acid Battery technology based Energy Storage System (ESS) while owner of other micro-grid may integrate Compressed air energy storage technology based ESS. In other case, the EPDUC may create redundant ESS banks comprising of different technologies and deploy any particular technology which suits the dynamics of the business. Moreover, EPDUC are increasingly applying autonomous condition monitoring systems (CMS) to cut the cost of human workforce. The situation calls for development of robust Decision Support System (DSS) which can recommend BESS technology based on objectivity of data rather than depending on the subjective judgment by human observers.

This paper illustrates the application of a novel hybrid Multi-criteria decision making (MCDM) based DSS, that can help an autonomous CMS to choose from different available BESS technologies based on their performance criteria. The MCDM techniques are Criteria Importance through Inter Criteria Correlation (CRITIC) [7] and Evaluation Based on Distance from Average Solution (EDAS) [8] methods which are applied in solving many MCDM problems [9-12] on individual levels, however their hybrid application for BESS technology selection is not observed till the development of this work.

## II. METHODS AND MATERIALS

This paper presents seven different kinds of battery technologies with their sixteen different criteria [13]. The batteries which have selected for these MCDM processes are Lead Acid Battery ($T_1$), Li-ion Battery ($T_2$), Super capacitors ($T_3$), Hydrogen Storage ($T_4$), Compressed air energy storage ($T_5$), Pumped Hydro storage ($T_6$) and Thermal energy storage ($T_7$). The sixteen different criteria along of these batteries are Area Intensity ($K_1$), Material Intensity ($K_2$), Energy Intensity ($K_3$), $CO_2$ Intensity ($K_4$), Lifecycle of Green House Gas Emission ($K_5$), Capital Intensity ($K_6$), Operating Cost ($K_7$), Current Installed Capacity ($K_8$), Growth Rate ($K_9$), Health and Safety ($K_{10}$), Specific Energy ($K_{11}$), Energy Density ($K_{12}$), Specific Power ($K_{13}$), Cycle efficiency ($K_{14}$), Cycle Life ($K_{15}$), Adaptable for Mobile ($K_{16}$).

*A. Summary of Performance Criteria*

***Area Intensity* (K$_1$):** Area intensity refers that intensity of the energy which is transferred in the aspect of per unit area. Unit of the area intensity is watt per square meter.

***Material Intensity* (K$_2$):** Material intensity is universally identified parts of materials which are required for manufacturing, processing and destruction of a portion of a good or a material. It can be also classified as total resources of metals like energy or fuels are consumed in per unit of manufacturing or the production. The unit of the metal intensity is $kg / MJ$ .

***Energy Intensity* (K$_3$):** Energy intensity is a part of the energy inability of a monetary system. Energy intensity can be optimized by calculating the ratio of usage of the energy to the gross domestic products (GDP). Energy intensity also describes how well the recession disciples energy into the monetary outcome. This is unit less as this intensity is described the ratio value of the energy supply to the GDP.

***$CO_2$ Intensity* (K$_4$):** $CO_2$ Intensity indicates that the radiation rate of the carbon di oxide which is ejected during the industrial production process. On the other hand, when it comes to the electricity or the power generation process then, it indicates that the amount of grams of $CO_2$ is required to generate one unit of electricity which is measured as Kilowatt per hour (KW/hr).

***Lifecycle of Green House Gas Emission* (K$_5$):** Lifecycle of greenhouse gas emission associates with considering the global warming potential of the energy resources through the lifecycle estimate. However, this is occurred only by the electrical energy but sometimes it is also happened of heat which is evaluated.

***Capital Intensity* (K$_6$):** Capital intensity is classified as the total amount of capital which is related with various types of factors of the production of the energy especially the workers or the labors. Capital intensity plays a crucial role in the productivity of an industry which implies the economic growth of the industry for a long-term process.

***Operating Cost* (K$_7$):** Operating cost is expressed as the maintenance cost, resources cost and the workers cost of an industry. This cost leans on the quantity of electricity that a plant generates. Operating cost is mainly two types one is fixed operating cost which includes with the capital cost, maintenance and the royalty. On the other hand, the other one is variable operating cost which is associated with the electricity, fuel and the feedstock which can be predicted by the latest financial data from the vendors' quote.

***Current Installed Capacity* (K$_8$):** Installed capacity of a power generation plant means the highest capacity that the system is constructed to drive this plant. Current installed capacity is generally optimized by kilowatt or megawatt.

***Growth Rate* (K$_9$):** The chunk by which a variable expands beyond a particular span of time as a percentage of its prior measure. The growth rate generally indicates the percentage of fraction over a period of year.

***Health and Safety* (K$_{10}$):** Health and safety plays an important role in the battery energy storage systems.
Batteries have the probability to be risky if they are not attentively constructed or if they are corrupted. Health condition of the battery is a normal condition of the battery.

***Specific Energy* (K$_{11}$):** Specific energy can be defined as the energy for every unit of mass. Furthermore, this is helped to measure the requirements of energy of each and every process.

***Energy Density* (K$_{12}$):** Energy density can be classified as the total quantity of the energy reserved in a particular space or the reservoir in per unit of the volume. Contrarily, the batteries which have a higher energy density may last for a longer time and the weigh is less.

***Specific Power (*K$_{13}$*)*:** Specific power of the battery energy system can be defined as the gravimetric power density and this can be asserted as watt per kilograms (W/kg).

***Cycle efficiency* (K$_{14}$):** Cycle efficiency is also called the Coulombic efficiency which can be described by the number of electrons are conveyed in the battery. Cycle efficiency is the ratio of the electrons squeezed from the battery to the total charge inserted to the battery over a complete cycle.

***Cycle Life* (K$_{15}$):** Cycle of a battery can be identified as the total number of the charge cycles as well as the discharge cycles that a battery energy storage system can complete before failing its conductivity.

***Adaptable for Mobile* (K$_{16}$):** Adaptable for mobile termed as the batteries which can be move as per the requirements and there are some batteries which have this advantage.

*B. Summary of MCDM Methods*

*1) CRITIC Method:* CRITIC method is one of those weighthing method which includes the intensity of the opposition and the dispute in the structure ogf the decision-making problem. It uses the correlation to find out the differences between the criteria and utilizes the result to assign a weight to them.

**Step 1.** Make a choice matrix of PAs.

$$[X_a] = [x_{aij}]_{m\times n} = \begin{bmatrix} x_{a11} & x_{a12} & \cdots & x_{a1n} \\ x_{a21} & x_{a22} & \cdots & x_{a2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{am1} & x_{am2} & \cdots & x_{amn} \end{bmatrix} \quad \text{(i=1,2,........., m and j=1,2,...., n)} \qquad (1)$$

**Step 2.** Make a standardized form of a decision matrix.

$$[X_a]_{normal} = [N_{a_{ij}}] \qquad (2)$$

Where, $[N_{aij}]$ can be indicated as

$$N_{a_{ij}} = \frac{x_{a_{ij}} - x_{a_j}^{\min}}{x_{a_j}^{\max} - x_{a_j}^{\min}}$$

For beneficial criteria
(3)

$$N_{a_{ij}} = \frac{x_{a_j}^{\max} - x_{a_{ij}}}{x_{a_j}^{\max} - x_{a_j}^{\min}}$$

For Non-beneficial (cost) criteria
(4)

**Step 3.** Calculate the approaches of the information in each column.

$$C_{a_j} = \sigma_{a_j} \sum_{i=1}^{m} 1 - \rho_{ij} \quad (5)$$

Where, $\sigma_{a_j}$ represents the value of the standard deviation of each column of [ $N_{a_{ij}}$ ],

And, $\rho_{ij}$ represents the correlation coefficient of each column of [ $N_{a_{ij}}$ ].

**Step 4**. Estimate the objective weight criteria.

$$w_{a_j} = \frac{C_{a_j}}{\sum_{i=1}^{m} C_{a_i}} \quad (6)$$

*2) EDAS Method:* The evaluation based on distance from the average solution or EDAS technique centers to embrace the best option dependent on a number of components, and the last positioning of the components is made by deciding the unity level of every component.

**Step 1.** Demonstrate a decision matrix $A$ by inserting the criteria and the alternative as interpreted.

$$[X_a] = [x_{a_{ij}}]_{m \times n} = \begin{bmatrix} x_{a11} & x_{a12} & \cdots & x_{a1n} \\ x_{a21} & x_{a22} & \cdots & x_{a2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{am1} & x_{am2} & \cdots & x_{amn} \end{bmatrix} \quad \text{(i=1,2,........., m and j = 1,2,...., n)} \quad (7)$$

**Step 2.** Calculate the average value of the alternatives in the aspect of the criteria.

$$AVG = \frac{\sum_{i=1}^{m} x_{a_{ij}}}{m} \quad (8)$$

Where, $AVG$ represents the average value of the alternatives and the average value will be calculated in the respect of the $i^{th}$ value.

**Step 3**. Estimation of Positive distance (PD) and negative distance (ND) from the normal arrangement grids are relying on the kind of the models either favorable or non-favorable (cost).

When, the criteria are favorable:

$$\left[PD_{a_{ij}}\right] = \frac{\max\left(0, \left(x_{a_{ij}} - AVG\right)\right)}{AVG} \quad (9)$$

$$\left[ND_{a_{ij}}\right] = \frac{\max\left(0, \left(AVG - x_{a_{ij}}\right)\right)}{AVG} \quad (10)$$

When, the criteria are non-favorable (cost criteria):

$$\left[PD_{a_{ij}}\right] = \frac{\max\left(0, \left(AVG - x_{a_{ij}}\right)\right)}{AVG} \quad (11)$$

$$\left[ND_{a_{ij}}\right] = \frac{\max\left(0, \left(x_{a_{ij}} - AVG\right)\right)}{AVG} \quad (12)$$

**Step 4.** Estimation of the weighted amount of Positive distance (SoP) and amount of negative distance (SoN) independently for all chose the alternatives, as portrayed.

$$SoP_{a_i} = \sum_{i=1}^{m} w_{a_i} PD_{a_{ij}} \quad (13)$$

$$SoN_{a_i} = \sum_{i=1}^{m} w_{a_i} ND_{a_{ij}} \quad (14)$$

Where, $w_{a_i}$ is the weight of the criteria.

**Step 5.** Calculate the Standardizing values of the sum of positive distance (SSoP) and the Standardizing values of the sum of positive distance (SSoN).

$$SSoP_{a_i} = \frac{SoP_{a_i}}{\max_i SoP_{a_i}} \quad (15)$$

$$SSoN_{a_i} = 1 - \frac{SoN_{a_i}}{\max_i SoN_{a_i}} \tag{16}$$

**Step 6.** Estimate the appraisement score (APS) for all the chosen alternatives.

$$APS_a = \frac{1}{2}\left(SSoP_{a_i} + SSoN_{a_i}\right) \tag{17}$$

## III. Proposed Framework

### A. IoT-BDA Based DSS Architecture

The proposed architecture of DSS for BESS technology selection is simple, it consists of three main units. The first unit is the data collection and curation mechanism which employs IoT based sensors to collect data field as well as Battery Management Systems (BMS), the data is routed through a low-power wide area network (LP-WAN) [14] gateway to optimize the long term operational cost. The second unit consists of a combination of data ware house and a cloud based data storage system and finally the third unit consists of a hybrid MCDM engine which is hosted in cloud computing environment. Figure 1 shows the center segments of the DSS architecture.

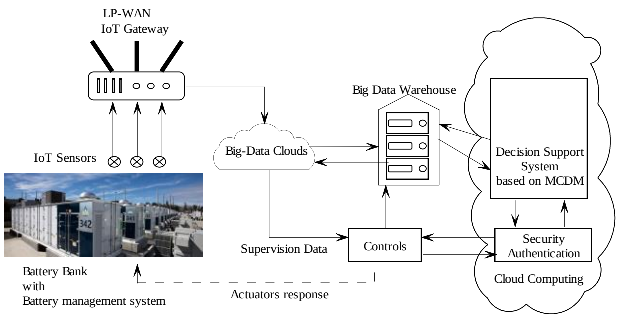


Fig. 1. DSS Architecture for Autonomous BESS Selection.

### B. MCDM Hybridization

This segment presents the algorithm and the corresponding flowchart developed for the automated DSS.

Step 1: Collect and curate performance criteria of the Battery Technologies. [Using Big-data Analysis]

Step 2: Create the decision matrix (DM) of the different types of performance criteria.

Step 3: Normalize the DM and determine the average solution of DM. [Using the equation (3), (4) & (8)]

Step 4: Calculate the value of the standard deviation of each column of DM and create the matrix of PDA and NDA.

Step 5: Create symmetrical correlation matrix of DM.

Step 6: Calculate the measure of conflict for each column of DM.

Step 7: Determine the quantity of relation in each column of DM. [Using the equation (5)]

Step 8: Created the weighted matrix of Positive Distance Average Solution (wPDA) and weighted matrix of Negative Distance Average Solution (wNDA). [Using the equations (9), (10), (11) & 12]

Step 9: Estimate the summation value of each row in wPDA and wNDA matrix. [Using the equations (13) & (14)]

Step 10: Create the column vectors of wPDA and wNDA matrix row of summation. [Using the equations (15) & (16)]

Step 11: Normalized the obtained matrix.

Step 12: Estimate the average performance score. [Using the equation (17)]

Step 13: Obtain the rank of the battery technologies i.e. the lowest average value is the best and the vice-versa.

Fig. 2 presents the flowchart of the paper.

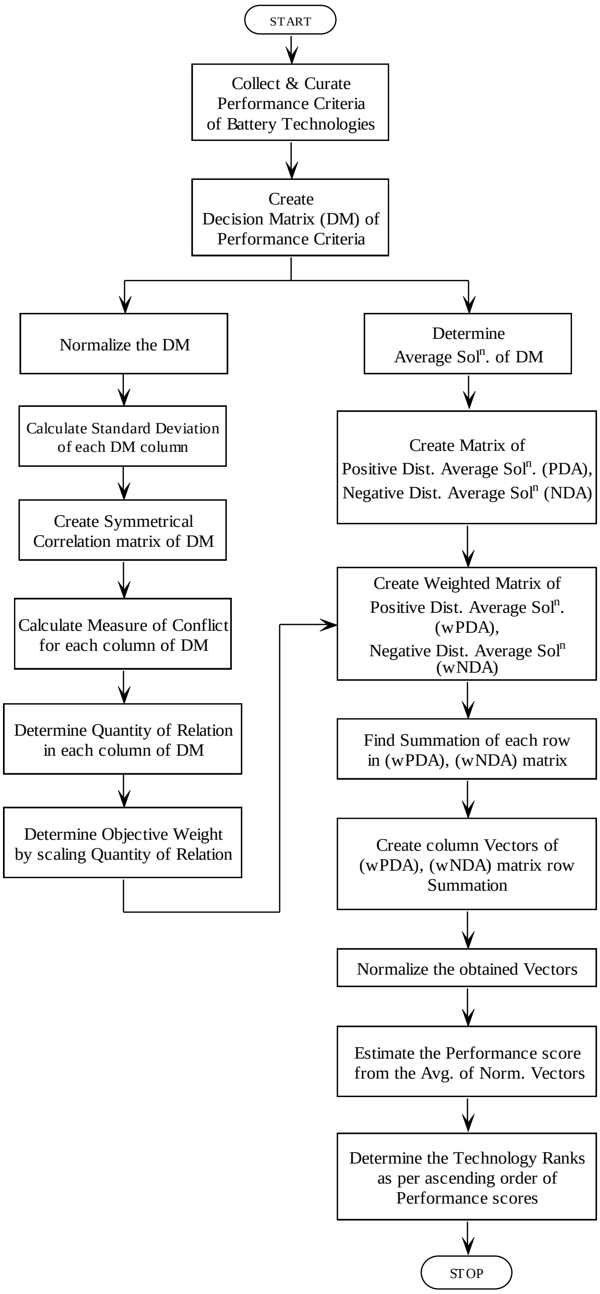


Fig. 2. Flowchart of the proposed MCDM based DSS

## IV. IMPLEMENTATION AND RESULT

In this work, all calculations are performed employing MS-Excel 2016. For assessing the weight applying the CRITIC technique first the engaging insights of the MDV are counseled to test for the standard deviation. This is trailed by the methodology referenced in segment 3.2 to appraise the loads, the consequences of the system are as per the following $K_1$ is 0.050845566, $K_2$ is 0.065671, $K_3$ is 0.047908, $K_4$ is 0.047212, $C_5$ is 0.080340, $K_6$ is 0.049437, $K_7$ is 0.061592, $K_8$ is 0.077503, $K_9$ is 0.083922, $K_{10}$ is 0.069380, $K_{11}$ is 0.067289, $K_{12}$ is 0.071749, $K_{13}$ is 0.049280, $K_{14}$ is 0.055863, $K_{15}$ is 0.050072, $K_{16}$ is 0.071936. Finally, EDAS is used for determining the final ranks from the weighted criteria. Table 1 shows the positioning of battery technologies as per their performance scores.

TABLE I. RANKS OF THE BATTERIES BASED ON THEIR PERFORMANCE

| **Score** | **0.0042** | **0.0094** | **0.2266** | **0.2404** | **0.2789** | **0.3169** | **0.6943** |
|---|---|---|---|---|---|---|---|
| **Rank** | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Batteries** | $A_7$ | $A_5$ | $A_1$ | $A_6$ | $A_2$ | $A_4$ | $A_3$ |

## V. CONCLUSION

Maintaining a sustained balance between cost and reliability of the power distribution network is a major challenge to the power distribution companies. Hence, EPDUC acting in the liberated energy market consistently endeavors to give a steady energy supply to their consumers cost cutthroat price. Due to the involvement of the multiple vendors in the power business it creates a confusion to select the proper BESS from a stack of battery. Thus, this paper highlighted on the DSS by implementing a hybrid computational method of MCDM strategies namely CRITIC and EDAS for choosing the most adequate BESS technology. Hopefully, this paper will help the readers to select the proper battery technology from the battery-stack in a simple way as per their performance criteria. Therefore, the power distribution utility companies have integrated the BESSs with micro as well as the macro-grid which will provide a budget-friendly power supply to their consumers without any disruption. Moreover, EPDUC are progressively employing the autonomous CMS to reduce the expenses of the labor cost.

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