The Security Effectiveness Assessment of Power Grid Assets Based on Life Cycle

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Abstract. By studying the economic efficiency evaluation model of the power grid asset life cycle, a grid asset economic efficiency evaluation model SEC that comprehensively considers safety and efficiency factors is proposed. This paper takes the transformer as an example to calculate its economic efficiency index in a certain period, and verifies that the economic efficiency evaluation model of the current equipment can evaluate the life cycle economic efficiency index of individual equipment or power grid equipment. Finally, the improved models are proposed in terms of energy consumption and compared to further improve the current evaluation model.

1. Introduction
Life Cycle Asset Management (LCAM) optimizes the entire process of asset formation to reduce the total life cycle cost of assets. This management approach focuses on the management of the entire process of assets and seeks to minimize life cycle costs (LCC) and to improve the reliability and safety of assets (or equipment)[1]. The process of LCAM combines the processes of value flow, real logistics and information flow. Life-cycle management is a ranking management of planning, procurement, operation and maintenance, and post-disposal in a time series. The purpose is to achieve lean management of assets.

LCAM is a management method and concept that pursues the lowest cost of the life cycle. The concept is based on the premise of efficiency, benefit and safety. The concept takes into account the entire process from planning and design to procurement and construction until the end of life. Literature [3-4] put forward the ideas and basic methods of LCAM based on the study of reliability, maintainability and economy, but it did not establish corresponding models to participate in the life management of power assets; literature [6] introduced ERP and PMS systems from the perspectives of equipment asset information integrity, equipment asset status consistency, and asset value validity, which realized the functions of asset monitoring, analysis and coordination, but the method did not fully consider the economic problems in the asset management process and reduced the feasibility of the method; literature [7] proposed a life cycle management framework for power assets based on mobile internet technology by using system analysis methods, qualitative and quantitative analysis, field research and analysis methods, based on RFID technology and planar bar code technology, and it realized the three-in-one integration of enterprise asset value flow, information flow and real logistics,
but this method only realized the management of things on the basis of physical objects, lacked the management of factors such as the safety and efficiency of assets, and the management factors are relatively single. This paper takes grid assets as the research object, and considers the security factors and performance factors of assets from the overall goal of the system, and pursues the optimal life cycle cost of assets under the premise of satisfying safety and efficiency. It further deepens the application of asset life management in grid asset management, realizes the visualization of grid asset management and the quantification of grid equipment economic benefit assessment, and provides systematic support for asset management and benefit assessment.

Constructing a life cycle asset assessment decision model is one of the key technologies for asset life management assessment. At present, the commonly used comprehensive evaluation methods include analytic hierarchy process, weighted comprehensive assessment method, Delphi illegal, principal component analysis, etc. [9]. In view of the characteristics of large grid assets and many equipment, State Grid Corporation has established an “asset life cycle management assessment decision system” to achieve automatic acquisition of grid asset basic data. Grid assets are regularly evaluated in terms of safety and efficiency, and the Safety and Efficiency Cost (SEC) ultimately responds to the economic efficiency of grid assets over a certain period of time.

This paper focuses on the methods and models for evaluating the economic efficiency of grid assets implemented by State Grid Corporation, proposes a model for assessing the economic performance of grid assets based on safety and effectiveness factors, and calculates the economic performance index of a transformer in a certain period, and compares it with the evaluation model SEC0 which does not consider safety and efficiency factors. Finally, the improvement strategy is proposed from the perspective of energy consumption, and the shortcomings of the improved evaluation model in energy consumption evaluation are further compared.

1.1. Evaluation Model of Safety effectiveness cost indicator
The evaluation model adopted by the asset life cycle management evaluation decision system includes only five major types of equipment, such as main transformers, circuit breakers, GIS, overhead lines, and cable lines, and other equipment. The comprehensive economic performance evaluation model is shown below.

\[
\text{Synthesis } SEC = SEC_0 \times f_E \times f_S
\]  

Synthesis \( SEC \): Comprehensive safety effectiveness cost indicator; \( SEC_0 \): \( SEC \) (yuan \( \div \) kVA) without considering efficiency and safety; \( f_E \): performance indicator factor; \( f_S \): safety indicator factor.

1.1.1. \( SEC_0 \) evaluation model.
\( SEC_0 \) refers to the asset economic performance indicator that does not consider performance and safety factors. It is based on the evaluation model of various equipment asset economic efficiency indicators. The single-class equipment and evaluation models are as follows. In each model, \( m \) represents different voltage levels such as 220kV, 330kV, 500kV, and 750kV.

(1) The evaluation model of \( SEC \) for main transformer:

\[
SEC_{Tm} = SEC_{0Tm} \times Rzbm
\]

\( SEC_{0Tm} \): the \( SEC \) (yuan/kVA) of transformers that do not consider efficiency, reliability, and safety; \( Rzbm \): load factor ratio conversion factors for different voltage levels.

\[
SEC_{0Tm} = \frac{C_{Tm}}{S_{Tm} / 1000}
\]

\( C_{Tm} \): total transformer cost (yuan); \( S_{Tm} \): total transformer capacity (MVA);
1. \[ C_{Tm} = C_1 + C_2 + C_3 + C_4 + C_5 \]  

\[ C_1 = V/L, \quad V \] is the original value of the asset, \( L \) is the expected service life of the asset.  

\[ C_2 : \text{the operation and maintenance cost in the asset cycle}; \quad C_3 : \text{the maintenance cost in the asset cycle}; \quad C_4 : \text{the failure disposal cost in the asset cycle}; \quad C_5 : \text{the disposal cost in the asset cycle}. \]

(2) The evaluation model of SEC for circuit breaker:  

\[ SEC_{Bm} = SECO_{Bm} \times E_{Bm} \]  

\( SECO_{Bm} : \text{the SEC (yuan/kVA) of circuit breaker that do not consider efficiency, reliability, and safety}; \)

\( E_{Bm} = (1-\text{Cycle out time/Hours in the cycle}) \times 100; \)

Circuit breaker utilization ratio: \( SECO_{Bm} = C_{Bm} / S_{Tm} / 1000 \)  

\( C_{Bm} : \text{total cost of circuit breaker (yuan), including the same content as formula}; \)

(3) Evaluation Model of SEC for GIS:  

\[ SEC_{GISm} = SECO_{GISm} \times E_{GISm} \]  

\( SECO_{GISm} : \text{the SEC (yuan/kVA) of GIS that do not consider efficiency, reliability, and safety}; \)

\( E_{GISm} = (1 - \text{outage time in cycle / number of hours in cycle}) \times 100\%; \quad \text{GIS utilization ratio:} \)

\( SECO_{GISm} = C_{GISm} / S_{Tm} / 1000 \)  

\( C_{GISm} : \text{total cost (yuan) of circuit breaker, including the same content as formula 5.} \)

(4) The evaluation model of SEC for overhead lines:  

\[ SEC_{Olm} = SECO_{Olm} \times Rzh_{bm} \]  

\( SECO_{Olm} = C_{Olm} / S_{Olm} / 1000 \)  

\( S_{Olm} = Ln_{Olm} \times P_{S_{Olm}} / P_{S_{Tm}} / 1000 \)  

\( C_{Olm} : \text{Total cost (yuan) of overhead lines, including the same content as formula 5}; \)

\( S_{Olm} : \text{Conversion capacity (MVA) of overhead line}; \quad Ln_{Olm} : \text{Total length of overhead lines (km)}; \)

(5) The evaluation model of SEC for cable line:  

\[ SEC_{Clm} = SECO_{Clm} \times Rzh_{bm} \]  

\( SECO_{Clm} = C_{Clm} / S_{Clm} / 1000 \)  

\( S_{Clm} = Ln_{Clm} \times P_{S_{Clm}} / P_{S_{Tm}} / 1000 \)  

\( C_{Clm} : \text{total cost (yuan) of cable line, including the same content as formula 5.} \quad S_{Clm} : \text{cable line conversion capacity (mVA)}; \quad Ln_{Clm} : \text{total length of cable line (km)}; \quad P_{S_{Tm}} = \text{original value (yuan) of cable line}/\text{total length (km) of cable line, unit cost (yuan/km) of cable line}; \quad P_{S_{Tm}} : \text{unit capacity cost (yuan/kVA) of main transformer}. \)

(6) The evaluation model of SEC for other equipment in Station  

\[ SEC_{Om} = SECO_{Om} / 1 \]
\[ SECO_{Om} = C_{Om} / S_{Tm} / 1000 \quad (16) \]

SECO_{Om} : the SEC (yuan/kVA) of other equipment that do not consider efficiency, reliability, and safety; C_{Om} : the total cost (yuan) of other equipment in the station, including the same content as formula 5.

The above model can be used to evaluate the economic benefits of various types of power grid equipment within a certain period, that is, the economic performance of the five major categories of equipment such as main transformer, circuit breaker and GIS and other equipment can be evaluated separately within a certain period. It is also possible to use formula 2 to evaluate the economic performance of all five types of equipment above 220kV, and finally use SEC to represent the operation and maintenance cost of the grid equipment in the period.

\[
SEC = [(SEC_T + SEC_g + SEC_{GIS} + SECo) \times \sum S_{Tm} + SEC_{OL} + \sum S_{OLm} + SEC_{CL} \times S_{CLm}] / S_{sum} \quad (17)
\]

1.1.2. Evaluation Model of Comprehensive Security Effectiveness SEC.

The grid asset economic effectiveness indicator SEC_{O}, which does not consider safety and effectiveness factors, is given above. In the actual grid production, the safety and efficiency of equipment must be considered, which has an important contribution to grid production and economic costs. The economic benefit assessment of grid assets must take into account the safety effectiveness of grid equipment during operation, which leads to the comprehensive SEC of asset safety effectiveness cost indicators, namely Equation 1, where B and C are effectiveness indicator factors and safety indicator factors, respectively. The models and meanings are as follows.

\[ f_E = f_{E1} \times f_{E2} \times 1 \quad (18) \]

In the formula, \( f_{E1} \) is expressed as the power supply reliability factor. When 0<supply reliability rate<1, it is calculated according to formula 19; \( f_{E2} \) is expressed as voltage pass rate factor. When 0<voltage pass rate<1, it is calculated according to formula 20.

\[
f_{E1} = \left[ K_{E1} - \ln \left( 100 - 100 \times E_{E1} \right) \right] / \left[ K_{E1} - \ln \left( 100 - 100 \times R_1 \right) \right] \quad (19)
\]

\[
f_{E2} = \left[ K_{E2} - \ln \left( 100 - 100 \times E_{E2} \right) \right] / \left[ K_{E2} - \ln \left( 100 - 100 \times R_2 \right) \right] \quad (20)
\]

\( R_1 \) : power supply reliability; \( K_{E1} \) : power supply reliability index adjustment factor (10); \( E_{E1} \) : evaluation value of power supply reliability index for the whole network; \( R_2 \) : voltage pass rate; \( K_{E2} \) : voltage qualification rate adjustment factor (10); \( E_{E2} \) : voltage qualification rate assessment value.

\[ f_S = f_{ST} \times f_{Ss} \times f_{SY} \quad (21) \]

In the formula, \( f_{ST} \) is expressed as a mega-complete factor, \( f_{Ss} \) is expressed as a major safety factor, and \( f_{SY} \) is expressed as a general safety factor. When applying the model to calculate the synthesis, the \( f_{ST}, f_{Ss}, \) and \( f_{SY} \) index factors are 1 when there is no safety accident in a certain period, and the safety factor corresponding to the accident level is 0 when there is an accident.
2. Case analysis
Taking the main transformer as an example, the monthly operating cost per unit of variable capacity is calculated to be 0.29 yuan/kVA. The basic data and calculation results of the main transformer are shown in Table 1. The basic factors A, B, C, and D of the performance factor are all referenced web indicators.

Table 1. Basic data and calculation results of main transformer

|                      | SEC of main transformer (yuan/kVA) | SECO of main transformer (yuan/kVA) |
|----------------------|------------------------------------|------------------------------------|
| Calculation process  | 0.287                              | 0.308                              |
| Result of SECO       |                                    |                                    |
| For 500KV main       |                                    |                                    |
| Transformer          |                                    |                                    |
| SEC_{Tm} (yuan/kVA)  | 0.21                               | SEC_{Tm} (yuan/kVA)                |
| (Obtained by formula 2) |                                  | (Obtained by formula 2)             |
| SECO_{Tm} (yuan/kVA) | 0.19                               | SECO_{Tm} (yuan/kVA)               |
| (Obtained by formula 3) |                                  | (Obtained by formula 2)             |
| R_{zbn}              | 1.12                               | R_{zbn}                            |
|                      |                                    |                                    |
| Calculation process  | 0.287                              |                                    |
| Result of SECO       |                                    |                                    |
| For 220KV main       |                                    |                                    |
| Transformer          |                                    |                                    |
| SEC_{Tm} (yuan/kVA)  | 0.39                               |                                    |
| (Obtained by formula 2) |                                  |                                    |
| S_{Tm}               | 23589                              |                                    |
| C_{Tm}               | 4555392.15                         |                                    |
| C_{1} = V / L        | 4282048.67                         |                                    |
| C_{2}                | 273343.48                          |                                    |
| V (yuan)             | 1156153140.709                     |                                    |
| L (month)            | 270                                |                                    |
| Safety factor,       | 1                                  |                                    |
| effectiveness factor  |                                     |                                    |
| f_{S}                | 1                                  |                                    |
| f_{ST}               | 0                                  | 0.931                              |
| f_{S2}               | 0                                  |                                    |
| f_{SY}               | 0                                  |                                    |
| f_{E1}               | 0.95                               | E_{S1} 0.9998                      |
|                      |                                     | R_{1} 0.9999                       |
|                      |                                     | K_{E1} 10                         |
| f_{E2}               | 0.98                               | E_{S2} 0.9996                      |
|                      |                                     | R_{2} 0.9997                       |

It can be seen from the above table that the A and B of the main transformer calculated according to the relevant data and formula are 0.287 yuan/kVA and 0.308 yuan/kVA, respectively, and the safety...
performance index \( SEC \) of the main transformer is 0.021 yuan/kVA lower than B without considering the efficiency and safety factors. This suggests that the safety energy efficiency cost metrics will be appropriately reduced if efficiency and safety factors are considered and also reflect the fact that the safety performance indicator \( SEC \) is more realistic and the practicality and intuitiveness of the evaluation method. In the table, only the main transformer is taken as an example, and the evaluation model adopted by the asset life cycle management evaluation decision system includes five major types of equipment, such as main transformers, circuit breakers, GIS, overhead lines, and cable lines, and other equipment. Their economic performance models are given in the text and can be derived from the calculation process of the main transformer. In addition, the management of safety performance cost indicators is guided by the system management thinking, based on the premise of safety and reliability, with the system as the guarantee, the lean method as the means, the information system as the support, the optimization of asset allocation as the guide. And it focuses on improving the life of the asset and aims to reduce the life cycle cost of the asset. The relationship between safety (S), efficiency (E), and cost (C) is also coordinated. Therefore, the grid can pass the management model to optimize resource allocation and improve grid management level and operational efficiency [11].

3. Conclusion
Applying the safety performance cost indicator evaluation model and referring to the main change SEC calculation process, the SEC values of circuit breakers, GIS, overhead lines, cable lines and other equipment can also be calculated, and then the economic performance indicators of the grid assets, quantitative analysis and assessment can be obtained. However, the current so-called Grid Asset Economic Effectiveness Index (SEC) only considers the operation and maintenance cost of grid assets and the impact of safety and efficiency (power supply reliability rate, voltage qualification rate) on the SEC. The influence of energy consumption (line loss rate) on the operation cost of power network assets is not taken into account. In order to reflect the economic efficiency of power grid assets more realistically and objectively, it is necessary to consider the equipment energy consumption factor in the evaluation model.

Therefore, it is recommended to increase the equipment energy factor in the SEC calculation model and modify Equation 1 to:

\[
\text{Synthesis } \frac{\Delta S}{EC} = \frac{\Delta S}{EC} \times f_E \times f_S \times f_{\Delta A}
\]

\( f_{\Delta A} \) represents grid energy consumption (line loss rate),
\( f_{\Delta A} = 1 + \Delta A \)
\( \Delta A \): line loss rate

Using the modified formula and calculating the grid asset loss rate of 5.15%, the SEC of the main transformer can be 0.302 yuan/kVA, that is, after considering the line loss rate factor, the SEC of main transformer increased by 0.014 yuan/kVA, which represents the economic performance index of the main line loss rate contributed 0.014 yuan / kVA.

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