Techno-economic Analysis on AC/DC Power Distribution Network based on Flexible Substation

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Abstract: With development of technologies and the society, the shortages of traditional AC power distribution technology show up gradually, and more power devices start adopting DC power transmission technology. During that process, the flexible substations emerge correspondingly. This paper, taking the example of Zhangbei flexible substation and AC/DC power distribution network demonstration project, collects various economic data of the project since its commissioning, evaluates its techno-economic performance, analyzes its economic benefits and social benefits and makes expectations about the future.

1. Introduction
In recent years, DC loads and variable frequency loads appeared in large numbers, and the AC/DC conversion of electric power energy plays a more important role. In order to improve power transmission efficiency of power distribution network, and guarantee long-time effective operation and sustainable development of the technology, it is urgent to carry out techno-economic analysis on it. In 2018, the first AC/DC power distribution network based on flexible substation in the world- Zhangbei flexible substation and AC/DC power distribution demonstration project was put into commercial operation. This paper takes this project as example, applies techno-economic analysis and proposes effective suggestions on the AC/DC power distribution network based on flexible substation.

2. Current status of AC/DC power distribution technology at home and abroad
At present, the global study on AC/DC power distribution network technology is still in starting stage. This paper will introduce the current status of domestic and overseas development of AC/DC power distribution network, and lay foundation for subsequent techno-economic evaluation of AC/DC power distribution network based on flexible substations.

2.1. Current status of overseas AC/DC power distribution technology development
In initial stage of power industry, the DC school represented by Thomas Alva Edison and the AC school represented by G. Westinghouse arose. With technical development, the technologies of transformers and electric motors become more perfect, and the AC power distribution mode was prevailing in the power system. Now, however, the emergence of large amount of frequency variable equipment drives further development of DC power distribution technology. In 1954, the first high-voltage DC power transmission line in the world was built in Sweden, opening the new era for
AC/DC hybrid technology. The European Union proposed the idea of “Supergrid”, laying the foundation for AC/DC hybrid power grid [4]; the USA put forward “Grid 2030” after summarizing several accidents in its power system operation.

2. Current status of domestic AC/DC power distribution technology development

The AC/DC hybrid grid which, with AC power distribution grid as framework, integrates nationwide clean energy by DC power transmission, distributes electric power with wide medium-voltage AC/DC hybrid power distribution network, and connects to local low-voltage power distribution grid, is formed gradually [5]. Hulun Buir - Liaoning AC/DC hybrid power transmission and distribution project is the first AC/DC hybrid power transmission and distribution project in Northeast China [6]. The Three Gorges Power Transmission and Distribution Project is the largest scale AC/DC hybrid power transmission and distribution system with the most complicated technologies in the world, and it makes the power grid planning ability of China reach the international leading level. In 2018, Guizhou Five-end flexible DC power distribution demonstration project was put into commissioning as the first medium-voltage five-end flexible DC power distribution demonstration project. In this project, China’s first flexible AC/DC interconnected power distribution center integrating AC power distribution grid, AC micro-grid, DC micro-grid, distributed power source and electric vehicle charging station is built.

3. Theoretical foundation about techno-economic evaluation

The techno-economic analysis confirms the optimal economic status with advanced technology and reasonable economy through seeking for the optimal combination of technology and economy. The common indexes contain dynamic investment return period, net present value, net present value index, net annual value, net future value, present cost and annual cost, internal rate of return and external rate of return. The calculation formula and judgment standard can be seen in Table 1.

| Index                              | Calculation formula                                                                 | Judging standard                                                                 |
|------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Dynamic investment return period   | $\sum_{t=0}^{n} (CI - CO) (1 + i_o)^t = 0$                                           | The project is acceptable if the dynamic investment return period is no larger than the benchmark dynamic investment return period. |
| Net present value (NPV)            | $NPV = \sum_{t=0}^{n} (CI - K - CO) (1 + i_o)^t$                                    | The project is acceptable if NPV is no smaller than 0.                             |
| Net present value index (NPVI)     | $NPVI = \frac{NPV}{P}$                                                              | Subject to the maximum NPVI.                                                      |
| Net annual value (NAV)             | $NAV = NPV(A / P, i_o, n) = \sum (CI - CO) (1 + i_o)^t \times (A / P, i_o, n)$ | The project is acceptable if NAV is no smaller than 0.                             |
| Net future value (NFV)             | $NFV = NPV(F / P, i_o, n) = NAV(F / A, i_o, n)$                                     | The investment program is acceptable if NFV is larger than 0.                     |
| Present costs and annual costs (PC, AC) | $PC = \sum_{t=0}^{n} CO (1 + i_o)^t$                              | In comparison of multiple programs, the one with the minimum PC or AC will be the optimal. |
| Internal rate of return (IRR)      | $\sum_{t=0}^{n} (CI - CO) (1 + IRR)^{-t} = 0$                                      | The project is acceptable if IRR is no smaller than the benchmark discount rate.   |
| External rate of return (ERR)      | $\sum (NB) (1 + i_o)^{n-t} = \sum (K) (1 + ERR)^{n-t}$                             | The project is acceptable if ERR is no smaller than the benchmark discount rate.    |
4. Case analysis

4.1 Data selection

This paper takes the Zhangbei flexible substation and AC/DC power distribution network demonstration project as example, and carries out techno-economic analysis according to data acquired by project investment estimation. The cost standard that the project investment estimate is based on shall be set according to Standards for Construction Budget Preparation and Calculation of 20kV or Smaller Power Distribution Grid Project, and the quota shall adopt 2009 Budget Quota Estimation Table of 29kV and Smaller Power Distribution Grid Project. Among main economic data acquired by estimation, the static total investment of the project shall be RMB 60.78 Million, and dynamic total investment shall be RMB 61.98 Million. The conventional DC part is RMB 12.91 Million, flexible substation and DC project is RMB 49.07 Million, Xiaertai flexible substation DC project and newly built PV DC booster station project is respectively RMB 27.86 Million and RMB 18.82 Million, and ±10kV DC line project is RMB 2.39 Million.

4.2 Techno-economic evaluation

Aforesaid data is used to apply techno-economic evaluation to the project to calculate the dynamic investment return period, net present value, net present value index, net annual value, net future value, present cost and annual cost, internal rate of return and external rate of return of the project. Results are as follows.

1) Dynamic investment return period

\[ \sum_{t=0}^{T^*} (CI - CO)_t (1 + i_0)^{-t} = 0 \]

According to the benchmark discount rate of 8%, the dynamic investment return period of the project is 19.987 years through calculation. The project calculation period shall be 20 years, and the investment could barely be recovered within the calculation period. The project is basically acceptable in economics.

2) Net present value (NPV)

\[ NPV = \sum_{t=0}^{n} (CI - K - CO') (1 + i_0)^{-t} \]

The total investment in the beginning of the year shall be RMB 61.98 Million. As calculated, the NPV of the project is RMB 1,600; although the NPV is larger than 0, the value is small, so the project is not very feasible in economy.

3) Net present value index (NPVI)

\[ NPVI = \frac{NPV}{P} \]

The NPV of the project is RMB 1,600, and the sum of present value of the investment plan is RMB 61.98 million. Therefore, the NPVI shall be 0.003%. The NPVI is larger than 0 but very low; the plan is acceptable but could not bring favorable economic benefits.

4) Net annual value (NAV)

\[ NAV = NPV \left( \frac{A}{P}, i_0, n \right) = \sum (CI - CO)_t (1 + i_0)^{-t} \times \left( \frac{A}{P}, i_0, n \right) \]

Corresponding NAV is calculated according to the NPV of RMB 1,600. The NAV apportioned to every year of the calculation period shall be RMB 160, larger than 0 but the project is not that feasible in economy.
5) Net future value (NFV)

\[ NFV = NPV \left( F/P, i_0, n \right) = NAV \left( F/A, i_0, n \right) \]  

The NFV will be calculated according to NAV or NPV, and the value shall be RMB 7,470. The NFV is larger than 0, and the project is acceptable but the income is low during the project calculation period.

6) Present costs and annual costs (PC, AC)

\[ PC = \sum_{t=0}^{n} CO_t \left( 1 + i_0 \right)^{-t} \]  
\[ AC = \sum_{t=0}^{n} CO_t \left( 1 + i_0 \right)^{-t} \times \left( A/P, i_0, n \right) = PC \times \left( A/P, i_0, n \right) \]  

Through calculation, the PC of the project shall be RMB 68.86943 million, and AC shall be RMB 7.01435 million. Since PC and AC could only be used for comparison of techno-medical effects of multiple plans. It is meaningless for comparison of single plan as in this project. Therefore, the conclusion about feasibility of economic effect could not be acquired.

7) Internal rate of return (IRR)

\[ \sum_{t=0}^{n} \left( CI - CO \right)_t \left( 1 + IRR \right)^{-t} = 0 \]  

The IRR of the demonstration project calculated as per cash inflow and outflow of the project in every year shall be 8.004%, which is larger than the benchmark discount rate of 8%. It means certain investment is not recovered during the calculation period, and the project is barely acceptance in economic effect.

8) External rate of return (ERR)

\[ \sum \left( NB_t \right) \left( 1 + i_0 \right)^{n-t} = \sum \left( K_t \right) \left( 1 + ERR \right)^{n-t} \]  

The net income of the project every year is expected to be RMB 637,000, and net investment is expected to be RMB 6.25243 million. The ERR of the project according to 8% discount rate shall be 8.001%, slightly larger than the benchmark discount rate. The project is not feasible in economy.
4.3 Benefits analysis

The results of techno-economic evaluation based on aforesaid techno-economic analysis are as follows:

| Table 2 Techno-economic evaluation results | Value   | Unit       | Judging                                           |
|------------------------------------------|---------|------------|--------------------------------------------------|
| Dynamic investment                       | 19.987  | Year       | The value is smaller than the calculation period, and the project is barely acceptable |
| return period                            |         |           |                                                  |
| NPV                                      | ¥0.160  | Ten Thousand Yuan | The value is slightly larger than 0, and the project is barely acceptable |
| NPVI                                     | 0.003%  |            | The value is slightly larger than 0, and the project is barely acceptable |
| NAV                                      | ¥0.016  | Ten Thousand Yuan | The value is slightly larger than 0, and the project is barely acceptable |
| NFV                                      | ¥0.747  | Ten Thousand Yuan | The value is slightly larger than 0, and the project is barely acceptable |
| AC                                       | 701.4351446 | Ten Thousand Yuan | The single project is unable to compare |
| PC                                       | 6886.943 | Ten Thousand Yuan | The single project is unable to compare |
| IRR                                      | 8.004%  |            | The value is slightly larger than 8%, and the project is barely acceptable |
| ERR                                      | 8.001%  |            | The value is slightly larger than 8%, and the project is barely acceptable |

The results of techno-economic evaluation results of Zhangbei flexible substation and AC/DC power distribution network demonstration project can be seen in Table 1. Aforesaid results show AC and PC could not be used in judgment of single project; other techno-economic indexes could barely meet feasibility conditions of the project. The demonstration project is not that feasible in economy, and barely acceptable. That is because the project is still in the initial stage, and shall be put in trial as demonstration project. It still has many problems in terms of technology and economy. The initial expenses and costs of the project are high, leading to low profitability, and low economic feasibility.

From the angle of long-term economic benefits, since the commissioning of the project, the 3.86 million MWH electricity generated by PV is consumed locally or on grid, gaining RMB 4.06 million for Desheng Village; in the aspect of power grid, the AC/DC conversion links of power distribution grid is simplified, obviously improving electricity generation volume and energy consumption efficiency; in the aspect of load, the investment of about RMB 7 Million could be saved through simplifying electricity consumption links. In terms of industry-university-research institutions, the potential market demand of application of flexible substation to power transmission and distribution network in the future 5 years will exceed RMB 500 million. Thus, the project has vast economic benefits from the long-term perspective.

For social benefits, the project has prominent innovative and demonstrative performance. In the meantime, the project provides diversified power supply services for the emerging industry, and opens new mode for high-quality power supply; this project also realizes local efficient consumption of new
energy and realizes the in-depth combination of intelligent power grid and cloud computing for the first time. Generally, the project not only has extensive social benefits but also supports the national strategy of targeted poverty alleviation from the technical perspective.

5. Conclusion and outlook

According to the techno-economic evaluation results, in the case of Zhangbei flexible substation and AC/DC power distribution network demonstration project, the techno-economic indexes of flexible DC power transmission and distribution project are not feasible; however, from the angle of overall economic benefits, the project has brought higher economic benefits for many entities, and will have better development in the long run. Meanwhile, the AC/DC power distribution network technology based on flexible substation with the project as representative shows prominent innovative and demonstrative performance, and high social benefits.

In the future, the power distribution network with highly integrated AC/DC system, coordinated and interactive multi-voltage grades, and high intelligence will be an important development direction of power distribution network. It could provide solutions for clean and diversified power source, electronic and information-oriented network power and complex and interactive load characteristics, and has vast development perspective.

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