Application Research of Online Sensing Technology of Dynamic Capacity Increase

Li Hui chen¹,a, Yang Feng¹,b*, Fu Zhong yuan¹,c, Cui Rong ye¹,d

¹shanghai university of electric power, LinGang, Pudong New District, shanghai, china
²email: hclisuep@163.com
³email: yangfeng@shiep.edu.cn

Abstract. With the continuous development of my country's national economy, the demand for electricity in various regions continues to increase, and the operation of high-voltage overhead transmission lines in many regions is already facing transmission bottlenecks. Therefore, it is very important to study the dynamic capacity increase technology of high-voltage overhead lines. This article points out the main technologies and methods to increase the transmission capacity of transmission lines, analyzes the advantages and disadvantages of each technical method, evaluates the advantages and limitations of dynamic capacity expansion technology and economic feasibility, and finally proposes that dynamic capacity expansion technology is developing. The existing problems and the future development trend point out the broad application prospects and important practical significance of the research on the new capacity-increasing wire of the online state-aware technology.

1. Introduction

Since the beginning of the 21st century, China's economy has developed rapidly, and its electricity demand has continued to increase. The total installed capacity has continued to increase, but the problem of power shortage is still quite prominent, especially during the high-temperature period in summer. With the rapid growth of power capacity and demand for electricity, the increasing shortage of resources and energy, and the urgent requirements of environmental protection, a large number of new transmission lines are needed to greatly improve the transmission capacity of the grid. However, these cannot solve the short-term and sudden power shortage problem and will be restricted for various reasons. Therefore, it is necessary to consider the use of built transmission lines to increase the line transmission capacity under the conditions of safe operation. To solve the short-term power shortage problem.

Dynamic capacity increase technology is to monitor the meteorological conditions (ambient temperature, sunshine, wind speed, etc.) around the transmission line in real-time, and use specific meteorological conditions to calculate the actual maximum allowable current carrying capacity of the wire. Dynamic capacity-increasing technology has the advantages of low investment, extremely short construction period, no environmental protection, and land acquisition pressure. It is one of the most economical, feasible, widely applicable, and most anticipated capacity-increasing technologies among the above technologies for improving grid transmission capacity.
2. Three models for calculating the current carrying capacity of the capacity-increasing line

Based on the heat balance equation, different models can be used to calculate the current carrying capacity of the capacity-increasing line. The following three models for calculating the transmission capacity of the transmission line will be discussed, and their advantages and disadvantages will be analyzed and compared.

(1) Calculation of transmission capacity of transmission line based on climate model

The climate model uses ambient temperature, sunshine, wind speed, wind direction, and wire temperature to directly calculate wire capacity. Similarly, the radiation heat dissipation and solar heat gain are calculated according to the thermal balance of the wire, and the calculation formula is the same as the above formula. Regarding the convective heat dissipation power [2], according to the "Electrical Design Manual of Power Engineering":

\[ Q_c = \pi k_f (t_c - t_a) [A + B (\sin \phi)] C (\frac{V D}{\mu_f})^p \]  

(1)

among them

\[ k_f = 2.42 \times 10^{-2} + 7 \times 10^{-3} \left( \frac{t_c - t_a}{2} \right) \]  

(2)

In the formula: \( \phi \) is the angle between the wind direction and the wire, n, A, B, C, and p are all constants, see the "Electrical Design Manual of Power Engineering" for specific values; \( k_f \) is the air thermal conductivity, \( \mu_f \) is the dynamic viscosity of air.

Due to the complicated convection heat dissipation process, it is impossible to accurately estimate the amount of radiation heat dissipation, rapid changes in wind speed and direction, and inaccurate measurement, resulting in large errors in the calculation results; the temperature of the wire can easily reach 70°C at low wind speeds, but the existing instruments have errors when measuring low wind speed. Larger, it is a very dangerous situation for the operation of the transmission line; at the same time, there are also great difficulties and errors in the measurement of sunshine intensity. The changes in the latitude and sunshine angle considered in the calculation will also bring great calculation errors. In an entire route, large errors are prone to occur due to changes in regions and weather. The problem of large errors can be effectively solved by adding measuring devices, but at the same time, it also increases the cost of system design, which is economical.

(2) Calculation of transmission capacity of transmission line based on conductor temperature model

The heat transfer coefficient is introduced into the steady-state heat capacity equation, and the wire capacity is calculated using the approximate heat transfer coefficient. Directly obtain the temperature value of the wire through the wire temperature measuring instrument, and monitor the meteorological environment (sunshine, ambient temperature) where the wire is located. Combining these measurement data, the effective wind speed that affects the temperature of the wire at this time is derived through the heat balance equation of the wire, and then the maximum available current carrying capacity value is obtained. This calculation method is called the wire temperature model.

Using the wire temperature model, the heat balance equation is rewritten as:

\[ I^2 R(t_c) + Q_s = h(t) (t_c - t_a) + Q_r \]  

(3)

In the formula, \( h(t) \) is the heat transfer coefficient, which represents the comprehensive effect of ambient temperature and wind speed and direction. It is obtained by known parameters such as wire temperature, wire current, etc., which eliminates the inaccuracy of wind speed measurement. The error.

Calculate the heat transfer coefficient \( h(t) \) from the temperature and current of the wire during operation, and then approximate \( h(t) \) to the heat transfer coefficient \( h_{70}(t) \) when the wire temperature reaches 70°C, and further obtain the maximum allowable temperature of the wire 70°C Heat capacity:

\[ I = \sqrt{\frac{h_{70}(0)(70-t_a)+Q_r-Q_s}{R_{70}}} \]  

(4)

The temperature of the transmission line does not reach 70°C. When calculating the current-carrying capacity, the approximate \( h(t) \) value used for \( h_{70}(t) \) will cause deviations in the calculation results of the model, and the calculation of the current-carrying capacity of the wire will not be accurate [3].
The wire temperature model introduces the heat transfer coefficient and uses the approximate heat transfer coefficient to calculate the wire transmission capacity, eliminating the need for wind speed measurement. It is suitable for high wire temperature and low wind speed. The calculation is small and convenient for monitoring [4]. However, because the temperature of the wires at different points within the same span varies greatly, it is not accurate to measure the temperature of the wire at one point instead of the average temperature of the entire line. The temperature measuring instrument is in direct contact with the high-voltage wire, and the high-voltage electromagnetic field will have a certain impact on the measurement. Therefore, measures should be taken to reduce or avoid the influence of the electromagnetic field [5].

(3) Calculation of transmission capacity of transmission line based on tension model

The tension follows the average temperature change of the wire in the tensile section of the line. The wire sag and wire temperature can be calculated through the measured tension value. The relationship between temperature and sag is proposed in the literature. The sag can be obtained by measuring the tension. For a uniform wire, the wire temperature can be obtained using the following one-dimensional cubic equation:

\[ t_c = t_0 + a(H - H_0) + b(H - H_0)^2 + c(H - H_0)^3 \]

In the formula: \( H_0 \) is the tension of the wire in the initial state; \( t_0 \) is the wire temperature in the initial state; \( a, b, \) and \( c \) are constants to be found.

A tension sensor is installed on the tensile section to measure the wire tension. According to the field test data, the relationship between the tension and the wire temperature is fitted, the wire temperature is calculated, and the current carrying capacity of the wire is calculated by combining the formula. In the calculation of the transmission capacity of the transmission line, the wind has the greatest influence. The wind speed and direction change greatly at different positions of the line. The wind speed and direction at a certain point of the line are directly used to replace the effect of the wind on the entire line, and the calculation error is large. It is also inaccurate to replace the average wire temperature with a point measurement. The advantage of the tension model is that it can avoid these two problems. Tension follows the average temperature change of the tensile section of the line, and measuring tension is equivalent to measuring sag or wire temperature. In comparison, the cost of measuring tension is much lower than the cost of measuring sag and temperature. The tension of the wire is obtained by the tension measuring device, and the sag of each span can be calculated according to the mechanical model, reflecting the average temperature of the entire tensile section [6].

However, the mathematical relationship between line tension, sag, and the average temperature of the conductor is different for different tensile sections of different transmission lines, and it mainly depends on the type of conductor, the number of strands, the length of the span, and the size of the sag. Moreover, the relationship between the tension-wire average temperature curve is not easy to obtain, and the relationship obtained at room temperature is difficult to generalize to high-temperature applications [7].

3. Advantages and limitations of dynamic capacity expansion technology

The dynamic capacity increase technology of transmission lines can increase the short-term transmission power flow of overhead lines and improve the flexibility of the system without the need to increase the transmission level or erect new transmission lines. Related articles have summarized the four main advantages of dynamic capacity increase technology for transmission lines to reduce certain abandonment of wind power, assist power market coupling, reduce transmission congestion losses, and improve system reliability to stimulate the potential capacity of the power system. The application of this technology has brought obvious advantages to the power system, but it also has its limitations. The related literature compares different application methods in the dynamic capacity increase technology of transmission lines. A review of dynamic capacity-increasing technology for transmission lines discusses the advantages and limitations of the application of this technology [8].

By investigating the existing domestic and foreign research results of dynamic capacity-increasing technology and combining them with the on-site application of the device, the feasibility and necessity
of dynamic capacity-increasing technology have been fully verified. At present, there are still some areas that need further study [9]:

1) The reliability of the device is not high enough. Since the device is installed on the high-voltage power transmission line, its installation characteristics determine the requirements for the installation device: non-maintainability. At present, the reason why these devices are not widely promoted in China is that the reliability of the devices cannot be guaranteed.

2) Many types of magnetic cores can be obtained by using mutual inductance methods. With the emergence of new materials and technologies, further research is needed to choose a more suitable energy-deriving core.

3) Because it is difficult to obtain accurate on-site meteorological parameters, the error of the maximum current carrying capacity of the conductor calculated in the existing monitoring system is relatively large.

4) With the continuous development of science and technology, the emergence of some sensors with better performance has caused the problem of backward technology in some modules used in the device.

4. Economic analysis and development trend of dynamic capacity-increasing technology

4.1. Economic analysis
The extensive research and application of dynamic capacity increase technology for transmission lines has brought potential benefits to the transmission capacity and flexible scheduling of power networks. Researchers have paid great attention to the optimization and safety methods of the dynamic capacity increase technology of transmission lines.

However, due to the analysis of the economic aspects of this technology, many factors need to be considered, and there is not much literatures on the evaluation of the economic benefits of the dynamic capacity increase technology of transmission lines. Relevant literature proposed a systematic method to select the optimal line, and evaluate the economy by saving fuel costs. Research shows that the application of the dynamic capacity increase technology system of transmission lines has the highest line revenue. Some studies have proposed a method to evaluate the economic benefits and feasibility of the dynamic capacity increase technology of transmission lines and apply this technology to alleviate the congestion of transmission lines [10]. Based on historical grid-related data, this research proposes a relatively conservative method to initially evaluate the benefits of the dynamic capacity increase technology of transmission lines, and proves that this technology can reduce expenditures for users and transmission operations.

For European and American power systems, the economic analysis of the dynamic capacity increase technology for transmission lines also need to consider the impact of the application on the power market. My country is ushering in the reform of the electricity market. The establishment of multiple electricity market mechanisms will have a profound impact on the future operation of the power system. Therefore, the application of dynamic capacity expansion technology for transmission lines should also consider this aspect. This is a combination of the real-time power market and power system dispatching process to better optimize transmission line dynamic capacity increase technology method [10]. Among them, the transmission line dynamic capacity increase system should consider the real-time power market and the day-ahead power market operating mechanism at the same time, to avoid price conflicts between the two markets during optimization analysis. This view takes into account the impact of the electricity market and its forecasts on the evaluation and is necessary to determine the economic profit of the use of dynamic capacity expansion technology for transmission lines.

4.2. Future development
In the actual operation process, the dynamic capacity increasing technology has certain errors, which are mainly manifested in: (1) There are great difficulties and errors in the monitoring of solar intensity, the main reason is the change of latitude and solar angle. (2) Wind speed and direction change instantaneously, so it is difficult to measure accurately. Especially when the wind speed is low, the
accuracy of the sensor is very high and the sensor is exposed to a harsh environment for a long time, its
accuracy and reliability will decrease, resulting in measurement errors. (3) The dynamic capacity
increasing model has calculation errors, which are mainly manifested in the current value and
temperature value of a certain point in the capacity increasing model to replace the current value and
temperature value of the wire. A large number of experiments have proved that the current and
temperature distribution on the wire is not uniform, and we need to improve the new model method.

By investigating the research results of the existing domestic and foreign dynamic capacity-
increasing technology and combining the on-site application of the device, the following aspects can be
summarized in the future:

1) Accumulate field data of transmission line overload operation, provide data support for the
formulation of wind speed boundary conditions, and further investigate the general applicability of
increasing the allowable temperature of conductors to 800°C, and provide a theoretical basis for the
formulation of new standards for current-carrying power transmission lines in my country.
2) Further analyze the short-term (transient) overload capacity of the transmission line and its
application strategy to provide a reference for the emergency operation and dispatch of the power system.
3) For the dynamic capacity increase technology of wind farm transmission lines, the impact of
wind power integration on the power flow of the power grid and the static and transient stability of the
power grid should be studied in depth.
4) Based on methods such as deep learning, historical and current environmental parameters and
load data are used to predict the changing trend of the current carrying capacity of the transmission line
in a short period to provide a basis for the capacity increase and overload operation of the transmission
line[11].

5. Conclusion

With the continuous increase in power demand and the penetration rate of renewable energy, the
dynamic capacity increase technology of transmission lines as an effective means to improve the
transmission capacity of transmission lines and integrate renewable energy has received extensive
attention from domestic and foreign scholars.

The research on dynamic capacity increase technology of transmission lines has been relatively
mature in data collection and perception analysis, but there are still problems such as low data collection
accuracy, inaccurate models, and limited model versatility. Based on real-time dynamic expansion
technology, combining the expansion model with the environmental prediction model can predict the
short-term dynamic limit in the future and improve the practicability of the dynamic expansion
technology, but further research is still needed. In the actual projects done, the dynamic capacity increase
technology has been applied to certain scenarios such as new composite conductor power generation
and grid connection and line transmission capacity improvement under fault conditions. However, due
to the many uncertainties of capacity increase, it has not yet been applied in the power system. In the
promotion operation.

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