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Voltage optimization and benefit evaluation based on transformation of distribution transformer

Shuting Ma

School of North China Electric Power University, Baoding 071003, China

582132452@qq.com

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Abstract: Through the analysis of the economic operating voltage of the distribution network, the relationship between the bus voltage of the substation and the grid loss under the on-load voltage regulation of the distribution transformer is clarified, and the influence of different voltage regulation levels on the various substations is deeply studied. The voltage of the line is qualified and the influence of power loss. According to the analysis results, it is planned to carry out on-load voltage regulation transformation of the distribution transformer, and evaluate the transformation benefit through the analysis of its full life cycle

Text:

The "Power System Technical Guidelines (Trial)" stipulates that for transformers of 110kV and below, it should be considered that transformers with at least one-level voltage should be used for load regulation. Therefore, for the on-load tapping transformer that directly supplies power to the power supply center, under the premise of realizing the in-situ balance of reactive power divisions. With the increase or decrease of the regional load, the switching of parallel capacitors and low-voltage reactors in conjunction with reactive power compensation equipment, Adjust the tap to ensure the quality of the power supply voltage to the user at any time. At the end of the 1990s, many cities actively transformed the 110kV and below transformers of power supply centers into on-load tap-changing transformers, which played a positive role in improving the quality of the power supply voltage. By the end of 1998, the six main transformers of the three 220kV substations of Zhuhai Electric Power Bureau had been changed to LTC transformers. There were 22 110kV substations, with a total of 39 transformers. All urban substations are LTC transformers. In 1997, Doumen had carried out the transformation of on-load tapping transformers on three main transformers, and planned to transform or replace the remaining part of the main transformers in 1999. These LTC transformers have indeed played an active role in ensuring the voltage quality of the 10kV distribution network, laying a solid foundation for striving for a first-class power supply company. In addition, the LTC transformer can keep the grid running at a higher voltage level, optimize reactive power, thereby reducing line losses and improving the economic benefits of the grid. Therefore, it is necessary to transform the distribution transformer on-load tapping transformer.

In order to stabilize the system voltage, make the voltage fluctuation not exceed the national standard, and effectively reduce the loss of the power grid, the most effective method is to adopt on-load voltage regulation technology. During the operation of the distribution network, the on-load tap-changing transformer has been gradually adopted for voltage regulation. For example, the on-load tap-changing transformer is used for the quality of the control center point voltage of the pivot substation of the distribution network; in the case of load changes, In substations with a large operating range and large voltage fluctuations, an on-load tapping transformer must be used to adjust the voltage in time; when the power grid is running in parallel, the on-load tapping transformer is often used to reasonably distribute the reactive power between the two power grids. Power: For industrial power users that require high-quality output voltage, such as hospital emergency centers, electronic communications, cement plant electrochemistry, etc., an on-load tapping transformer is required to effectively regulate the voltage and ensure voltage quality. To put it simply, long-line power supply transformers, transformers with large load changes, and some power plants' transformers can only be adjusted with on-load tap-changing transformers. As the national grid reduces losses the emphasis on energy conservation, on-load voltage regulation transformers will be more and more widely used in power systems.

In the normal operation of the distribution network, the phenomenon of network loss emerges endlessly. It is not only restricted by the increase or decrease of the load, but also related to the change of the operation mode. At the same time, it causes the deviation of the voltage nodes in the operation of the system. At present, my country stipulates that the allowable supply voltage deviation under normal operation of the power system is as follows: the allowable voltage deviation of 220V single-phase supply voltage cannot exceed +7% and -10% of the rated voltage; the allowable voltage deviation of three-phase supply voltage of 10kV and below It cannot exceed ±7% of the rated voltage; the sum of the absolute value of the positive and negative deviations of the supply voltage of 35kV and above cannot exceed 10% of the rated voltage. Each load point in the power system supplies power through some main power supply points, which are the central points. In order to ensure that the voltages in the distribution network meet the national standards, the power system must be adjusted. However, due to the large number of load points in the network and the wide spread, it is impossible to monitor and adjust every load point under normal circumstances, we adjust the central point voltage to change within the common allowable range, so that other load points can meet the voltage regulation requirements.

1. Economical operating voltage

Under the condition of the same power grid structure and the same operating data, the operating voltage calculated based on the minimum loss of the entire network is the economic voltage.

The power loss of the distribution network is:

$$\Delta P = \frac{P_i^2 + Q_i^2}{U_i^2}\left(R_{\mathrm{L}} + R_{\mathrm{T}}\right)\times 10^{-3} + \sum P_0 \left(\frac{U_i}{U_{\mathrm{N}}}\right)^2 \tag{1}$$

R_T——Equivalent resistance of distribution transformer, Ω;

R_L——Equivalent resistance of grid line, Ω;

U_N——Rated voltage of power grid, kV;

U_i——power grid operating voltage, kV;

$\sum P_0$——Total excitation loss of distribution network, kW;

P_i——The active power injected at the head end of the power supply, kW;

Q_i——reactive power injected at the head end of the power supply, KVar;

Set the network parameter structure as a fixed value, that is, RT and RL are constants

It can be deduced from the formula that when the iron loss and copper loss in the distribution network are equal, the power loss is the smallest, and the corresponding voltage at this time is the economic voltage.

The iron loss is the fixed power loss. When the power load characteristics and network structure parameters of the distribution network are relatively stable in the short term, it can be seen that there is an inverse relationship between the copper loss and the square of the voltage. The voltage rises, and the copper loss decreases; while the iron loss is proportional to it. In summary, the change in operating voltage is related to the direction of loss. When the voltage decreases, the variable loss increases; otherwise, it decreases. At the same time, the loss of grid power is related to the ratio of variable and fixed losses. When the variable loss rate occupies the dominant proportion, the voltage increases with the decrease of power loss; when the rated loss rate occupies the dominant proportion, the voltage increases with the increase of power loss. Therefore, use the on-load tap-changing transformer to adjust the operating voltage to achieve the purpose of loss reduction, and then obtain economic benefits.

According to the change of load, under the premise of sufficient reactive power in the system, the main transformer in the power grid adopts the on-load voltage regulation method, and timely adjusts the main transformer on-load tap changer, so as to reasonably select the economic voltage corresponding to the on-load voltage regulation. . The relationship between the bus voltage of the substation and the loss of the power grid is analyzed, and the influence of different voltage regulation levels on the voltage qualification and power loss of each line of the substation is deeply studied. From the calculation results, it can be seen that the active power loss and total loss of each line increase with the increase of the load rate, and the economic voltage with the smallest loss also changes. Therefore, the voltage must be adjusted based on the minimum power loss.

2. Evaluation and Analysis of the Benefits of Transformation of On-load Tap Transformer

1) Cost index (based on the whole life cycle)

The total cost of on-load voltage regulation transformation refers to the life cycle cost, including investment cost, operating cost, maintenance cost, failure cost, decommissioning disposal cost, etc. [1]

① Construction investment cost C_I (one-time investment)
② Annual operating cost Co
③ Annual maintenance cost C_M (maintenance cost)
④ Annual breakdown cost C_F (loss caused by failure to use)
⑤ Scrap disposal cost C_D (processing cost and residual value at the time of decommissioning)

① Construction investment cost C_I

Refers to the cost paid for the on-load tapping transformer from the initiation of the project to the formal putting into operation, including all costs paid in the preliminary planning and design phase (including the decision-making phase and the design phase) and the construction phase. This cost is generated at the beginning of the entire life cycle of the project, so it belongs to the present value of the time value of capital.

② Annual operating cost Co [2]

Operating cost refers to the sum of all costs required for safe, stable and reliable operation of the on-load tapping transformer, including personnel labor costs, equipment energy costs, building energy costs, environmental protection costs and other costs. This cost occurs in the project operation and maintenance phase. This type of expense occurs every year and is an annuity in the time value of funds.

③ Annual maintenance cost C_M

Maintenance costs refer to the costs incurred in repairing the on-load tap-changing transformers invested during the operation process, including maintenance personnel costs, equipment failure maintenance and replacement costs, etc. This cost occurs in the project operation and maintenance stage. This expense occurs every year and is an annuity in the time value of funds.

④ Annual failure cost C_F

Failure cost refers to the economic loss to power supply companies and users due to various types of failures and blackouts. Power failure loss includes the loss of corporate profits caused by power outages, that is, the direct cost of power outages; and the loss of power users that need to be compensated due to unplanned power outages, that is, the social costs of power outages. This cost occurs in the project operation and maintenance phase. Both of these are often expressed in the form of unit power loss costs. This cost occurs every year and is an annuity in the time value of funds.

⑤ Scrap disposal cost C_D (processing cost and residual value at the time of decommissioning)

Asset disposal cost refers to the cost of cleaning and destroying the equipment at the final stage of the life cycle of the on-load tap-changing transformer. This cost is generated during the scrapping stage of the project, at the end of the life cycle of the project, so it belongs to the final value of the time value of capital.

The salvage value is obtained through the depreciation of fixed assets. The depreciation of fixed assets adopts the straight-line depreciation method, which refers to a method in which the accrued depreciation of various fixed assets is evenly allocated within the predetermined depreciation period.

The residual value of fixed assets refers to the value recovered at the end of the depreciation period when it is scrapped or transferred in the middle of the process. The value is equal to the fixed asset value multiplied by the corresponding net residual value rate.

$$\begin{cases} D_j = \dfrac{S_j \times (1 - R_z)}{T_j} \\ M_j = S_j \times R_z \end{cases}$$

D_j is the annual depreciation of the j-th fixed asset; R_z is the net residual value rate; T_j is the depreciation period of the j-th fixed asset, and M_j Is the residual value of the asset

Through the analysis of the life cycle cost, the calculation formula of the total cost index is obtained from the above economic cost indicators

$$LCC = \frac{C_I}{(1+i)^m} + \sum_{j=0}^{k} \frac{C_O + C_M + C_F}{(1+i)^j} \times \frac{1}{(1+i)^m} + C_D \times \frac{1}{(1+i)^n}$$

In the formula, LCC---the present value of life cycle cost and

C_I-construction investment cost

Co---annual operating cost

C_M---Annual maintenance cost

C_F---annual failure cost

C_D---Scrap disposal cost

i---discount rate

n---Full life cycle of on-load tapping transformer

m---On-load tapping transformer construction period k---Operation and maintenance period

2) Profit indicators

① Emission reduction benefits

Under the traditional power generation mode, thermal power generation still dominates, and coal-fired power generation accounts for up to 80%. The combustion of coal will inevitably emit CO2, SO2, NOx and other pollutant gases. A large number of coal-fired power plants will cause huge damage to the environment, such as the increasingly serious smog and acid rain in recent years. Proper pressure regulation and energy saving will have the effect of reducing emissions and generate emissions reduction benefits.

Peak shaving and valley filling power saving

Peak clipping and valley filling can not only reduce the active power loss of the transformer, but also reduce the reactive power loss of the transformer, and the saving of reactive power is far greater than the saving of active power

② Social benefits

a. Voltage qualification rate

Voltage qualification rate is an important indicator to measure voltage quality,

The qualified range of voltage on the voltage side of the distribution station area is the rated voltage +7%～-10%, the voltage limit is generally a one-way limit, and the amplitude of the limit does not exceed 5%.

b. Power factor

Reactive power, also called magnetizing power, is a medium of electromagnetic conversion and a physical quantity that represents the relationship between electromagnetic field characteristics and electrical conversion. It does not consume energy itself, nor does it perform work, but it is a necessary condition for active work balance to proceed during energy conversion. The power factor is a sign value that measures the degree of fulfillment of this necessary condition, and its magnitude is

Low power factor will increase the loss of power supply lines, or increase investment in order to reduce the loss by increasing the cross-section of the power supply lines; it will increase the voltage loss of power supply facilities and reduce the voltage quality; it will reduce the effective utilization of power generation, supply and use equipment; Increase the electricity expenses of some users, increase the user's production cost, and affect the user's product quality.

Adjusting the voltage through the on-load voltage regulation of the distribution transformer to improve the power factor has important social benefits. The level of the power factor has an important impact on the economics of power generation, supply and use and the social benefits of electrical energy use, improving and stabilizing The power factor of electricity consumption can improve the voltage quality for both the power grid and the users, reduce the power loss of the power supply and distribution network, improve the utilization rate of electrical equipment and save non-ferrous metals. [3]

③ Power quality improvement income

Power quality problems refer to voltage swells, drops, instantaneous interruptions, etc., and its characteristic parameters are the maintenance voltage value and its duration value [4]. Since the on-load tapping transformer is used to adjust the voltage, the economic loss caused by power quality problems is reduced.

Taking the cost of an instantaneous power supply interruption as a benchmark, the cost of other power quality problems is converted to the benchmark. This relationship is defined by the conversion rate C.

Assuming that the economic impact of a voltage drop with a 60% drop is 80% of an instantaneous power supply interruption, the conversion rate of this voltage drop is 0.8. Similarly, if the economic impact of a voltage drop with a drop of 25% is 10% of an interruption, the conversion rate is 0.1.

Different loads, different industries, and different market conditions have different conversion rates, which need to be determined according to specific conditions. Count the number n of different voltage quality problems occurring in a period of time, and multiply it with the corresponding economic evaluation conversion rate m to obtain the total conversion rate C

The sum of the cost of all power quality problems during an evaluation period can be converted into the cost of instantaneous power supply interruption and then summed.

References

[1] Han Nengxia. The scheme and analysis of 35kV transformer no-load voltage regulation to on-load voltage regulation [J]. Electrical Engineering, 2009 (08): 35-37+41

[2] He Fengnian. The economic benefit analysis of the application of SVR feeder automatic voltage regulator in the distribution network [J]. Science and Technology Information, 2010(34): 759-760.

[3] Cai Yu, Lin Jin, Wan Can, Chen Xiaoshuang, Song Yonghua. Active distribution network operation optimization strategy considering step-down and energy-saving regulation in market environment [J]. Power System Technology, 2016, 40 (10): 2951-2960.

[4] Luo Kuang, Wang Li, Chen Chao, Wei Guoen, Lao Yongzhao, Liu Youzhi, Wang Yuhan, Xue Ancheng, Bi Tianshu. Distribution network voltage quality evaluation index considering voltage stability and over-limit [J]. Southern Power Grid Technology, 2019, 13(04): 48-53+72.