Mathematical Modeling Analysis of Operation Strategy after External Transmission Line Series Compensation

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Abstract. Nujiang power grid is at the end of the Yunnan power grid, which is the side of power supply. Due to the regional restrictions and the lag of economic development and other factors, the structure of the power grid in Nujiang is relatively weak, and the voltage of the regional power grid is more prominent. Based on analysis on voltage exceeding limits of Nujiang different power grid, combined with the operating characteristics of regional power grid and reactive power compensation measures, this paper proposes measures for adjustment of Nujiang grid voltage, and analyses the result of adjustment of voltage exceeding limits, which can effectively improve the voltage and power quality.

1. Introduction

In recent years, the scale of the development of Yunnan power grid has been expanding, in the power grid development process, the regional power grid due to the weak structure of the grid voltage stability caused by the problem is very prominent [1]. Nujiang Power Grid is a rich area of water resources in Yunnan Power Grid. Due to the influence of geographical environment, power distribution and regional load distribution, Nujiang Power Grid is a long chain distribution of "string grape", and the control measures of reactive power flow in the network are limited, the reactive power compensation device in the regional power grid is unreasonable, and the capacity of the grid station is small and the adjustment capacity is poor, and the space of the grid space is extended to produce the long-distance transmission and so on, which leads to the problem that the local voltage is more prominent[2]. In the flood season, when the electricity load of the silicon industry is fully loaded, the reactive power compensation of the Lushui Area is insufficient, resulting in the lower limit of the local network voltage. After entering the dry season, the industrial load of the silicon industry, a large number of reactive power can not be balance in the local network, resulting in the local network voltage to exceed the limit. With the continuous construction of the Nujiang power grid, small and medium hydropower plants continue to put into operation, the voltage limit will continue to exist or even intensified [3]. The voltage limit of the Nujiang power grid directly affects the power quality of the Nujiang power grid [4]. In this paper,
the main reason of the voltage quality is analyzed and the solution is put forward to improve the Nujiang power grid quality, to ensure the operation of the Nujiang power grid security and reliability.

2. Voltage limit analysis of Nujiang power grid
Nujiang has rich water resources, by the end of 2015 the installed capacity of 1135.854MW, including 220kV hydropower plant 1; affected by the inherent characteristics and geographical area economic development, Nujiang has formed 4 local area network structure, namely, Lushui area power grid, Fugong area power grid, Gongshan area power grid, Lanping area power grid. Among them, the Lushu power grid is a typical regional self-balancing adjustable power grid, Fugong, Gongshan power grid is the send out power grid, Lanping power grid is power supply grid. At present, the trunk grid of Nujiang power grid has formed four 220kV substations (respectively located in the four area power grid), and through four 220kV lines connected with the main network, 110kV station (switch station) 20, 110kV contact line 93. Nujiang area power grid structure diagram shown in Figure 1.

![Figure 1: Schematic diagram of main grid structure of power grid in Nujiang area](image)

Through the multi-zone, multi-period and multi-level system analysis of Nujiang power grid, Nujiang power grid is divided into three areas: Lushui Area, Fugong-Gongshan Area and Lanping Area. In terms of time segment interception, the data of the study are based on the time series of the measured annual curve and the measured daily curve, focus on the 220kV busbar and the line voltage limit of the 220kV plant in the network, and try hard to find the power and voltage characteristics of the 110kV station, detailed analysis of the network reactive equipment and hydropower plant unit operating conditions.

2.1. Voltage of 220 kV Station in Nujiang power grid
By the end of 2015, the Nujiang power grid within the jurisdiction of the 220kV substation 4, 220kV Gongshan substation is put into operation by the end of 2015, because this paper is used in the analysis of data is the annual data, so the analysis of the voltage limit is not collected Gongshan substation data, Gongshan area of the problem is mainly reflected in the Fugong substation. 220kV Fuqiang substation, Lanping substation, Chongren substation voltage average annual voltage curve shown in Figure 2 (has been removed maintenance and failure is the voltage fluctuation value). It can be seen from the figure, Lanping substation voltage limit is more serious, Fugong substation voltage limit situation followed.
2.2. 110kV voltage situation in Nujiang power grid

Nujiang existing 110kV substation (switching station) 19, of which 8 substation is equipped with 31 sets of reactive power compensation device (2 group reactance), reactive power compensation capacity or packet capacity is too large, the packet is too large to cause investment subsidies, do not put under compensation situation, wet period overall voltage low voltage, low flow period overall high phenomenon is obvious. Through the 110kV voltage level voltage analysis, it is found that the power station and the network line in the dry season are still exists power flow, station contact line has a large number of reactive power exchange cannot self-balancing etc., line reactive power flow diagram is shown in figure 3. This led directly to the 110kV voltage limit more obvious.

2.3. Voltage of 35kV and below in Nujiang power grid

There are 31 35kV substations and 37 main transformers in Nujiang and a relatively complete distribution network system of Nujiang has been constructed, but limited to the Nu River terrain, produced a long line, low voltage distribution transformer area more problems, resulting in the local area in Gongshan, Fugong level of low-voltage distribution network show insufficient reactive power low voltage phenomenon, while the region (related Chongren area) Lushui by industry, transmission
channel, transformers and other aspects are presented and left without intermittent high voltage phenomenon.

3. Voltage limit analysis of Nujiang power grid

As of 2015, the new project in the Nujiang area of Danzhuhe power plant, in the case of power plant leading phase can effectively alleviate the region's high voltage problem, but in the dry small mode, as well as during the holiday season there are still high voltage problems.

The reactive power compensation capacity of the substation is insufficient or the capacity of the packet is too large, and the group is too large, resulting in excessive input, no investment and lack of compensation. The voltage in the full water season is overall low, and the overall high voltage phenomenon still exists in the dry season.

The load in Lanping area has no change, the transmission power of long distance line leads to the excessive charging power, and the 220kV Lanping is operated on the low voltage side without reactor to adjust voltage, the power supply of the Lanping district is limited, and the leading phase capability of the unit is limited, which leads to the voltage exceeding the limit.

Fukang Gongshan area load lighter, reactive load overload, only 220kV Fu Gong substation two groups of 35kV reactor can not balance the reactive power, resulting in high voltage situation.

Under the way of dry season and flood season, Chongren area only a small amount of load production, can not consume Chongren area reactive power, 220kV Chongren substation reactor into operation, after the unit into the leading phase operation, the voltage is still high.

4. Voltage reactive power management of Nujiang power grid

4.1. The relationship between voltage and reactive power

The relationship between voltage and reactive power is shown in Figure 4

![Figure 4: Relationship between voltage and reactive power](image)

If the intersection of curve 1 and curve 2 is A, the rated voltage point under the system operation, the corresponding voltage size is Ue. When the load reactive power increases, the system reactive power without a corresponding increase, the intersection curve of 1 and 4 at the curve represents the new operation point, the voltage corresponding to the Ua, obviously Ua < Ue, which indicates that the reactive load increases, the total reactive power supply can not meet the new operating conditions if the system will make the system voltage drop. Similarly, when the system reactive power overdraft will lead to high voltage system, so the need to adjust the system reactive power makes the voltage near Ue, as shown in Figure 4, adjust the system reactive power, so that the operating point to run point B.

4.2. Reactive power compensation of Nujiang power grid

The reactive power of the system will directly affect the voltage, in order to solve the Nujiang power grid voltage limit situation, Nujiang power grid has invested a large number of reactive power compensation equipment, and capacitive reactive power compensation is shown in the following Table 1:
Table 1: Capacitive reactive power compensation capacity

| Voltage level | Reactive power of line charging(MVar) | Reactance capacity(MVar) | Reactive power consumed by line(MVar) | Capacitance capacity(MVar) | Capacitive reactive power balance(MVar) |
|--------------|-------------------------------------|--------------------------|--------------------------------------|----------------------------|---------------------------------------|
| 220kv        | 92                                  | 84                       | 120                                  | 132                        | +12                                   |
| 110kv        | 59                                  | 7                        | 48.2                                 | 51.6                       | +3.4                                  |
| 35kv         | 2.6                                 | 0.9                      | 8.3                                  | 10.1                       | +1.8                                  |

Nuijiang power grid according to the line charging power perceptual reactive power compensation is shown in Table 2 below:

Table 2: Inductive reactive power compensation capacity

| Voltage level | Total line length(km) | Reactive power of line charging(MVar) | Reactance capacity(MVar) | Reactive power compensation level(100%) | Distance full compensation(MVar) |
|--------------|-----------------------|--------------------------------------|--------------------------|----------------------------------------|----------------------------------|
| 220kv        | 646.263               | 92                                   | 84                       | 91.30%                                 | -8                               |
| 110kv        | 1611.242              | 59                                   | 7                        | 11.80%                                 | -52                              |
| 35kv         | 635.242               | 2.6                                  | 0.9                      | 34.60%                                 | -1.7                             |

From Table 1 and Table 2 can be seen, the Nuijiang power grid reactive power compensation, the total capacity of capacitive reactive power compensation to meet the operating conditions, reactive power compensation levels more than the more, taking into account the main transformer and other reactive power loss. But the sensible reactive power compensation slightly less, 220kv and 35kv basic to meet the operation, but 110kv charge power is larger, the need for further inductive reactive power compensation. From the overall analysis, 220kv through the unit, transformers and compensation equipment, to meet the needs of reactive power balance. But in 110kv safe and stable operation, the need for timely cooperation with the hydropower unit to ensure the balance of reactive power. 35kv reactive power balance through the grid structure can also be maintained.

4.3. Problems existed in voltage and reactive power management

In the regulation of Nuijiang power grid 220kV substation two groups of reactors, Fugong Gongshan 220kV substation two groups of reactors and 220kV Chongren substation two reactor, two sets of capacitors, to ensure voltage quality, long-term operation of capacitor 220kV substation 220kV reactor, Fugong Gongshan substation and Chongren substation reactor.

Large customer load fluctuation and not paying attention to voltage regulation are important reasons for the difficulty of grid voltage adjustment. It is necessary to strengthen user reactive power management and operation supervision, so as to improve the planning of power failure maintenance.

Voltage quality statistics and monitoring are difficult, Nuijiang power grid 35kV and 10kV voltage monitoring point and voltage monitoring device set less, to adjust the grid voltage real-time monitoring and statistical analysis of the more difficult.

The power away from the load center, 220kV grid voltage is high, a large number of reactive power in long distance transportation, resulting in high network loss, affect the safety and economical operation of power network.
5. Study on voltage over limit adjustment

5.1. Voltage over limit adjustment strategy

According to the Nujiang power grid voltage limit of the actual situation, combined with the basic principles of voltage adjustment, the Nujiang power grid voltage adjustment strategy can be divided into the following points:

Optimal allocation of reactive power compensation. According to the "electric power system voltage and reactive power", "technical guidelines for power system voltage quality and reactive power management regulations" provisions, optimize on the basis of calculation, by selecting the compensation of reactive power compensation capacity, reasonable, rational allocation of reactive power compensation equipment, reasonable adjustment of reactive power, strengthen the Nu River power grid in compensation capacitor maintenance, improve the operation level of reactive power equipment, so as to achieve the premise of no load and voltage quality requirements under the best economy.

Hierarchical partition in situ balance. Reactive power and voltage adjustment to follow the principle of hierarchical partition in situ balance, run control using reverse voltage regulation mode, the substation voltage in strict accordance with the voltage curve control, shall not exceed the upper and lower limits.

Control the high voltage area of small power reactive power output. Small power failure control, is a key factor in the region's high voltage, therefore, in the flood season should be strictly required to adjust the county to adjust the power of small power output, to avoid a large number of reactive power into the 220kV system caused by high voltage.

Fully tap the depth of the power plant leading the phase. The actual coordination of the power plant has been basically clear the depth of the power plant, but in actual operation, some power plants still exist machine terminal voltage is limited, the unit vibration and other objective factors such as the impact of difficult to achieve the machine network coordination test leading phase depth operation, so in order to avoid the small area under the local area voltage is too high, should be a full assessment of the objective factors in the influence of leading phase depth on the unit, to further tap the power plant leading phase capacity.

Do a good job on the user side of the reactive power management, urging the user to configure a sufficient capacity of the reactive power compensation equipment, is strictly prohibited reactive power long-distance high-capacity transmission, and strictly control the user side power factor operation and management to ensure that the grid reactive power in place balance.

Strengthen coordination between the various levels of scheduling communication. The voltage adjustment is a systematic work, and the voltage problems faced by the plant stations within the jurisdiction of each dispatcher will affect each other therefore, in the process of regulation should be strengthened with the upper and lower scheduling communication between the coordination, standing on the whole system point of view, adjust the local voltage.

Flexible adjustment of system operation mode. When all kinds of measures have been adopted and the voltage is still difficult to adjust, the operation mode of the regional power network can be adjusted, and the reactive power distribution can be changed by changing the structure of the grid to ensure that the voltage is within the controllable range.

The Economical Operation of Organizational Transformers. Strengthen the reactive power compensation control, the application of static reactive power compensation technology to improve the compensation device input rate and operating power factor; reasonable consideration of load access, timely adjustment of grid operation, and strive to improve the transformer operating economy, with n (n ≥ 2 ) Taiwan transformer parallel operation of the substation, according to the changes in load changes in the number of containers shipped can reduce the power loss.

Timely adjust the grid reactive power and voltage operation. Do a good job in the daily analysis of reactive power and voltage management adjustment work, timely switching grid reactive power compensation equipment, adjust the transformer tap stalls, and strictly control the interface power factor, to ensure that the voltage qualified under the premise of appropriate to improve the system operating voltage; Month for the whole network reactive power operation analysis work, in accordance with the
province of the reactive power curve and interface power factor control objectives, according to the existing problems of power grid operation, put forward targeted measures.

10) Urging the substation management and county power supply bureau to do the daily operation and maintenance of electric power reactive power compensation equipment management, to avoid the operation and maintenance management is not in place lead to reactive power compensation equipment can not be put into use.

5.2. Analysis of voltage adjustment results
On the Nujiang state A, B, C, D four types of voltage monitoring, monthly data analysis, 2015 annual Nujiang power grid voltage pass rate as shown in Figure 5 below:

![Figure 5: Nujiang power grid voltage pass rate](image)

On the Nujiang grid voltage monitoring, and then according to the monitoring results for comprehensive statistics, Nujiang power grid voltage pass rate as shown in Table 3 below:

| Indicator name                             | 2015 planned value | 2015 completion value | 2014 completion value | Year on year | Compared with plan |
|-----------------------------------------------|---------------------|-----------------------|-----------------------|--------------|-------------------|
| Comprehensive voltage qualification rate(%)   | 98.738              | 98.759                | 98.324                | ↑0.435       | ↑0.021            |
| City residents terminal voltage qualification rate(%) | 98.6              | 98.667                | 98.374                | ↑0.293       | ↑0.067            |
| Rural residents terminal voltage qualification rate(%) | 98.3              | 98.399                | 97.128                | ↑1.271       | ↑0.099            |

As can be seen from Figure 5, Class B, Class C, and Class D of the average voltage pass rate in March is low, followed by voltage adjustment measures, the voltage was significantly improved. Class D voltage pass rate in September has been low to take a change with the file and other measures, Class D voltage pass rate has increased.

From Table 3 can be found in 2015 integrated voltage qualified in 2014 and 2015 plans are high, indicating that the Nujiang power regulator strategy is more feasible. At the same time, the rate of pass rate of rural residents is relatively large, which indicates that the voltage limit of Nujiang rural side is more serious, and the voltage regulation rate is obviously increased by adjusting the voltage. The voltage limit of the grid has a serious impact on the overall grid voltage pass rate. Through the voltage adjustment strategy, it can adjust the voltage of Nujiang power grid and improve the power quality of Nujiang power grid.
6. Summary
This paper analyzes the voltage limit of Nujiang power grid, and studies the voltage limit and adjustment strategy of Nujiang power grid. From the results of the voltage pass rate can be seen, through the voltage limit adjustment strategy can significantly improve the network voltage, is conducive to stable and reliable operation of the power grid. The voltage limit is an important factor that affects the power quality of the power grid. It has received the strong concern of the power grid and has been able to run the grid more securely and reliably through continuous tracking and timely control.

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