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Original Paper

Local Grid Planning and Design

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Abstract

This design is based on Etap simulation software to complete the following steps: analysis of original data, determination of power grid voltage level and preliminary selection of power grid connection scheme, technical and economic operation of optimal scheme, operation characteristics and material statistical calculation. Through this design, I have mastered the general principles and common methods of power network planning and design. I am skilled in using Etap simulation software to cultivate my analytical ability in various aspects of technology and economy, improve my ability of calculation, data analysis and arrangement, and design specification compilation.

Keywords

Power system, Etap simulation, relay protection

1. Introduction

The electric power industry is the basic industry for the development of the national economy. The fundamental task of power system planning, design and operation is to rationally develop and utilize power resources under the overall arrangement of the national economic development plan, and use less investment and operating costs to meet the growing needs of various sectors of the national economy and people's lives. Need, provide sufficient, reliable and qualified electrical energy. The static insulation level of the vacuum interrupter is the basis for improving the overall insulation reliability of the vacuum circuit breaker, and the optimization of the internal insulation structure of the vacuum interrupter is the main way to improve its static insulation level. Therefore, this article will try to optimize the internal structure of a 3.6kV vacuum interrupter to improve its insulation level.

This design is based on ETAP simulation software to complete the planning of the power grid and the design of relay protection configuration.

ETAP is the abbreviation of comprehensive analysis software system for electric power analysis and electric energy management. ETAP is a comprehensive power and electrical analysis and calculation software with comprehensive functions, which can provide a comprehensive analysis platform and solution for the planning, design, analysis, calculation, operation and simulation of power generation, transmission and distribution, and industrial power electrical systems. ETAP is OTI The power and electrical system comprehensive calculation and analysis software and real-time online control and smart grid system products developed and produced by the group company are also an all-round comprehensive engineering company for power system planning, design, analysis, operation, training and computer simulation.

2. Research Background

2.1 Basic Background Information

The relative geographical locations and distances of the involved power plants and substations are shown in Figure 1. The specific system situation is the number of installed units as Figure 2 shown, capacity: 2×300 (MW), rated voltage (kV): 21kV rated power factor: equivalent system S: power plant A is connected to a system S through 500kV, and the total installed capacity of the system is 2000MW. The average power factor is 0.92, the maximum integrated load is 1900MW, cosφN=0.9. The specific load data of the project at each location is shown in Figure 2. The grid voltage is determined as shown in Figure 3. The calculation method and principle of electric energy loss fee are as follows: (1) The maximum power loss of the entire network is obtained from the power flow calculation results; (2) According to the annual maximum load utilization hours and load power factor given in the appendix, (3) Calculate the entire power grid Annual power loss (kWh/year); (4) Calculate the power loss fee based on the comprehensive cost electricity price of the power system (take 0.35 yuan/kWh). The relationship between maximum load loss hours, maximum load utilization hours, and power factor is shown in Figure 4.

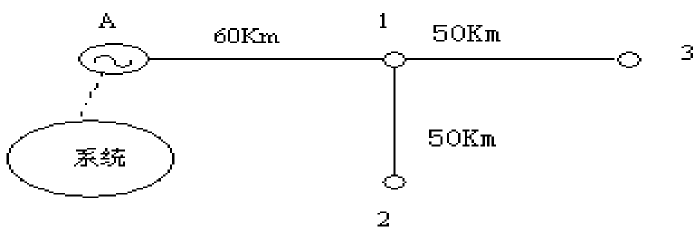


Figure 1. Relative Geographical Location and Distance of Power Plants and Substations

Project		Place		
		1	2	3
Load MW	Max	180	15	10
	Minimum	90	7	5
Power Factor	Max	0.9	0.9	0.9
	Minimum	0.85	0.85	0.85

Load Category	I%	50	40	30
	II%	30	40	50
	III%	20	20	20
Maximum Load Time(h)		5500	5500	5500
LV Bus Voltage(kV)	110		10	10
Regulator Requirements	Inverse Regulation			

Figure 2. Load Data and Related Requirements of Areas to be Planned

Rated Voltage (kV)	Transmission Power (kW)	Conveying Distance (km)
35	2000～10000	20～50
60	3500～30000	30～100
110	10000～50000	50～150
220	100000～500000	100～300

Figure 3. Suitable Transmission Capacity and Transmission Distance for Various Voltage Levels

$\cos\varphi$ / $T_{\max}$	0.80	0.85	0.90	0.95	1.00
2000	1500	1200	1000	800	700
2500	1700	1500	1250	1100	950
3000	2000	1800	1600	1400	1250
3500	2350	2150	2000	1800	1600
4000	2750	2600	2400	2200	2000
4500	3150	3000	2900	2700	2500
5000	3600	3500	3400	3200	3000
5500	4100	4000	3950	3750	3600
6000	4650	4600	4500	4350	4200
6500	5250	5200	5100	5000	4850
7000	5950	5900	5800	5700	5600
7500	6650	6600	6550	6500	6400
8000	7400		7350		7250

Figure 4. Relationship between Maximum Load Loss Time, Maximum Load Utilization Time and Power Factor

2.2 Basic Design Method

This power system planning is based on the given original data of power plants and substations (substations) to complete the following design. The specific design steps are as follows: 1. Based on the

ETAP simulation platform, complete the planning and design of the power grid, and output power flow simulations under various operating modes Report. 2. Based on the ETAP simulation platform, complete the grid voltage regulation calculation and output the simulation report. 3. Based on the ETAP simulation platform, complete the coordinated design of relay protection, and output the STAR simulation report of each short-circuit point.

3. Design Options

3.1 Balance of Electric Power

The balance of electric power is divided into the balance of active power and the balance of reactive power. The calculation method of active power balance is to first calculate the installed capacity of the generator SN=2X300=600MW, and take 8% of the factory power load. The calculation of reactive power balance and load is

$$Q_{综合} = K1\sum_{i=1}^{n} Qi\,max + K2\sum_{i=1}^{n} Qie$$

$$Q\,max = \frac{Pmax}{Cos\Phi max * Sin\Phi\,max}$$

Therefore, substation one, substation two, and substation three are

$$Cos\Phi_{max} = 0.9, Sin\Phi_{max} = 0.44$$

Therefore, its power can be calculated as

$Q1\,max = 454.55MVar, Q2\,max = 37.88MVar, Q3\,max = 25.25$MVar

while the apparent power is

$S_s = \frac{1900}{0.9} = 2111.11$MVA， $S_1 = \frac{180}{0.9} = 200$MVA， $S_2 = \frac{15}{0.9} = 16.67$MVA

at the same time

$$S_3 = \frac{10}{0.9} = 11.11\text{MVA}$$

Generator set A300MW unit power is

$$Q_1 = \frac{300}{0.85}*2=705.88\text{MVar}$$

The integrated power is

$$Q_{综合} = 0.95\sum Q\text{MAX}+0.2\sum S = 537.25MVar$$

The unit power is

$$Q_{装} = 705.88\text{MVa}$$

The difference is

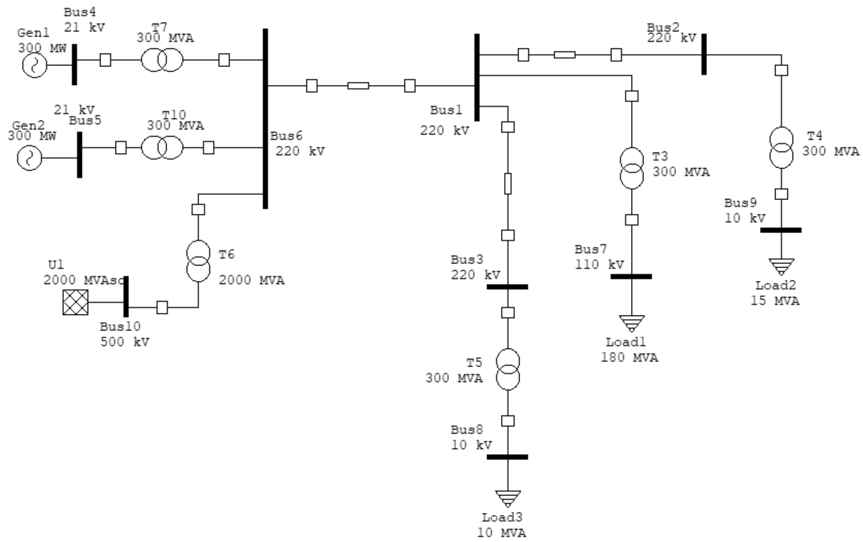
$$\Delta Q = Q装 - Q综合 = 705.88 - 537.25 = 168.63\text{M}$$

Therefore, the reactive power of the installed generator capacity of the system is sufficient.

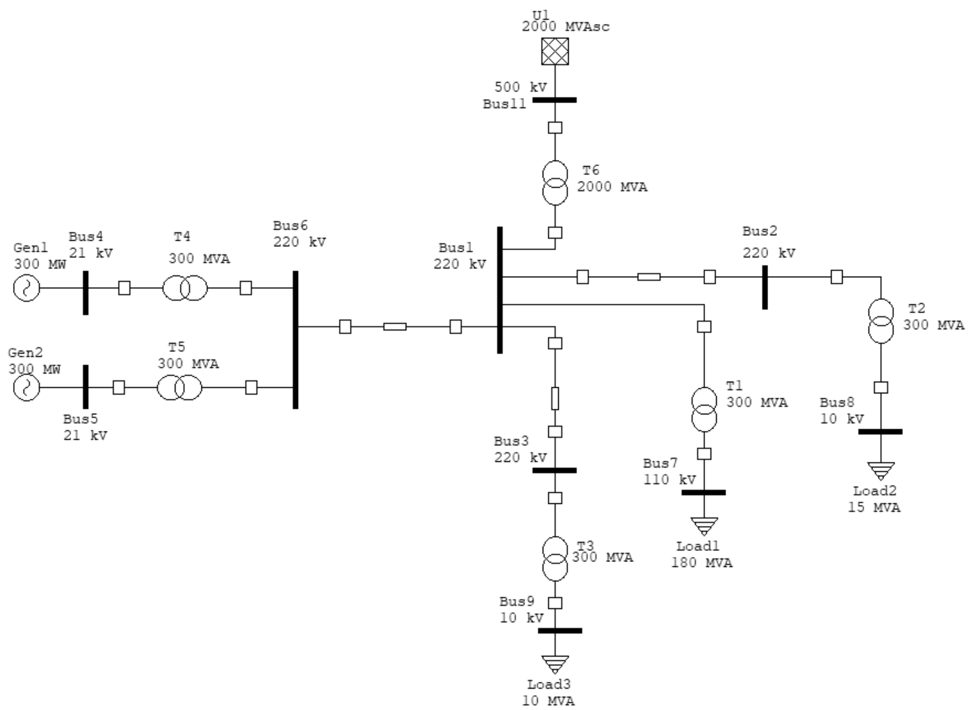
3.2 Determination of Power Grid Level and Preliminary Selection of Grid Wiring Scheme

3.2.1 Preliminary Selection of Grid Wiring Schem

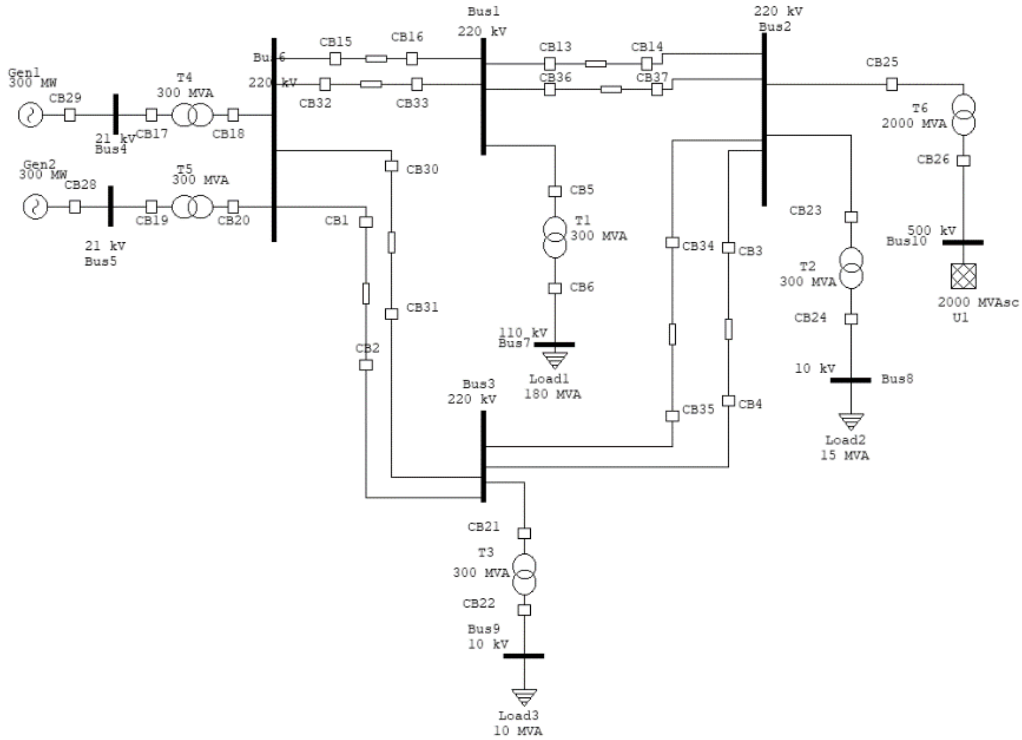
The preliminary selection of grid connection scheme 1 is shown in Figure 5, the preliminary selection of grid wiring scheme 2 is shown in Figure 6, and the preliminary selection of grid wiring scheme 3 is shown in Figure 5.



Option 1 Wiring



Option 2 Wiring

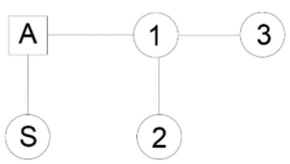


Option 3 Wiring

Figure 5. Preliminary Selection of Grid Wiring Scheme

3.2.2 Preliminary Comparison of Grid Wiring Schemes

According to the summary of the ETAP power flow analysis report, the specific data of each scheme is shown in Figure 6.

Plan	Line Length (km)	Total Demand MW	Loss $MW \cdot km^2$	Number of Switches	Advantages and disadvantages
 Plan 1	160	88.491	61064.3	18	Advantages: the line is short, the loss is very small, and the wiring is more flexible Cons: less reliable

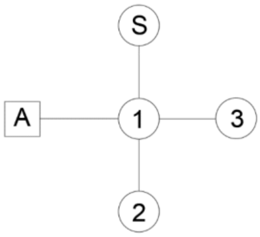
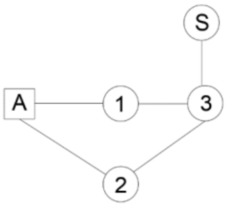
 Plan 2	160	191.65	65484	18	Advantages: more reliable power supply, simple circuit structure Disadvantages: difficult maintenance, large loss
 Plan 3	258.81	176.07	66790.1	28	Advantages: good stability, easy maintenance; Disadvantages: longer lines, more protection devices

Figure 6. Preliminary Comparison of Grid Wiring Schemes

There are four preliminary comparison indicators for the grid connection scheme, namely line length, path length, load moment and number of high-voltage switches. The smaller the four indicators, the better the technical and economic performance.

After the initial comparison of the above-mentioned preliminary plans through these indicators, the first plan has excellent values. Next, we will use Etap to analyze the operation of each scheme under load short circuit, equivalent grid short circuit, one generator short circuit and busbar (BUS) short circuit.

According to the summary of some data in the Etap short-circuit analysis report, the following table is obtained as shown in Figure 7.

Voltage kV	Option One			Option Two			Option Three		
Operating Status	Load1	Load2	Load3	Load1	Load2	Load3	Load1	Load2	Load3
Load one Short circuit	0	5.39	5.39	0	5.42	5.42	0	6	6
load two short circuit	59.28	0	5.39	59.31	0	5.39	65.88	0	5.99
Load three short circuit	59.28	5.39	0	59.31	5.39	0	66.02	6	0
Equivalent grid short circuit	12.62	1.15	1.15	35.36	3.21	3.21	12.81	1.08	1.16
A generator short circuit	58.33	5.3	5.3	57.79	5.25	5.25	57.11	5.23	5.19

BUS1 short circuit	0	0	0	0	0	0	0	0.33	0.35
BUS2 short circuit	37.12	0	3.37	28.73	0	2.61	2.1	0	0.19
BUS3 short circuit	37.12	3.37	0	28.73	2.61	0	3.8	0.33	0

Figure 7. Summary of Short Circuit Situation of Each Scheme

From Figure 7 we can analyze and get:

1) In the case of short-circuit of each load, the voltage levels of the three schemes are roughly the same, and the scheme three is better.

2) In the case of a short circuit in the equivalent network, the voltage level of Scheme 2 far exceeds that of Scheme 1 and Scheme 3

3) In the case of a short circuit of a generator, the voltage levels of the three schemes are roughly the same, and scheme one is superior.

4) In the case of short-circuit of the three busbars directly linked to the load. Option one is better.

Based on the above analysis, the design of scheme one is simple, the cost is the lowest, and the loss is small, but the stability is not as good as scheme two and scheme three. The second scheme has better stability, but the loss is the highest. Although the third option has the longest line, it has the best stability and is easy to repair and maintain because of the structure of the ring network. Therefore, option three is adopted.

4. Economic Calculation Analysis

4.1 Selection of Conductor Sections for Overhead Transmission Lines

1) Select wire cross-section for economical current density. For overhead transmission lines of 35kV and above, the conductor cross section is generally selected according to the economic current density, and is verified by techniques such as mechanical strength, heat generation and corona. The formula for calculating the wire cross-section of the economic current density is

$$S = \frac{P}{\sqrt{3} J V n \cos\phi} (mm^2)$$

In the formula, P is the active power passing through the line (kW); VN line rated voltage (kV); is the power factor of the power passing through the line; J is the economic current density. As shown in Figure 8 Generator A to bus one: Line6, Line1.Bus 1 to bus 2: Line3, Line7. Busbar 2 to busbar 3: Line4, Line8Bus three to generator A: Line2, Line5.

	Model	Cross-sectional Area(mm^2)	Resistance(Ω)	Reactance(Ω)	Active Power (MW)	Reactive Power ($MVar$)
Line1	CHLORINE-7	34.4	1.05	0.296	0.42	0
Line2	CHLORINE-7	34.4	1.05	0.296	0.42	0
Line3	CHLORINE-7	34.4	1.05	0.296	0.42	0
Line4	CHLORINE-7	34.4	1.05	0.296	0.42	0
Line5	CHLORINE-7	34.4	1.05	0.296	0.42	0
Line6	CHLORINE-7	34.4	1.05	0.296	0.42	0
Line7	CHLORINE-7	34.4	1.05	0.296	0.42	0
Line8	CHLORINE-7	34.4	1.05	0.296	0.42	0

Figure 8. Option 3 Line Information

2) Check the cross section of the wire according to the mechanical strength

For lines crossing canals, highways, communication lines, and residential areas, the conductor interface shall not be less than 35mm; for lines passing through other areas, the minimum cross-section is generally stipulated as: 35Kv and above for lines; 35Kv and below for lines.

3) Check the cross section of the wire according to the heat generation

The selected cross-section of the wire must be checked for heat generation according to the power transmission capacity of various possible normal operation modes and accident operation modes. Under normal circumstances, the maximum temperature of aluminum, aluminum alloy and steel-reinforced aluminum wire does not exceed, and does not exceed under accidental conditions.

4) Check the cross section of the wire according to the corona

The corona phenomenon will cause power loss and interfere with the surrounding communication lines. Increasing the cross section of the wire can reduce the electric field intensity on the surface of the wire, so that the working voltage of the line is lower than the critical voltage for corona generation.

For lines with a voltage level of 110KV greater than, there will be no corona phenomenon. Because our voltage level is 110kv, and the selected lines are all greater than 110kv, so there is no corona phenomenon.

4.2 Calculate the Maximum Voltage Loss of the Line

After the line parameters are determined, recalculate the power distribution (using the maximum load) and find out the maximum voltage loss of each scheme. It should be noted that when calculating the voltage loss here, only the preliminary calculation is carried out, that is, the power loss of the line is not considered, and the voltage of each node is calculated by the rated voltage of the grid, that is, the calculation formula of the voltage is

$$\Delta V = \frac{PR + QX}{V_N}$$

In order to ensure the user's power quality, under normal circumstances, the maximum voltage loss from the power point to the load point in the network should be less than 10% of the rated voltage; under fault conditions, it should be less than 20%. If the maximum voltage loss of a scheme exceeds the index requirement when it is normal or faulty, the scheme should be eliminated.

According to the Etap power flow analysis report, the branch loss summary is as follows.

Line	Head-end Bus Flow(Mvar)	Terminal-head Bus Flow(Mvar)	Loss(kvar)	Bus Voltage Drop(%)
Line1	-136.771	-8.089	137.432	8.198
Line2	-101.721	12.069	102.090	-12.092
Line3	61.910	-34.335	-61.732	34.227
Line4	-96.926	14.213	97.266	-14.248
Line5	-101.721	12.069	102.090	-12.092
Line6	-136.771	-8.089	137.432	8.198
Line7	61.910	-34.335	-61.734	34.227
Line8	-96.926	14.213	97.266	-14.248

Figure 9. Effect of Contact Thickness on Electric Field Distribution

After increasing the thickness of the contact, because the inertia during the opening and closing process is greater, the erosion caused by the bouncing process is likely to increase the unevenness of the contact surface, and the maximum value of the field strength inside the arc extinguishing chamber rises sharply, which is not conducive to The internal insulation capacity of the arc extinguishing chamber is improved; after increasing the thickness of the contact, the distance between the back of the moving contact and the end of the floating shield is reduced, because the overall length of the arc extinguishing chamber is still suitable, and the field strength in the gap between the two is not obvious increase. It can be seen from Figure 9 that appropriately increasing the thickness of the contacts can make the electric field distribution inside the arc extinguishing chamber more uniform, so the thickness of the moving and static contacts is increased from 10mm to 12mm.

4.3 One-time Equipment Investment Cost Calculation

Since the network wiring of each scheme is different, the main wiring of the power plant and the substation may also be different, so the number and type of lines and high-voltage circuit breakers of each scheme are different. When comparing the schemes, only the investment costs of the two types of equipment are taken into account. The comprehensive investment per unit length of various wire lines of different voltage levels (that is, including all costs of materials and installation) can be checked from the table. High-voltage circuit breakers should be selected and verified, but this is generally done in the design of power plants and substations. In grid planning, it is only necessary to determine their type, and then calculate the gas investment cost according to the voltage level and the number of units (intervals). The comprehensive investment for one interval of circuit breakers of various types and different voltage levels can be obtained from the table.

4.4 The Annual Operating Cost of the Grid

The annual power loss of the power grid. The annual power loss of each line segment is calculated according to the maximum load loss time method, and the sum of the annual power loss of each line segment is the annual power loss of the entire network (the power loss of the transformer is not included here).

$$\Delta W_L = \sum_{i=1}^{L} \Delta Wi = \sum_{i=1}^{L} \Delta Pi\, max \times \tau i (kW \bullet h)$$

In the formula, $\Delta P_{\text{imax}} = \frac{P_{\text{imax}}^2 + Q_{\text{imax}}^2}{V_N^2} R_i$ is the active load when the i-th line is at its maximum load, and it is calculated with the rated voltage of the network, is the maximum load loss time of the i-th line, which can be obtained from the table.

$$\Delta W_L = \Delta Pi_{imax}$$

5. Detailed Technical Calculation of the Optimal Solution

5.1 Determination of Transformer Capacity

1) Determination of transformer capacity

Generally, two transformers are selected for connecting the voltage busbar of the power plant to the system, and the capacity of one transformer is selected according to the capacity that can bear 70% of the power plant capacity. When the generator is connected to the transformer unit, a margin of 10% is left after deducting the factory load of the unit according to the rated capacity of the generator.

(2) Determination of the capacity of the main transformer of the substation

There are generally two main transformers connected to the substation and the system. When a main transformer is out of service, the remaining transformer capacity should guarantee 70%-80% of the total load (calculated by the maximum load of the substation), or the main production electricity of important users.

After the transformer capacity is selected, its nameplate parameters can be found according to the attached table, so as to calculate the impedance and admittance of the transformer.

Look up the table to select a transformer with appropriate capacity. The selected capacity of the power plant transformer is 60MW, the selected capacity of the substation 1 transformer is 31.5MW, the selected capacity of the substation 2 and 3 transformers is 40MW, and the selected capacity of the system S transformer is 63MW. Record the parameters of each transformer in a form. Transformer impedance calculation formula:

$$\mathrm{R_T} = \frac{1}{2} \times \frac{\mathrm{P_S V_N^2}}{1000\mathrm{S_N^2}}, \mathrm{X_T} = \frac{1}{2} \times \frac{\mathrm{V_S\% V_N^2}}{100\mathrm{S_N}}$$

The parameters of each transformer are recorded in Figure 10 through Etap:

	Capacity(MVA)	Number of Windings	Rated Voltage (KV)	Loss (Kvar)	short circuit voltage (%)	No-load current(%)	R_T (Ω)	X_T (Ω)
T1	300	2	220/10	137.432	12.498	0.25	0.02	50
T2	300	2	220/10	-13.255	12.498	0.25	0.02	50
T3	300	2	220/10	-8.910	12.498	0.25	0.02	50
T4	300	2	220/21	-239.522	12.5	0.25	0.02	50
T5	300	2	121/10.5	-239.522	12.5	0.25	0.02	50
T6	300	2	500/220	-303.933	12.5	0.25	0.02	50

Figure 10. Transformer Parameters

5.2 Power Flow Calculations for Maximum and Minimum Load Cases

Four operating conditions are set for the load, which are

	Loading Category	% Loading	MW	Mvar	MW	Mvar
1	Design	100	101.488	62.897	0	0
2	Normal	75	76.116	47.173	0	0
3	Brake	0	0	0	0	0
4	Winter Load	50	50.744	31.448	0	0
5	Summer Load	90	91.339	56.607	0	0
6	FL Reject	0	0	0	0	0
7	Emergency	0	0	0	0	0
8	Shutdown	0	0	0	0	0
9	Accident	0	0	0	0	0
10	Backup	0	0	0	0	0

Power flow calculations under maximum load conditions

潮流报告

母线 ID	kV	电压 % 大小	角度	发电 MW	发电 Mvar	负荷 MW	负荷 Mvar	潮流 ID	MW	Mvar	安培	%PF	变压器 %分接头
Bus1	220.000	99.821	1.5	0	0	0	0	Bus6	-129.417	-4.978	340.5	99.9	
								Bus2	86.061	-24.145	235.0	-96.3	
								Bus6	-129.417	-4.978	340.5	99.9	
								Bus2	86.061	-24.145	235.0	-96.3	
								Bus7	86.713	58.245	274.6	83.0	
Bus2	220.000	99.558	1.4	0	0	0	0	Bus1	-85.781	24.083	234.9	-96.3	
								Bus3	-106.174	10.389	281.2	-99.5	
								Bus1	-85.781	24.083	234.9	-96.3	
								Bus3	-106.174	10.389	281.2	-99.5	
								Bus8	7.235	4.514	22.5	84.8	
								Bus10	376.675	-73.457	1011.6	-98.2	
Bus3	220.000	99.914	1.5	0	0	0	0	Bus6	-109.101	8.824	287.5	-99.7	
								Bus2	106.575	-10.396	281.3	-99.5	
								Bus6	-109.101	8.824	287.5	-99.7	
								Bus2	106.575	-10.396	281.3	-99.5	
								Bus9	5.052	3.146	15.6	84.9	
Bus4	21.000	100.816	7.3	240.000	20.000	0	0	Bus6	240.000	20.000	6567.6	99.7	
Bus5	21.000	100.816	7.3	240.000	20.000	0	0	Bus6	240.000	20.000	6567.6	99.7	
Bus6	220.000	100.281	1.6	0	0	0	0	Bus1	130.005	5.053	340.5	99.9	
								Bus3	109.520	-8.825	287.5	-99.7	
								Bus3	109.520	-8.825	287.5	-99.7	
								Bus1	130.005	5.053	340.5	99.9	
								Bus4	-239.525	3.772	626.9	-100.0	
								Bus5	-239.525	3.772	626.9	-100.0	
Bus7	110.000	97.383	-0.6	0	0	86.622	53.683	Bus1	-86.622	-53.683	549.3	85.0	
Bus8	10.000	99.364	1.2	0	0	7.234	4.483	Bus2	-7.234	-4.483	494.5	85.0	
Bus9	10.000	99.779	1.4	0	0	5.052	3.131	Bus3	-5.052	-3.131	343.9	85.0	
* Bus10	500.000	100.000	0.0	-376.489	82.742	0	0	Bus2	-376.489	82.742	445.1	-97.7	

Power flow calculations for minimum load conditions

潮流报告

母线 ID	kV	电压 % 大小	角度	发电 MW	发电 Mvar	负荷 MW	负荷 Mvar	潮流 ID	MW	Mvar	安培	%PF	变压器 %分接头
Bus1	220.000	99.532	1.2	0	0	0	0	Bus6	-136.771	-8.089	361.2	99.8	
								Bus2	61.910	-34.335	186.7	-87.5	
								Bus6	-136.771	-8.089	361.2	99.8	
								Bus2	61.910	-34.335	186.7	-87.5	
								Bus7	149.722	84.847	453.7	87.0	
Bus2	220.000	99.370	1.1	0	0	0	0	Bus1	-61.734	34.227	186.4	-87.5	
								Bus3	-96.926	14.213	258.7	-98.9	
								Bus1	-61.734	34.227	186.4	-87.5	
								Bus3	-96.926	14.213	258.7	-98.9	
								Bus8	13.256	6.512	39.0	89.8	
								Bus10	304.063	-103.391	848.2	-94.7	
Bus3	220.000	99.688	1.2	0	0	0	0	Bus6	-101.721	12.069	269.7	-99.3	
								Bus2	97.266	-14.248	258.8	-98.9	
								Bus6	-101.721	12.069	269.7	-99.3	
								Bus2	97.266	-14.248	258.8	-98.9	
								Bus9	8.911	4.357	26.1	89.8	
Bus4	21.000	100.559	7.0	240.000	20.000	0	0	Bus6	240.000	20.000	6584.4	99.7	
Bus5	21.000	100.559	7.0	240.000	20.000	0	0	Bus6	240.000	20.000	6584.4	99.7	
Bus6	220.000	100.025	1.3	0	0	0	0	Bus1	137.432	8.198	361.2	99.8	
								Bus3	102.090	-12.092	269.7	-99.3	
								Bus3	102.090	-12.092	269.7	-99.3	
								Bus1	137.432	8.198	361.2	99.8	
								Bus4	-239.522	3.894	628.5	-100.0	
								Bus5	-239.522	3.894	628.5	-100.0	
Bus7	110.000	96.056	-2.5	0	0	149.473	72.393	Bus1	-149.473	-72.393	907.5	90.0	
Bus8	10.000	99.087	0.8	0	0	13.255	6.420	Bus2	-13.255	-6.420	858.1	90.0	
Bus9	10.000	99.499	1.0	0	0	8.910	4.315	Bus3	-8.910	-4.315	574.5	90.0	
* Bus10	500.000	100.000	0.0	-303.933	109.918	0	0	Bus2	-303.933	109.918	373.2	-94.0	

Figure 11. Power Flow Calculation

6. Conclusion

This design is completed by using Etap simulation software: determination of power network voltage level, design of network connection mode, selection of electrical equipment, etc., and calculation of power flow and voltage regulation is carried out, and then the best power grid connection is obtained through technical and economic comparison plan.

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