The Research of High-Voltage Auxiliary Power System Neutral Point Grounding Modes Between the Nuclear Power Plant and Conventional Fossil Fuel Power Plant

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Abstract Having induced the grounding modes of the high-voltage auxiliary power system neutral point in the large-scale nuclear power plant and the conventional fossil fuel power plant, having analyzed determining principles, commonly used grounding modes, requirements of related codes, determining methods of the neutral point grounding modes, having done the research of nuclear power plant and conventional fossil fuel power plant auxiliary power system’s different characteristics leading to different demands of the grounding modes, and having done the research of the main nuclear power plants and the partial fossil fuel power plants high-voltage auxiliary power system neutral point grounding modes’ selection and calculation with the practical engineerings, also having put forward optimal design schemes, at last, a conclusion works out: high-voltage auxiliary power system neutral point grounding modes directly affect the running of the auxiliary power system and even affect the security of the nuclear safety and the operation of the power plant. First, choose the suitable grounding mode according to the calculation result of capacitive current. Then, choose more conducive grounding mode to the operation of power plant according to the operation of technology equipments, the power requirement from the configuration, the connection of auxiliary power, and the cut from the accident of auxiliary power. I hope this article can play a role for reference on the selection of the auxiliary power system grounding modes. Currently, in power plants, the application of the extinction coil in high-voltage auxiliary power system neutral point is less experienced. As some power plants which are under-construction will be putting into operation one after another, a whole set of perfect security arrangements and operating experiences will also be accumulated inevitably.
Keywords Nuclear power plant · Fossil fuel power plant · Neutral point · Grounding mode · Nuclear safety · Capacitive current

1 Introduction

Affected by the Fukushima incident in Japan, nuclear power is a clean and efficient energy once stagnant development. With the increasing development of China’s industrialization process, environmental degradation is worse in some parts of the region, and environmental pressure increases rapidly, such as the large area of fog and haze in 2013 is irrefutable evidence. Restart nuclear power is the trend. But after the nuclear power plant project approved to restart, its access threshold is improved, and the requirements of technology and safety indicators must reach the international level of the three generations of nuclear power units. At present our country has been put into operation for most of the M310 units, in the construction including WWER-1000 improved, AP1000, and other third-generation units. Recently, our country developed a 1000 MW level with independent intellectual property rights of the third generation of nuclear power brand “Hualong 1.”

The grounding mode of the high-voltage auxiliary power system of power plant relates to the safe operation of power plant, the continuity of power supply, and other important issues, in professional technology aspect at the same time, also involves auxiliary power system overvoltage and insulation coordination, relay protection, grounding design, and many other fields. At present put into production or in construction of domestic nuclear power units and conventional fossil-fired power plant in different ways of high-voltage auxiliary power system, neutral point grounding continuously improves the capacity of power plant; auxiliary electrical capacitance currents are more; influence of safe operation of the auxiliary power system is greater. Although there are rules and regulations on the grounding mode of neutral point, the choice of most suitable for plant operation of grounding mode and implementation plan is still controversial. Besides, the determination of resistor connected way and resistance also needs in the actual project, through the analysis and calculation, after comprehensive consideration of various factors.

There are conclusions of determination principles and methods of power plant high-voltage auxiliary power system neutral point, and findings of nuclear power plants and conventional fossil-fired power plants of high-voltage auxiliary power system neutral point grounding mode. We study and draw the design requirements and design optimization, and then analyze to improve the safety of equipments and reliability of power supply, and apply to the following localization of nuclear power plant design, for the choices of nuclear power plant high-voltage auxiliary power system neutral point grounding mode to provide reference in the future.
2 Principles for Determining the Neutral Point Grounding Mode

Most of the faults of power plant high-voltage auxiliary power system are caused by single-phase grounding, so that the generator outage occurred frequently, often burn circuit breakers, switch cabinets, mutual inductor, transformers, cables, and other equipments, even the occurrence of burning generatrix, the unit stopped several hours, directly cause economic losses. With the increase of capacity of generating units in power plant, the increasing high-voltage auxiliary power system load and high-voltage cables, there have been a corresponding increase in, resulting in, high-voltage auxiliary power system of the single-phase grounding fault current which increases, directly affecting the power plant safety, reliability, continuous and equipment insulation level, and single-phase capacitor current of equipment damage.

Due to the heat capacity of power equipments in power plant, auxiliary power system is relatively low. Therefore, we should limit single-phase grounding fault current magnitude to prevent burning; at the same time, equipment which fault cannot restore should be as soon as possible withdraw from the operation, to prevent the expansion of the equipments damage or malfunction. In order to ensure the reliability of its operation, it can be automatically eliminated to prevent the failure of the power supply reliability; when there is occurrence of unrecoverable faults, the fault equipment must be isolated as soon as possible, so as not to affect the normal power supply. Therefore, it is important to identify and isolate the ground fault branch.

According to the above factors, the basic principle of the neutral point grounding mode of power plant auxiliary power system is determined:

1. The minimum impact to continuous power supply is single-phase grounding fault, and equipments of auxiliary power system can continue to run for a long time.
2. When the single-phase grounding fault occurs, the sound phase of a low-voltage multiple occurs, not to destroy the power system insulation level, so that there is a development of interphase short circuit.
3. When the single-phase grounding fault occurs, the fault current can be limited to the minimum level to the motor, cable, etc.
4. To minimize the impact of inter-plant equipments.
5. Grounding equipments are easy to order, and the grounding protection is simple, and the investment is small.
3 Regulation, Standard Requirements

3.1 Nuclear Power Plant

(NB/T20051-2011 Nuclear power plant power system design code)

As specified in the specification 5.2.2.2.1 pressure water reactor nuclear power plant medium voltage auxiliary power system neutral point grounding mode: when the medium voltage auxiliary power system grounding capacitor current is 10 A and below, it should be the neutral point grounding mode in order to be able to run continuously, and allowed within the time limit with single-phase grounding fault conditions, to gain time for handling fault, and this time the need for insulation of continuous monitoring system. When the grounding capacitance current is higher than 10 A, the security and availability of the nuclear power plant can be met, and other grounding modes are available. The specification is RCC-E-2002 (The pressurized water reactor nuclear power plants nuclear island equipments design and construction rules) for the development of reference, combined with the domestic nuclear power plant design, construction, and operation experience in the preparation, for reference to France 900 MW series of pressurized water reactor nuclear power plant design of nuclear power plant.

3.2 Fossil-Fired Power Plant

3.2.1 (GB 50660-2011 Large- and Medium-Sized Fossil-Fired Power Plant Design Code)

The 16.3.2 section provides the following way of the neutral point grounding mode of the high-voltage auxiliary power system of fossil-fired power plant:

1. The neutral point grounding mode of high-voltage auxiliary power system of fossil-fired power plant can be used in the form of non-grounding, and grounding with grounding resistance.

2. When the grounding capacitance current of high-voltage auxiliary power system of fossil-fired power plant is in the following 10 A, the neutral point can be used in the form of a non-grounding mode, and can also be used with high resistance grounding mode. When using the high resistance grounding method, the total current of the single-phase grounding fault is less than 10 A, and give an alarm to protection, all above should be based on the reasonable choice of grounding resistance.

3. When the grounding capacitance current of high-voltage auxiliary power system of fossil-fired power plant is in the 7 A above, the resistance grounding mode can be used in the resistance. Grounding resistance should make when single-phase grounding fault occurs, the resistive current is not less than capacitive current, and single-phase grounding fault current total value that protection device for accurate and sensitive action on the trip.
3.2.2 (DL/T620-1997 Over Voltage Protection and Insulation Coordination for AC Electric Device)

The 3.1 provisions of the specification are as follows:

1. The design of high resistance grounding system should conform to the standards of $R_0/C_0$, to limit transient overvoltage due to arc grounding fault. Generally the grounding fault current is less than 10 A. $R_0$ is a system equivalent zero sequence resistance, and $C_0$ is a system for each phase of distribution capacitance.

2. A low resistance grounding system attempt to obtain adequate current for fast and selective relay protection, grounding fault current is generally used for 100–1000 A. For general system, limit transient overvoltage $(R_0/X_0) \geq 2$. $X_0$ is the equivalent zero sequence inductive reactance of system.

Content above and DL/T5153-2002 (Thermal power plant with electric design technical requirements) are consistent with the requirements.

4 The Methods of Determining the Mode of Neutral Point Grounding

4.1 Capacitance Current Calculation

To determine the neutral point grounding mode, the current flowing through the neutral point is first calculated. General calculation method is the maximum capacity of a plant with a station transformer or auxiliary transformer connected to the power supply network of single-phase grounding capacitor current and according to this determines the grounding mode, the selection of equipment and setting relay protection.

The capacitance of the high-voltage power system is mainly based on the capacitance of the cable. The calculation of total capacitance of the cable according to the capacitance relates to the grounding of various cables, and the total capacitance of system is calculated by multiplying the total capacitance of the cable by 1.25. Single-phase grounding capacitive current can be obtained by formula (4.1):

$$I_c = \sqrt{3}U_e \omega C \times 10^{-3}$$  \hspace{1cm} (4.1)

Type: $\omega = 2\pi f_e$

$I_c$—the capacitance current of single-phase grounding (A);
$U_e$—the rating line voltage of auxiliary power system (kV);
$\omega$—angular frequency;
$f_c$—rating frequency (Hz);
$C$—per phase resistance to earth of auxiliary power system (μf).

The capacitance current of single-phase grounding of 6–10 kV cables can be calculated by the following formula:

Line of 6 kV cables:

$$I_c = \frac{95 + 2.84S}{2200 + 6S} \times U_e$$  \hspace{1cm} (4.2)

Line of 10 kV cables:

$$I_c = \frac{95 + 1.44S}{2200 + 0.23S} \times U_e$$  \hspace{1cm} (4.3)

Its $S$—cross section of cables (mm$^2$).

### 4.2 According to the Calculation Results of the Capacitance Current

For the methods of determining mode of neutral point grounding of high-voltage auxiliary power system by the calculation results of capacitance current, contrastive study of neutral point grounding mode is shown in Table 1.

| Type of plants          | The name of the project                                                                 | Grounding mode                                    |
|------------------------|----------------------------------------------------------------------------------------|---------------------------------------------------|
| Fossil-fired power plant | 200 MW and below                                                                       | Non-grounding or grounding by arc suppression coil |
|                        | 300 MW and above                                                                      | Grounding by resistance                           |
| Nuclear power plant    | The first and second phase of the Qinshan project, Dayawan project, The first and second phase of the Lingao project | Non-grounding                                     |
|                        | The first phase of the Tianwan project, Sanmen project                                 | Grounding by resistance                           |
|                        | The first phase of the Fuqing project, Fangjiashan project                             | Non-grounding in normal time, grounding by arc suppression coil when single-phase grounding |
5 Contrastive Study

Limited information and space, the following comparative study is only for the current domestic M310, WWER, AP1000 nuclear power units and 300 MW and above of conventional fossil-fired power units, and study is about the grounding mode of high-voltage auxiliary power system.

5.1 Situation Analysis

At present, neutral point grounding modes of high-voltage auxiliary power system of domestic nuclear power plant and fossil-fired power plant are shown in Table 1.

5.2 Contrastive Study

From Table 1, we can choose the grounding mode by meeting the requirements of calculation of capacitor current, the mode of non-grounding can be used in the following 10 A; while the capacitor current is 10 A above, we can only use the mode of grounding by arc suppression coil or resistance. Different grounding modes of single-phase grounding fault occur, and take different fault measures, non-grounding, high resistance grounding, and arc suppression coil grounding at the time of the first single-phase grounding fault which is only alarm without tripping, and resistance grounding mode trip directly, which directly affects the operation of the mode of auxiliary power plant, and nuclear safety and operation safety of the nuclear power plants and fossil-fired power plant. It is believed that the selection of the grounding mode and the operation mode of the power plant process equipment is closely related to the requirements of the power supply, the service power of the plant and the exchange of power accident. Typical wiring diagram of high-voltage auxiliary power system of M310, WWER1000, AP1000, and fossil-fired power units of 300 MW and above is shown in Figs. 1, 2, 3 and 4.

5.2.1 Power Supply Requirements of Process Equipment

Configuration and Operation

The biggest difference of nuclear power plants and conventional fossil-fired power plants is that the load classification and nuclear power plants with nuclear safety and the safety of equipment and related equipment, to meet the requirements of “defense in depth”, needs to set up emergency shutdown installations, containment isolation, emergency installations of cooling core heap and heat discharge, and safety features of preventing radioactive substances to the surrounding...
environment. Fossil-fired power equipment only includes safety equipment, and no nuclear safety-related equipment.

1. M310 and WWER1000

The M310 and WWER1000 are in the presence of medium voltage power load, in any working condition (the whole plant, the design reference accident) to ensure that these loads are reliable power supply. Without normal power supply, emergency power supply is supplied by emergency diesel engine to the special safety
facilities. M310 emergency power supply system of diesel engine is a neutral point ungrounded system, and when the first single-phase grounding fault occurs, the action on the signal, without tripping, also can ensure continuous power supply time. WWER emergency power supply system of diesel engine with high resistance grounding; when first single-phase grounding fault occurs, the situation is as same as the M310, also moves to the signal. From the above setting, we can find that the M310 and WWER types need to maintain the operation of the medium voltage auxiliary power supply system. The emergency power supply system can meet the needs of losing continuous power supply and ensure the safety of nuclear power.

**Fig. 3** Typical wiring diagram of high-voltage auxiliary power system in the AP1000

**Fig. 4** Typical wiring diagram of high-voltage auxiliary power system in 300 MW and above of fossil-fired power units
2. AP1000

AP1000 maintains reactor core cooling and containment isolation and heat output safety function no longer depend on AC power supply system of both inside and outside the plant, and compared with M310 and WWER1000, AP1000 has no emergency medium voltage load, in addition to main pump circuit breaker, it pumps power when the heap shutdown, and the rest of the AC power has safety-related functions of executing the cutting main system for non-security level.

One resecting a circuit of 6 kV bus line. From Table 2, if most of the loops of 6 kV bus jump back due to single-phase grounding fault, the unit output has no effect, and only the resection of wind machine and other few load need to reduce the unit load. With the continuous expansion of the power grid capacity, the output of the unit has little effect on the system, but the sudden failure of the 300 MW and the above units has a greater impact on the system.

Based on the above analysis, from the view of the process and equipment configuration and operation mode, requirements of power supply should ensure nuclear safety defense in depth and the safety of the equipment; when single-phase grounding fault occurs, it has the highest reliability requirements of the M310 units for medium voltage auxiliary power supply, the mode of neutral point grounding by non-grounding or arc suppression coil grounding, fault action in signal in favor of nuclear safety facilities of power supply. Emergency diesel engine power supply system is a neutral point non-grounding system; the fault of single-phase grounding is able to meet the requirements of continuous power supply. The reliability requirements of medium voltage auxiliary power supply of WWER are also higher; in the normal operation, the mode of neutral point grounding is resistance grounding, and the grounding protection action is tripping, but due to emergency diesel engine using high resistance grounding, reliability also meets the requirements. Medium voltage AC system of AP1000 has no nuclear safety requirements. The mode of neutral point grounding is resistance grounding, and the grounding protection action is tripping. And 300 MW and above conventional fossil-fired power only has equipment safety requirements, the mode of neutral point grounding

| The name of the loop                              | The unit output/\%          |
|--------------------------------------------------|----------------------------|
| Circulating water pump                           | Summertime 60, Wintertime 100 |
| Condensate pump                                  | 100                        |
| Coal mill, mill exhauster                        | 100                        |
| Belt conveyor                                     | 100                        |
| Induced draft fan, pressure fan, primary air fan | 70                         |
| Forepump                                         | 100                        |
| Open circulating water pump                      | 100                        |
| Mortar pump                                      | 100                        |
| Low-voltage power supply of main plant and auxiliary shop | 100                        |
is resistance grounding, and the grounding protection action is tripping. The portion of loop tripping on the output of electric power has certain influence, but compared with non-grounding, single-phase grounding may cause bus short-circuit fault, and cause the unit shutdown; this harm is much smaller and more to ensure the safety of the device.

5.2.2 Leading for Service Power

Unit plant equipments of M310 reactor only by main power outside the factory, it is single supply, standing load from main and auxiliary power supply outside the factory, it is dual power supply; WWER1000 and AP1000 unit load from main and auxiliary power supply outside the factory, respectively, in the shutdown process, load power supply by main and auxiliary power supply outside factory, and the emergency diesel generator power supply. Whether it is on the unit and standing load or emergency power supply reliability is higher than the M310. 300 MW and above of the unit load from the high-voltage station transformer and the high-voltage start/standby transformer each lead a power, the power to continue the process of the security load in addition to the above two power supplies. The power supply of diesel generator set the reliability of the unit and the load power supply is higher than M310. Auxiliary power device of M310 unit is with a single power supply, if WWER high-voltage station transformer has failure, it can switch to standby power, but still need to stop. AP1000 unit load is at least with two power supplies, when there is a failure to continue to operate, while the fossil-fired power unit load has two power supplies, when one failure can be switched to another power to continue to run. From the view of ensuring the continuous and stable operation, the safety of the main equipment power plant, and improving the operation time of the power plant, the M310 unit has the highest requirements for power supply. That is why many different grounding modes can suit neutral point of high-voltage auxiliary power system of units.

5.2.3 Results of Factory Power Accident

M310 reactor and WWER1000 reactor are with double heap layout, four sets of high-voltage station transformer and two auxiliary transformers in two sets; capacity of auxiliary transformer of the M310 is smaller than the single-station transformer; capacity of auxiliary transformer of the WWER1000 and single-station transformer is basically the same. The AP1000 reactor type uses a single heap layout and sets two high-voltage station transformers and two auxiliary transformers of same capacity and number.

In the type of the M310, when the power supply is switched to the standby power supply, the unit needs to stop. While in the WWER1000, when switch to standby power supply, turbine generator set down to load but to maintain the load required by 40% power of reactor, only to stop the pile. From the current
understanding of operating mode of the AP1000, when switching to the standby power supply, the unit can take power under generation operation, but the actual practice has not yet run experience; still need to further implement the project. Fossil-fired power units are usually in the event of single-phase grounding fault when cutting off equipments, even if losing the power of the medium voltage bus, auxiliary power system can be quickly switched to the standby power supply, in the premise of ensuring the safety of equipment, basically does not affect the operation of power plant or load operation. Thus, when M310 high-voltage auxiliary power fault occurs, switching to auxiliary power directly into the shutdown state, to maintain the continuity of power supply is very important and necessary, and WWER and AP1000 plants with switching service power are not directly shut-down; there may be power back in operation as soon as possible; power supply continuity requirements are lower than the M310, and it is suitable for the resistance grounding mode, the selection of resistance grounding of fossil-fired power units, switching service power rapidly when single-phase grounding fault happens, which can satisfy the need of safety equipment, and also can meet the requirements of the power plant runs continuously.

5.2.4 Summary

From the above three aspects’ analysis, M310 units in single-phase grounding fault timely keep continuous operation for a period of time as soon as possible to eliminate the fault. WWER and AP1000 can occur after the single-phase to ground fault occurs in the immediate tripping protection equipment safety, also on nuclear safety has little effect or no effect. When single-phase grounding fault of separate circuit of fossil-fired power units happens, it trip immediately, to the power plant output, and it does not affect or less affected, mainly to meet the needs of safety equipment.

5.3 Engineering Application

According to high-voltage auxiliary power system neutral point grounding mode of the actual project of nuclear power plant and conventional fossil-fired power plant, to do one by one comparison research, and put forward the design optimization program. M310 nuclear power units in Fuqing nuclear power plant, WWER nuclear power units in Tianwan nuclear power plant No. 3 and No. 4, AP1000 nuclear power units in Sanmen nuclear power plant are taken as examples. A case study of fossil-fired power units is the 300–1000 MW unit designed by in a number of electric power design institutes.
5.3.1 Grounding Mode and Arc Suppression Coil Grounding Mode

1. Grounding scheme

In the first phase of the Fuqing project, the high-voltage station transformer A and auxiliary transformer supply, capacitive current of the auxiliary power system nearly 13 and 17 A, and in accordance with the requirements of the RCC-E, which neutral point should take non-grounding mode, in order to achieve with grounding fault operation for a period of time, there is a greater risk. According to EPRI test results of arc self-extinction behavior with single-phase grounding fault, in the neutral point grounding mode, capacitive current is more than 10 A, arc is difficult to extinguish and has not meet the reliability requirements; and in the event of single-phase grounding, such a large capacitive current will probably soon by the single-phase grounding develop phase to phase short circuit. For example, a 2 × 300 MW power plant hopper turbine circuit in 6 kV flat cable dragged improper, on the rail turbine wheels rolling off, resulting in phase A unstable grounding (Yellow cable core wire ablate, found at the scene) and generate intermittent arc grounding fault, non-fault phase B and C overvoltage. At this point, the switch cabinet in test position of a fan circuit corresponding to the vertical bus C support insulator is weak and under voltage breakdown occurs, resulting in heterogeneous (A, C) two grounding points to short-circuit in the 6 kV IIA section system. In the case of two points to ground, turbine loop through the large fault current bucket, A fuse blowing, contactor tripping, bucket turbine circuit grounding fault clearing, and 6 kV bus phase C grounding fault still exists, due to phase C of the bus connection failure cannot be eliminated, the metal vapor arc generated by the faults began to spread, causing static contact phase to phase short circuit of switch cabinet bus side. After phase-to-phase fault, high-voltage station transformer over current protection act, switch of the 6 kV IIA section of the inlet wire of power supply is tripped, the 6 kV IIA section of bus power loss. The fault ends. The whole failure process is only about 4–5 min. From the point of view of the failure process, the single-phase grounding fault is the basic reason for the development of the fault. If the fault is still used in the non-grounding mode, it cannot guarantee the reliable operation of the medium voltage system. And due to reasons described in 4.2.1, the M310 unit because of the plant with operation requirements, as much as possible with a ground fault operation for a period of time is needed, and low resistance does not satisfy this requirement; so the neutral point grounding mode makes comprehensive transformation, and finally determine the neutral point by eliminating arc circle (with adjustable) grounding capacitive current compensation and grounding line selection device method, normal fire extinguishing coil offline, the single-phase grounding fault quickly into the arc suppression coil compensation capacitance current, if it is permanent fault, fault line selection, but also greatly improve the personal safety protection.
2. Calculation of arc suppression coil capacity

It should adopt the way of compensation operation. The capacity of arc suppression coil is generally calculated by the following formula:

\[ Q = 1.35 I_c \frac{U_e}{\sqrt{3}} \]  

(5.1)

Type:

- \( Q \) — compensation capacity (kVA);
- \( U_e \) — rated line voltage (kV) of the auxiliary power system;
- \( I_c \) — capacitive current (A) of the auxiliary power system.

3. Existing problems

Although the fire arc suppression coil grounding mode has its own advantages, such as through the capacitive current compensation, slowing the rise speed of recovery voltage, it is advantageous to the connected arc extinguished, reduces the occurring probability of the intermittent arc grounding over voltage and the most instantaneous grounding fault automatically disappear. The grounding system with arc suppression coil and non-grounding system belongs to the category of ineffective grounding, and it can take 2 h of fault. But the grounding by arc suppression coil also has inherent defects, neutral point via arc suppression coil grounding divided into over compensation and under compensation, the so-called over compensation refers to the compensation way of inductive current which is greater than the volume of current; so-called under compensation refers to the compensation way of inductive current which is less than the capacitance current. In practice, the compensation method is adopted to prevent the operation mode from being changed, the capacitance current is reduced, and the arc suppression coil is in the resonance point. Arc suppression coil is close to full compensation operation, and it will enlarge the displacement voltage of neutral point; it is the “unreal grounding” phenomenon. Need to pay attention to arc suppression coil in domestic and international power plant auxiliary power system is rarely used. It is understood only in certain 200 MW steam turbine factory in Guangdong electrically neutral point and part of 100 MW and below the small units used is also a lack of a wide range of operating experience, in the actual application process; grounding mode of operation is relatively complex; grounding protection is also more complex; fire arc suppression coil through the contactor can be fast and reliable investment; and failure probability of the devices and the neutral point displacement is too limit problem remains to be further understood tracking.
4. Design optimization

For the capacitive current of the medium voltage auxiliary power system more than 10 A, but also want to take a neutral point of non-grounding mode operation, the following measures can be taken to reduce the capacitive current to 10 A.

Which is not directly related to the production of the power plant load, such as factory before the district office buildings, dormitories, and so on load not by the plant with power supply, replaced by public power supply.

Using the new technology of medium pressure casting bus instead of cable lines, can effectively reduce the capacitive current, the technology currently in the nuclear power plants built by China Guangdong nuclear power has been successfully applied.

For the long medium voltage load of individual cable lines, the method of setting the isolation transformer is adopted to reduce the capacitance current of the auxiliary power system.

5.3.2 Resistance Grounding Mode

1. Detailed classification

The traditional classification is divided into two types, which are high resistance grounding and low resistance grounding. With the development of resistance grounding technology, three kinds of grounding modes, which are high resistance, middle resistance, and low resistance, are gradually developed. The grounding fault current is less than 10 A in high resistance grounding fault. Low resistance grounding fault current is generally 100–1000 A. Which does not give the definition of resistance of 30–300 A interval, according to the relevant literature, such as Table 3 (system voltage is 6.3 kV).

2. The resistance value of grounding resistance calculation

Our country still has no standard to make clear regulation to the choice of neutral point resistance.

The choice of neutral point resistance value must be according to the specific conditions of power plant; it is necessary to consider the factors restrict the gap arc light grounding overvoltage and ratio of relay protection sensitivity, on the lines of communication interference, touch voltage and step voltage, analysis and comparison, according to the comprehensive effect of the best original in choice.

Neutral point resistor direct access system resistance calculation formula is as follows:

| The resistance division | High resistance | Middle resistance | Low resistance |
|-------------------------|-----------------|-------------------|----------------|
| Resistance range (Ω)    | >300            | 10–300            | <10            |
| Earth fault current IR (A) | IR < 10      | 10 < IR < 600    | 600 < IR < 1000 |
\[ R_N = \frac{U_e}{\sqrt{3} I_R} \]  

Type:

- \( R_N \)—the resistance value of a resistor direct access (K);
- \( U_e \)—rated line voltage (kV) of the bus bar of the high-voltage power plant;
- \( I_R \)—grounding resistive current (A), should not be less than the grounding capacitance current of the system.

3. Selection of grounding resistance in neutral point high resistance grounding mode

Control of single-phase grounding fault current is less than 10 A.

Generally according to \( I_R = (1–1.5) I_C \) to choose, calculation according to the 6.3 kV of medium voltage station voltage, grounding resistance to take 300–500 Ω or so.

In high resistance grounding mode, for capacitive current below 7 A, at present, whether nuclear power plant and conventional fossil-fired power plant, high-voltage auxiliary power system adopt the cable network, so capacitance current in large power plant basically are more than 7 A, high resistance grounding mode is not used.

4. Selection of resistance

\[ I_R = \frac{U_{ph}}{R_n} \]  
\[ K = \frac{I_R}{I_c} \]

\( R_n \)—neutral point resistance;
\( U_{ph} \)—rated phase voltage;
\( I_R \)—the current flowing through the \( R_n \) in single-phase grounding fault;
\( I_c \)—power grid capacitance current.

A. To limit the arc grounding over voltage requirements

The principle of neutral point grounding with resistance to limit the arc grounding over voltage is the role of the energy consumption of resistance, when the single-phase grounding fault happens, the fault arc from dying to reign takes half a cycle of the time; in this half a cycle, charge of non-fault grounding capacitor will be released to the earth through the neutral point grounding resistance \( R_N \), the speed of capacitor charge discharge is associated with \( K \) value (RN), with the
$K$ value increasing, arc over voltage is reduced accordingly. But arc over voltage ratio decreased and the $K$ value of the relationship is not linear relationship, when the $K$ value is greater than 4, then increase $K$; the effect of decrease of arc voltage is not obvious. At home and abroad lots of experiments and calculations of many research institutions and researchers show that, when the $I_R = I_C$, the ratio of intermittent arc over voltage can limit in less than 2.6 times. The ratio of intermittent arc over voltage can limit in less than 1.8 times when the $I_R = 4I_C$, generally selected $I_R = (1–4)I_C$ can meet the requirements to limit the overvoltage of the intermittent arc.

B. To ensure the sensitivity of relay protection

From the point of view of the sensitivity of relay protection, the bigger the $K$ value (the smaller the $R_n$), the better, however, the microcomputer protection generally has the function of zero sequence protection, and the current starting value is quite small (0.01 A). Whether in the middle or low resistance grounding system, the single-phase grounding fault current is much larger than that of each line, and it can meet the sensitivity of zero sequence protection generally.

C. From the consideration of personal safety

Neutral point through a small resistance connected to distribution network in the single-phase grounding fault and the fault point grounding potential rise caused by fault grounding short-circuit current is relatively large, and there may be resulted in the step voltage and the contact voltage exceeds the allowable value. If the person is close to the point of failure or contact with the failure of electrical equipment may cause casualties. So from the lower step and touch voltage angle of the fault point, neutral grounding resistance is as possible.

D. Consideration from the point of reducing the fault point grounding short-circuit current

Single-phase grounding short-circuit current of fault point is larger, the fault of equipment failure, the more damage, considering the reduced single-phase grounding fault current of equipment damage and the value of neutral point grounding resistance is the bigger, the better.

In summary, the choice of neutral point grounding resistance is a comprehensive technical and economic problem, according to the specific conditions of various plants and analysis comparison of characteristics of electrical comprehensive and makes selection of the best solution.

Previous years, China’s Motor Function Association High-pressure Committee Organization held repeatedly neutral point grounding technology seminar, the experts basically formed a consensus, in the premise of meeting the reduction of the intermittent arc grounding over voltage, choose the bigger resistance of neutral grounding resistance.
E. The value of grounding resistance

In 6 and 10 kV auxiliary power systems, the usual capacitive current is rarely more than 40 A. Therefore, neutral point access grounding resistance, the resistive component of the current limit value can be controlled at about 40 A; specific values also depend on the requirements of the system capacitive current size and sensitivity of protecting equipment. It should be explained that the single-phase grounding current of the system is still limited by the duration of the fault, so that the core of the burn can be prevented from occurring in the motor or transformer. For this should be satisfied: single-phase grounding current is less than or equal to $100t - 0.4$ $[6]$. The relationship between single-phase grounding current (A) and arc duration $t$ (s) is proposed. If the fault removal time to take 1 s, the single-phase grounding current of system should be less than 100 A, take 0.2–0.3 s, the single-phase grounding current of system should be less than 200 A; this value can be regarded as the upper limit of single-phase grounding current. It can be seen that when grounding by medium resistance, the single-phase grounding current is recommended in 40–200 A, and should not be too large. Personally think that the grounding current value from capacitive current is about four times of the value can limit intermittent arc over voltage ratio in less than 1.8 times, for the safe operation of cables and equipment is very favorable. The value of resistance current is mostly in the above range, as shown in Table 4.

In the first phase of the Sanmen nuclear power plant, resistance is 6.06/1000 A. In addition to the Sanmen nuclear power plant using neutral point grounding by low resistance, the above resistance grounding of nuclear power plants and fossil-fired power units are taken in a large number of medium resistance. In the Sanmen

| Table 4 Resistance/Single-phase grounding current |
|-----------------------------------------------|
| Fossil-fired power plants | CSCEC Henan Xinyang power plant 2 × 300 MW | 100 Ω/40 A (6 kV) |
|                             | Qinghai Huadian Datong power plant 2 × 300 MW | 40 Ω/100 A (6 kV) |
|                             | The first phase of the Shanxi Fugu power plant 2 × 1000 MW | 60 Ω/100 A (10 kV) |
|                             | The fourth phase of the Tianjin Zhouxian power plant 2 × 1000 MW | 60 Ω/100 A (10 kV) |
|                             | CPECC Tianjin Lingang power plant 2 × 350 MW | 18.2 Ω/200 A (6 kV) |
|                             | GEDI Shanwei power plant 2 × 600 MW | 40 Ω/100 A (6 kV) |
|                             | Datang Chaozhou Sanbaimen power plant 4 × 600 MW | 40 Ω/100 A (6 kV) |
| Nuclear plants             | CNADRI Tianwan No. 3, 4 power plant 2 × 1000 MW | 40 Ω/100 A (6 kV) |
|                             | ECADI The first phase of the Sanmen power plant 2 × 1250 MW | 6.06 Ω/1000 A (10 kV) |
nuclear power plant, the main reason of grounding by low resistance is the regulations of the IEEE 142 standard, the star-type wiring equipment, such as transformer and motor, should protect the 90 % winding, 10 % winding approach to the neutral point is still not protected, around single-phase grounding current of only terminal 10 % at close to 100 A. To ensure the sensitivity of single-phase grounding protection, electrical equipment external single-phase grounding fault current to reach about 1000 A to meet the requirements, while the domestic standard only on the 100 MW dynamo stator set protection area of not less than 90 % grounding protection requirements of electric machine and transformer requirements of single-phase grounding protection, different with the standard requirements.

5. Optimization of the design

Grounding by low resistance, because the single-phase grounding current is too large, will bring the following problems:

A. Fire camp. A single-phase grounding fault occurs in a cable trench or cable tunnel where a current arc of 600 A or more may burn the other cables.

B. Endanger personal safety.

Single-phase to ground potential or motor enclosure voltage will rise sharply. The contact voltage and step voltage and weak electronic equipment insulation are likely to exceed the standard.

C. Large volume, supplies more, and the price of resistor is high.

D. May cause malfunction of transformer differential protection.

The current of single-phase grounding fault flow through the neutral point resistance of transformer. When the current is too large to exceed the range of differential protection of the transformer, the differential protection will act to cut off the power circuit and expand the accident. Therefore, it is recommended to limit the use of low resistance grounding mode.

Personally think AP1000 units in the building. After the introduction of digestion and absorption, for neutral point grounding resistance and grounding fault current, it can be combined with the domestic standards, operation of power plant, and localization process of equipment for further optimization, such as manner of resistance grounding or eliminating arc suppression coil grounding.

6 Conclusion

Neutral point grounding mode of high-voltage auxiliary power system of nuclear power plant and fossil-fired power plant will directly affect the operation mode of power plant and the impact of the nuclear power plants and fossil-fired power plant nuclear safety and operation safety, first of all, according to the calculation results
of capacitive current can meet the specification requirements of grounding mode, and then according to the requirements of power supply from configuration and operation mode of process equipment of power plant, the connecting guide of service power supply, switch results of accident of auxiliary power system, and other requirements, choose more conducive to the operation of the power station grounding mode, it cannot be generalized.

Through the analysis and research on the neutral point grounding mode of high-voltage auxiliary power system in large nuclear power plant and fossil-fired power plant, it can enlighten and draw lessons from the selection of grounding mode for nuclear power unit in the future.

Application of fire arc suppression coil in the mode of neutral point of auxiliary power system of power plant is lack of experience, nearly 2 years, with nuclear power plants put into operation one after another will gradually accumulated a set of perfect safety measures and experience of operation.

References

1. NB/T 20051-2011 Design criteria of power system for nuclear plant
2. GB 50660-2011 Code for design of large and medium sized thermal power plant