INTRODUCTION

There is a large area of saline-alkali soil in Chinese coastland, especially in Tianjin and Cangzhou. The steel grounding bodies of the power plants, substations, transmission lines and distribution equipment in such area are corroded seriously by saline-alkali soil. For example, in some 220kV substations in Tianjin area, the steel grounding grids have been corroded by 60% after operating for only 7 years, with a rate of 1mm per year. The life of the grounding grids in such soil is usually not longer than 5 or 6 years. Thus, the expense for replacing them is very large.

Before we developed our anti-saline-alkali-corrosion grounding body other anti-saline-alkali-corrosion technologies than substitution of copper for steel were all not ideal. Copper has good performance of tolerating chemical corrosion and electrical corrosion. Reasonable design and construction of copper grid can ensure the life of copper grid longer than 30 years. However, copper material is expensive, and the primary battery effect may accelerate the corrosion speed of the steel frame when copper and steel are joined to work. Therefore, it is necessary to research and develop a kind of long-life non-copper anti-saline-alkali grounding body.

After three years’ trial-manufacture, experiment and research, and two years’ practical application in 110kV, 220kV and 500kV substations in highly saline-alkali area, we have ultimately developed a kind of anti-saline-alkali grounding body that has outstanding performance, cheap price and long life of over 50 years. This technology had become practical after over one year’s development of manufacture and construction techniques. It was firstly applied to the grounding grid reconstruction project for Xinhe 35kV Substation of Tianjin Electric Power Corporation (TEPCo) Binhai Branch in September, 2003. Then it was further applied to the grounding grid reconstruction projects for Shangzinkou 33kV Substation and Wangwenzhuang 35kV Substation.

A SUMMARY OF CORROSION THEORY FOR GROUNDING GRID

There are many factors in grounding grid corrosion, including the following ones:

Micro Battery Corrosion

There inevitably exists soil with micro ununiformity (in chemical structure, organization and physical status) at the surface of carbon steel underground. This ununiformity may result in the difference of potential of the different parts, engendering many micro cathodes whose potential is more positive and many micro anodes whose potential is more negative. The result of reaction is that the anodes are dissolved and corroded. The greater the difference of potential of the parts, the stronger the reaction of corrosion is, and the more serious the damage of corrosion is. Meanwhile, the lower the unit resistance of soil, the stronger the corrosion at its surface. In other word, the fundamental reason for the corrosion of grounding grid is that the micro battery of corrosion reacts on the soil media of low resistance and strong corrosion.

Galvanic Couple Corrosion

Galvanic couple corrosion is that when two different kinds of metal electrodes are joined and placed in electrolyte, the metal with more negative potential acts as anode and is dissolved and corroded. The greater the difference of potential of the two metals, the greater the driving voltage is, and the greater the corrosive galvanic current is. In addition, the area ratio of anode and cathode can also affect the magnitude of corrosive galvanic current. The corrosion may be accelerated when cathode is big while anode is small. This would result in serious local corrosive pit and perforation in the small anode area. Weld itself cause the metallographic change of welded pot, which leads to the difference of potential between welded area and non-welded area and thus forms corrosive battery. Moreover, the welded area is far smaller than the whole grounding grid, which makes it become the small anode of galvanic couple battery and be corroded seriously.

Ununiformity of Media

The ununiformity of soil leads to the difference of potential between the different parts of the same metal body and thus forms macro corrosive battery. The mechanism is as follows. The aeration is fairly different between different soil regions. The oxygen-density-difference battery is formed when carbon steel grounding grid passes through these regions. The grounding grid in low aerated region has more negative potential, thus acts as anode area and results in local corrosion of grounding grid. The oxygen-density-difference corrosion also occurred when the water level underground fluctuates frequently. Grounding grid is 80cm deep underground. The humidity of soil varies with seasons, which results in water level corrosion of grounding grids and grounding poles. In addition, interface corrosion may sometimes occur at the interface of down lead with earth.

Microbe Corrosion

It is proved that obvious microbe corrosion exists by mensurating the organic matter and redox potential. In microbe there are anaerobic sulfate reduction bacteria that can transform dissolvable sulfate into sulfureted hydrogen,
and thus increase the PH density of soil, expedite the depolarization of cathode during corrosion. Therefore, the soil with high-content sulfate may accelerate the corrosion process and result in local corrin of grounding grid.

Natural Corrosion

Natural corrosion occurs with the same metal. When the unit resistance of soil or the density of electrolyte around the metal is different, the different parts of the metal may exist difference of potential and form corrosive primary battery with local current flowing. The grounding metal is impossible to be absolutely pure, and the soil is impossible to be absolutely uniform, therefore the AC grounding grid is inevitably subject to natural corrosion. The natural corrosion speed has relation to not only the metallic character of grounding grid, but also the soil character and environment.

SURVEY AND ANALYSIS ON THE CORROSION SITUATION OF GROUNDING GRID IN TIANJIN

The unit resistance of soil is a token of capability of electric conduction of soil, also an important index to the degree that soil corrodes the metal buried underground. The unit resistance of soil in Tianjin is about 10 Ω • m, indicating that the soil has strong corrosiveness. In Tianjin, the corrosion ratio of the grounding equipment in the electric power system is above 1mm/year, and the service life of grounding grid of 220kV substation is only 5 to 7 years. The sample analysis result of the soil ingredients in Tianjin is shown in Table 1.

The main reasons for the corrosion of grounding grid in Tianjin are as follows:
1. The soil has high content of saline-alkali ingredients and has strong corrosiveness. This is the basic reason for grounding grid corrosion.
2. The underground water level varies considerably with seasons’ change. The variation of the underground water level results in the frequent alternation of dry and wet states of the soil around the grounding grid. This accelerates the corrosion of metal.
3. The redox potential (Eh) of the soil is low, which may bring forth microbe corrosion of metal easily.

NOVEL ASACGB

The ASACGB consists of the following two parts:
1. 5 × 50 mm² internal core made of zincified flat steel or other steel with equivalent section;
2. 10mm thick conductive concrete outer coating mixed with special material.

The unit resistance of the anti-saline-alkali grounding body is less than 100 Ω • m under dry condition. Its internal core function to release short-circuit current of power system. Its outer coating with special conductive concrete can obstruct the microbe corrosion in soil, isolate the steel surface from the water and oxygen in soil, and thus protect the steel well. In addition, the main ingredient of the outer coating is ferri-aluminate concrete, without calcium aluminate and calcium silicate that are corrosive to steel. The overall porosity of concrete is low, and the average aperture is small. These characters determine that this grounding body has very strong anti-corrosion capability in seawater and soil soaked with salt and alkali.

THE TYPE TEST FOR THE ASACGB

As a grounding body, mechanical performance and anti-corrosion performance are also its important performance indices besides conductive performance. Some experiments were made in order to verify its mechanical performance and anti-corrosion performance.

Experiment of Cracking by Heavy Current

1. Power-frequency heavy current experiments on 50 × 5 mm² flat steel and 16mm round steel coated with concrete test sample: 2kA, 3kA, 5kA, 13kA, 1.1 seconds; cosϕ=0.5; at Tianjin Electrics Institute.
2. Power-frequency heavy current experiments on 50 × 5 mm² flat steel coated with concrete test sample: 3kA, 1second; 5kA, 1second; 8kA, 1second; at Tianjin Electrics Institute.
3. Power-frequency heavy current experiments on 50 × 5 mm² flat steel coated with concrete test sample: 30kA, 1second; at China Electric Power Research Institute Breaker Division.
4. Lightning-surge heavy current experiments on 50 × 5 mm² flat steel coated with concrete test sample: 72kA, at China Electric Power Research Institute Breaker Division.
5. After the above experiments, some tiny crackles occurred at the surface of a few certain test samples, but they were smaller than 1mm, and the test sample concrete didn’t fall off or crack. The sample concrete would not fall off certainly if operated underground, because the grounding body would be enwrapped by compact soil.

The experiments indicate that the ASACGB can thoroughly tolerate the impact of power-frequency heavy current in the cracking experiments.

Experiments of Accelerating Corrosion

Two experiments were made to verify the anti-corrosion performance of the grounding bodies at whose surface crackles appeared.

1. The crackle test samples were soaked in the saturated solution of industrial salt and natrium sulfate. Seven months later, they were taken out and broken open. No perforative crackle was found, and the coated steel was not corroded by water.
TABLE1-The assay and analysis of the soil ingredients in different areas in Tianjin

<table>
<thead>
<tr>
<th>Sample place</th>
<th>Chemical Ingredients</th>
<th>Baimiao Substation, Hongqiao District number: 1</th>
<th>Wuqing Substation, Wuqing District number: 2</th>
<th>Boyang Road Substation, Tanggu District number: 3</th>
<th>Weiguo Road Substation, Dongli District number: 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td></td>
<td>Water %</td>
<td>18.18</td>
<td>10.15</td>
<td>17.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic matter %</td>
<td>3.470</td>
<td>1.160</td>
<td>1.810</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total nitrogen %</td>
<td>0.1350</td>
<td>0.059</td>
<td>0.084</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PH (1: 2.5)</td>
<td>8.550</td>
<td>8.730</td>
<td>8.070</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO3 Me/100g %</td>
<td>0.1299</td>
<td>0.0780</td>
<td>0.0829</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CI Me/100g %</td>
<td>0.1421</td>
<td>0.1015</td>
<td>46.690</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SO4 Me/100g %</td>
<td>0.3990</td>
<td>0.2520</td>
<td>16.065</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ca Me/100g %</td>
<td>0.4410</td>
<td>0.0780</td>
<td>0.0829</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg Me/100g %</td>
<td>0.3780</td>
<td>0.1015</td>
<td>46.690</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K Me/100g %</td>
<td>0.1229</td>
<td>0.2520</td>
<td>16.065</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Na Me/100g %</td>
<td>0.0434</td>
<td>0.0010</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total salt %</td>
<td>0.0690</td>
<td>0.0688</td>
<td>3.7525</td>
</tr>
</tbody>
</table>

2. The crackle test samples were buried at Boyang Road Substation for anti-corrosion experiment. When they were dug out one year later, it was found that the steel was not corroded.

3. The experiments indicate that the tiny crackles caused by surge current do not have big impact on the corrosion speed of metal conductor. Even though big short-circuit current passing through the ASACGB results in crackles on the special concrete coating, the anti-corrosion performance of the grounding body will not be damaged, and the service life of the grounding body may still exceed 50 years. It is difficult for the molecules of saline-alkali solution to convect in the tiny crackles whose width is about 0.1 mm, therefore the internal steel is little corroded.

Experiments on the Mechanical Performance of the Outer Special Concrete

Pressure-resisting and break-resisting experiments were made on the standard concrete test piece that was produced according to the prescription. In result, its pressure-resisting strength is 40MPa and its break-resisting strength is 8MPa, which is equivalent to the mechanical strength of no. 400 concrete. The experiments were made at China Building Materials Institute.

Experiments on Comparing the Corrosion Speeds

Examination was made on the corrosion degree of the test sample that was buried for 7 months. In result, the 60mm long naked steel at both ends of the test sample had a corrosion ratio of over 1mm/year, while the internal steel enwrapped by special concrete nearly had a corrosion ratio of zero. The experiments were made at Tianjin Electric Power Research Institute Metal and Chemistry Division.

TEST SAMPLES'OPERATION IN POWER SYSTEM WITH THE APPROVAL OF TEPCO

To ensure the security and reliability of the ASACGB, test samples were put in practical operation in power system at Wuzhuang Substation, Wuqing Substation, Boyang Road Substation, Weiguo Road Substation and Baimiao Substation, and the relevant tracking tests were made as well. The practical operation experiments verified that the test samples’ anti-corrosion performance and electric
conduction performance are very good.

**IMPACT OF ANTI-CORROSION CONDUCTIVE CONCRETE ON THE PARAMETERS OF GROUNDING GRID**

The impact of anti-corrosion conductive concrete on the parameters of grounding grid is an important issue which should be considered before the application of this technology. North China Electric Power Research Institute High Voltage Division used Canadian SES Corporation’s CDEGS software (Current Distribution, Electromagnetic Field, Grounding and Soil Structure Analysis) to make a simulative calculation according to the different unit resistance in different areas and the unit resistance of the ASACGB. The calculation result indicated that the anti-saline-alkali-corrosion material basically has little impact on the grounding resistance, contact voltage and step voltage.

**THE MANUFACTURE OF THE ASACGB AND THE FIELD CONSTRUCTION TECHNIQUE**

**Manufacture Techniques**

To ensure the whole quality of the grounding body, a few kinds of prefabricated products’ molds were developed (including “—” shaped, “┳” shaped, “╋” shaped and “┓” shaped horizontal grounding pole parts and column aspect vertical pole parts). The series of manufacture processes of material deployment and the finalization, demoulding, braising and waterlogging of the prefabricated products were carried out according to strict manufacture techniques, ensuring the performance indices of the ASACGB.

The synthesized technology indices of the ASACGB include the following items:

1. Anti-corrosion performance. The corrosion ratio of the enwrapped steel is below 0.01mm/year.
2. Electric conductivity. Its unit resistance in soil is less than 100 Ω·m.
3. Mechanical strength that the concrete tolerate. Its anti-pressure strength is 40MPa and anti-break strength is 8MPa.
4. The outer special concrete doesn’t distend to break after 30kA power-frequency current passes through the enwrapped steel during action time of 1 second.

**Construction Techniques**

In the process of laying anti-corrosion grounding grid, the techniques that facilitate field construction and control are adopted in laying horizontal and vertical grounding poles and joining adjacent prefabricated products. For example, in order to join prefabricated products easily, all interfaces may adopt simple “—” shaped interface. Use specialized joint mold to cast with quickly dry and distensible concrete at the interfaces in field after welding is finished. The laid anti-corrosion grounding grid blends into one integral whole after relevant processes.

In order to ensure construction quality, tracking monitoring should be carried out at any moment during construction process, consequently ensuring the excellent performance of the whole grounding grid. In the construction process of the grounding grid of Xinhe 35kV Substation in September, 2003, three vertical grounding bodies were sampled at random for grounding resistance test. Their measured values of grounding resistance were 3 Ω, 5.5 Ω and 6.8 Ω respectively, meeting the demanded performance index. In addition, the grounding resistance of a 150m long grid with two vertical grounding bodies was also measured. Its value was 0.3 Ω, fitting in with the index demand.

**Tracking Tests**

After finishing the reconstruction of the grounding grids of Wangwenzhuang Substation, Xinhe Substation and Shangxininkou Substation, we made tracking tests on two of the three substations on July 26, 2004. The grounding resistance of the grounding grids of Shangxininkou Substation and Wangwenzhuang Substation was measured with ZC-8 grounding resistance instrument, and the values were 0.8 Ω and 0.6 Ω respectively, meeting the technology demanded of grounding grid fully.

**CONCLUSION**

After four years’ development and practical application, a complete set of consummate manufacture techniques and field construction techniques about the ASACGB have been formulated. The technology conditions have been formed thoroughly to apply the ASACGB to the construction and reconstruction of grounding grids of every voltage classes.

The grounding grid constructed with the novel technology of the ASACGB has advantages including low construction cost, long service life, good effect, easy implementation, and so on. This technology would create a new access to solving the anti-corrosion problem for the grounding grids in highly saline-alkali regions.