

# Study on Internal Electric Field Simulation Analysis and Local Optimization Strategies of High Voltage Metal Enclosed Switchgear

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**Keywords:** High voltage metal enclosed switchgear; finite element method; electric field analysis; optimization.

**Abstract:** For the complexity of actual product structure, the three dimensional electric field finite element model of KYN-40.5kV high voltage metal enclosed switchgear was built and analyzed by using subarea modeling and partial thinning mesh. The calculation results show the distribution of the internal electric field of the switchgear and the concentrate parts of electric field are pointed out. The concentrate parts of electric field, such as the location of wall bushing and contact box, are analyzed. By numerical simulation techniques, the effect of insulating spacers, grading rings and shield cases on the local electric field distribution was analyzed, the corresponding sections were optimized. The finite element model for the lap joint and bolts of the busbar in switchgear was build up. Through quantitative analysis, the maximum number of exposed threads of bolt has been obtained as to the different distances between the busbars. These results provide certain valuable reference on improving the electric field distribution in the switchgear, increasing insulation level and guiding on-site maintenance.

## Introduction

In the process of manufacturing and maintenance of switchgear, especially in the compact high voltage switchgear, the insulating spacers or equalizing rings are usually used to make up the insufficient clearances in the contact box area. However, how to improve the effect and how to make optimization are still lack of quantitative reference. In most cases, the position of equalizing rings and the mounting style of insulating spacers are decided randomly<sup>[1-4]</sup>.

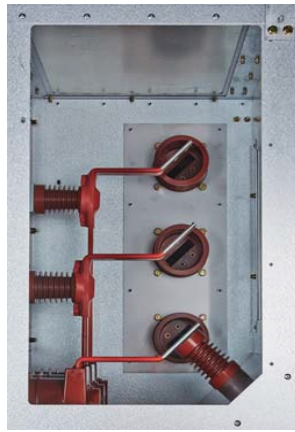
In the high voltage switchgear, The busbars are connected by the lap joint with the bolts mounted. The exposed threads of the bolts, if too much in length, can lead to the partial discharge and the insulating accidents. Although the related suggestions are given in the GB50149-2010 , which is the code for construction and acceptance of busbars installation of electric equipment installation engineering. As for the compact high voltage switchgear, the distance between the busbars is often not enough. The recommendations cannot fully guarantee the performance of insulation.

In this paper, the 3D finite element model of electric field analysis for the KYN-40.5kV metal

enclosed switchgear was built. By using subarea modeling method from the overall to local, the effect of insulating spacers and equalizing rings on electric field distribution in the contact box region was analyzed. Also the shield covers effect on electric field distribution in the wall bushing region was analyzed. For electric field distortion brought by the bolts of lap joint, the referenced maximum thread number of bolt to expose outside was obtained by quantitative analysis.

### **Electric field analysis of busbar chamber**

The insulating parts of metal enclosed switchgear usually include contact box, wall bushing, insulator and insulating spacers. The contact box and wall bushing play an important role on ensuring good insulation. The busbar chamber almost includes the entire insulating device. Thus, it is critical analyzing the electric field distribution of the busbar chamber, to ensure the overall electric insulation performance of high voltage switchgear. As shown in figure 1, the busbar chamber includes the high voltage busbars, branch busbars, contact box, grounding metal shell, wall bushing and mounting plates.



**Fig.1** The internal structure of busbar chamber

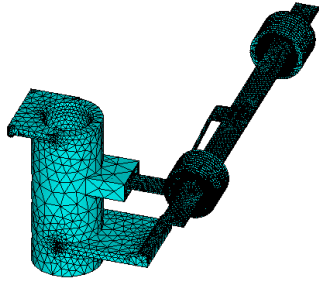
The structure and size of different parts in the switchgear has larger difference. The external contour of the insulator is usually irregular in order to increase the creepage distance. If the method of free mesh dividing is directly adopted, the quality of automatic generating finite element mesh usually is poor and the calculation accuracy is not high, even, the large number of grid cells may cause computer memory overflow. According to the structural characteristics of busbar chamber, the local refined mesh in the different domain should be used. The specific methods of meshing include as follows:

#### **(1) Subarea modeling**

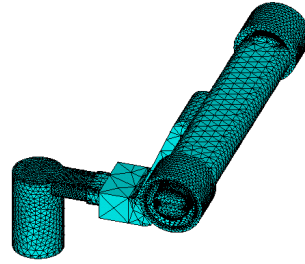
The whole solution domain was divided into several different regions or subareas, according to their geometrical characteristics and material properties, in which the different meshing methods were used to ensure the meshing size of each subarea was the same space scale and the adjacent areas were similar in the space scale. As shown in Figure 2, the finite element model of the single phase circuit, which consists of the wall bushings, busbars, and contact boxes. It can be found that the difference of the grid size is slightly in the same region. The distribution rule is beneficial to solve.

#### **(2) Local refining mesh**

The method of local refining mesh was carried out to improve accuracy in the region if concentrated electric field, such as the junction of the conductor, air gap between the busbars and wall bushing, air gap between branch busbars and fixed contact. Figure 3 show the air domain of surrounding the charged busbars, in which mesh was sliced and refined.

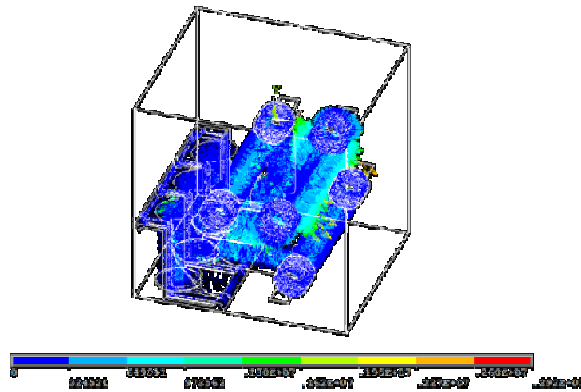


**Fig.2** The finite element model of the single phase circuit



**Fig.3** The finite element model of the air

With the above method, the grid cells of busbar chamber decreased sharply to about 1.5 million. If the method of free mesh dividing used, it would generate the excessive number of grid cells to cause the computer memory overflow. In this finite element model, the busbar of phase B was applied 40.5kV voltage, the busbars of phase A, C was applied -20.25kV voltage and the grounding metal case was applied 0V. Figure 4 shows the simulation result of the electric field distribution in the busbar chamber.



**Fig.4** The electric field distribution in the busbar chamber

As shown in figure 4, the finite element nodes with the higher electric field mainly concentrate on the area of the contact box and wall bushing. The maximum values of electric field strength reach 6.442kV/mm and 3.561kV/mm, respectively, in the wall bushing area and the contact box area. While the maximum value of electric field strength is only 0.336kV/mm at the intermediate position of two busbars. The distribution of electric field strength was serious uneven, which is not conducive to improve the overall insulation level of the high voltage switchgear.

## Local electric field optimization

### (1)Electric field optimization of contact box area

In this work, the electric field distribution at the most concentrated area in the busbar chamber and the corresponding optimization measures were studied. The influences on the electric field distribution of the contact boxes and the air field between them, such as the thickness and installation position of insulating spacer, were analyzed.

#### a) Effect of insulating spacer on the electric field

The influence of the thickness and installation position of the insulating spacer on the electric field distribution of the contact box was analyzed, with the material of epoxy resin composite (relative dielectric constant is 3.2). Table 1 lists the maximum electric field strength calculation results of the insulating spacer with different thickness of 10mm, 5mm, 3mm, arranged in the

middle position of the two busbars, and the result under the case of no insulating spacer.

It can be seen from table1, the thickness of the insulation spacer has no obvious effect on improving the electric field distribution in the contact box area, because the thickness of the insulating spacer is too thin relative to the space. In the further analysis, the maximum electric field strength in the area of the insulation spacer decreased significantly, which was similar effect on reducing the maximum electric field strength by using the heat shrinkable sleeve.

**Table1** The maximum electric field strength of different thickness insulating spacer in contact box area

Thickness ( mm )	Air in contact box( kV/mm )	Air out contact box( kV/mm )
10	4.403	0.354
5	4.389	0.401
3	4.382	0.391
0	4.373	0.367

The maximum electric field strength calculation results of insulating spacer at different mounting positions are list in table2. Selecting the intermediate position in A, B phase as the reference position 0, thus -10mm represents the position offset from the reference position to the position near the B phase 10mm, + 10mm indicates the position away from the B phase 10mm. It can be concluded that the small shift in the position of insulating spacer cannot obviously take effect on its electric field distribution, because the electric field strength of insulating spacer is relatively lower. Table 2 shows that the effect to improve the electric field distribution is relatively good, as the insulating spacer mounted on the middle position.

**Table2** The maximum electric field strength of different mounting positions in contact box area

Offset ( mm )	Air in contact box ( kV/mm )	Air out contact box( kV/mm )
-10	4.363	0.369
0	4.373	0.367
+10	4.375	0.371

Based on the above analysis, it can be concluded that the insulating spacer can improve the electric field distribution, but cannot decrease the electric field strength in all area. To minimize the switchgear, now, more and more manufacturers tend to mount the insulating spacers between the busbars and the grounding part. In the actual operation, when weather is wet, the fouling moisture come into being and is attached to the insulating spacer. Under the long term effect of high voltage, the partial discharge will occur frequently.

#### b) Effect of equalizing ring on the electric field

The simulation model of contact box is established. The impact of equalizing ring to the electric field distribution is analyzed. As shown in table 3, the contact box field strength value reduced and the field strength outside the contact box increased , with the equalizing ring mounted. Thus, the entire electric field distribution became more uniform.

**Table3** The maximum electric field strength of equalizing ring in contact box area

equalizing ring	Air in contact box( kV/mm )	Air out contact box( kV/mm )
yes	2.19	1.03
no	3.84	0.37

The electric field simulation models of three mounting position of equalizing ring were

established for further analysis. The equalizing ring is embedded in position 2 deeper than position 1 about 10mm. From the simulation results shown in table 4, comparing with the equalizing ring on the surface of the contact box, the equalizing ring embedded in the contact box improve the electric field distribution more efficient. Comparing the second data and the third data, the influence of the embedded depth is slight.

**Table4** The maximum field strength of different installing position in contact box area

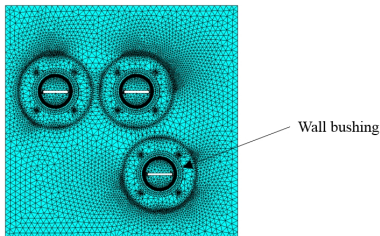
Installing position	Air in contact box ( kV/mm )
Surface	2.19
position 1(embedded)	1.71
position 2(embedded)	1.68

Based on the above analysis, the equalizing ring can increase the dielectric property of contact box area<sup>[5-7]</sup>.

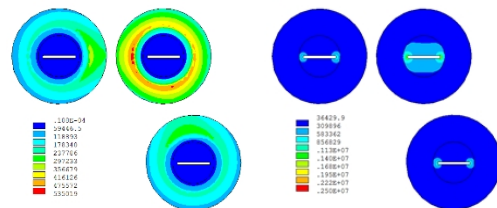
## (2)Electric field optimization of wall bushing area

The effect of the shield case or mesh on the electric field distribution in the wall bushing area was studied. The electric excitations and the boundary conditions were same with the simulation model of the busbar chamber. Figure 5 is the local refining finite element model of the wall bushing area.

Figure 6 shows the electric field distribution of the wall bushing with the shield or not. It can be seen that the shield case can significantly improve the electric field distribution. The maximum electric field strength position moved from the air gap between the wall bushing and busbars to the vicinity of the shield case, meanwhile, the maximum electric field strength decreased from 12.717kV/mm to 5.283kV /mm.



**Fig.5** The finite element model of wall bushing



**Fig.6** The electric field distribution calculation cross-section results of the bushing

Although the maximum field strength value of the wall bushing region increased, the wall bushing generally has the high dielectric strength, therefore, the shield case limited the electric field in the wall bushing, weaken the electric field intensity of the air gap between the bushing and busbars, so as to improve the phenomenon of electric field concentration and the overall insulating level in the wall bushing area<sup>[8]</sup>.

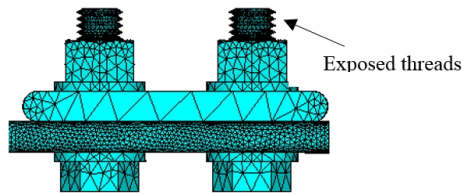
## (3) Effect of exposed threads of bolt and busbar junction box on the electric field distribution

The rules of different busbar spacing and different thread number of bolt exposed outside to the effect of local field strength distribution with busbar junction box or not was studied. It can provide quantitative information for the guidance of busbar installation.

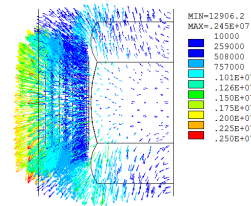
### a) Effect of exposed threads on the electric field

The simulation object is the copper busbar in the size of 8mm \* 80mm, jointing with M12x40 bolts. By adjusting the thickness of the gasket and preload to simulate the number change of threads

exposed outside. According to the standard of power frequency withstand voltage test, 95kV voltage was applied to the busbars, the simulation models and results are respectively shown in Figure7 and Figure8.



**Fig.7** The finite element model of bolt connection



**Fig.8** The finite element calculation result of bolt connection

The maximum electric field strengths have been calculated at the different distance and different number of exposed threads. Table5 shows that the fewer the number of exposed threads, the smaller the maximum electric field strength in the same distance. While reducing the distance of the busbars, the maximum field strength will increase.

**Table5** The maximum electric field strength at the different distance and different exposed thread number

Spacing (mm)	Exposed Thread number				
	1.5	2.5	3.5	4.5	5.5
300	2.12	2.25	2.36	2.52	2.55
290	2.19	2.33	2.44	2.60	2.63
280	2.26	2.41	2.52	2.69	2.72
270	2.34	2.49	2.61	2.78	2.81
260	2.42	2.57	2.70	2.88	2.90
250	2.50	2.66	2.79	2.98	3.00

The maximum exposed thread number of at different breakdown filed strength and different distance was given in table 6. It shows that when the buabars spacing is small, the number of exposed thread should be less than the value of 2-3 which is recommended in GB50149 - 2010.

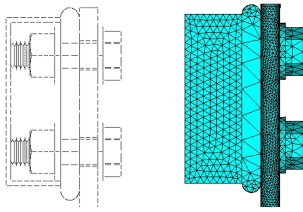
**Table6** The maximum exposed thread number of bolts at different breakdown filed strength and different distance

Spacing (mm)	Electrical filed strength(kV/mm)					
	2.5	2.6	2.7	2.8	2.9	3
300	2.25	3.00	3.75	4.25	N	N
290	1.75	2.25	3.00	3.75	4.25	N
280		1.75	2.50	3.00	3.75	4.25
270			1.75	2.50	3.25	3.75
260				2.00	2.50	3.25
250					2.00	2.50

#### b) Effect of busbar junction box on the electric field

In order to improve the insulation of switchgear, the busbar junction box, mounted on the lapper busbar, is used to make no exposed metal bolt. But the thickness and the distance between the bolt and the bottom of the box still lack of relevant standards. Figure 9 is the structure diagram and finite element model of busbar junction box. Table 7 shows the result of the maximum electric field strength at the different distance between the bolt and the bottom of the box, under the condition, in which the busbar spacing is 300mm, the thread number of bolt exposed is 2.5 and thickness of busbar junction box is 3mm. The maximum electric field strength was 2.254kV/mm without busbar junction box. Table 7 shows that the busbar junction box must be close to the bolts,

otherwise it will have the opposite effect.



**Fig.9** the structure diagram and finite element model of busbar junction box

**Table7** The maximum electric field strength at the different distance between the bolt and the bottom of the box

Spacing (mm)	Electrical filed strength (kV/mm)
3	2.65
1.5	2.28
0	2.00

Tables 8 show the results of the maximum electric field strength at the different thickness of busbar junction box under the condition, in which the busbar spacing is 300mm, the thread number of bolts exposed is 2.5 and the busbar junction box is closed to the bolts. Table 8 shows that the high thickness, the better insulation effect.

**Table8** The maximum electric field strength at the different thickness of busbar junction box

Thickness (mm)	Electrical filed strength (kV/mm)
0	2.25
1	2.14
2	2.06
3	2.00

Table 9 are the results of the maximum field strength under different exposed thread numbers and busbars spacing, when the thickness of busbar junction box is 3mm. Table 10 show the maximum exposed thread number at different breakdown filed strength and different distance was obtained. Comparing table 10 and table 5, the exposed thread number can increase averagely 1.25 with the busbar junction box mounted. Furthermore, the other facts such as mechanical property and thermodynamic property should be considered.

**Table9** The maximum electric field strength at the different distance and different exposed thread number with busbar junction box

Spacing (mm)	Thread number				
	1.5	2.5	3.5	4.5	5.5
300	1.65	2.00	2.20	2.34	2.45
290	1.70	2.07	2.28	2.42	2.53
280	1.75	2.14	2.35	2.50	2.62
270	1.81	2.21	2.43	2.58	2.71
260	1.88	2.28	2.52	2.67	2.79
250	1.94	2.36	2.60	2.76	2.90

**Table10** The maximum exposed thread number at different breakdown filed strength and different distance with busbar junction box

Spacing(mm)	Electrical filed strength(kV/mm)					
	2.5	2.6	2.7	2.8	2.9	3
300	3.50	4.25	5.00	N	N	N
290	3.25	3.75	4.25	5.00	N	N
280	3.00	3.25	3.75	4.25	5.00	N
270	2.50	3.00	3.25	3.75	4.50	5.00
260	2.25	2.50	3.00	3.25	3.75	4.50
250	2.25	2.50	2.75	3.00	3.25	3.75

## Conclusion

The 3D finite element simulation model of the high voltage metal enclosed switchgear was built by using the methods of the subarea modeling and local refining mesh. Some strategies to improve the electric field distribution have been studied. The main conclusions are as follows:

(1) The maximum electric field strength of the contact box can be reduced by installing the insulating spacers and equalizing rings, while the electric field strength between the contact boxes is slightly increased, making the electric field distribution of the entire contact box more uniform.

(2) The influence of the inner shield case on the electric field distribution was analyzed in the wall bushing area. The simulation results show that the shield case can limit the electric field in the wall bushing and make the distribution of the electric field in this region more uniform.

(3) The maximum exposed thread number of bolt under different spacing of busbar was obtained with the busbar junction box or not. The results provide a certain reference to improve the local electric field distribution around the lap joint of busbar as well as guide the on-site inspection.

## Acknowledgments

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