Optimization of Grading Ring Design for Metal Oxide Arrester Using Gravitational Search Algorithm

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***Abstract*—A high voltage metal oxide arrester (MOA) is used to protect power system against overvoltages. The electric field surrounding the MOA can be made uniform by installing a grading ring. It is important to have a proper way to design a grading ring with low electric field of the design. In this project, a model of 150 kV MOA was developed in COMSOL Multiphysics software. The grading ring dimensions were varied to study their effects on the electric field surrounding MOA. It was found that the grading ring dimensions strongly influence the electric field magnitude surrounding the arrester. Gravitational search algorithm (GSA) were used to obtain the optimum design of the grading ring for the MOA model. Comparison of the results between GSA and other optimization methods shows that GSA is the most suitable method to obtain an optimum design of the grading ring for MOA compared to genetic algorithm (GA), particle swarm optimization (PSO) and simulated annealing (SA). This is due to it yields the lowest electric field magnitude and has the fastest convergence.**

Keywords— Metal oxide arrester, gravitational search algorithm, finite element analysis

I. INTRODUCTION

Due to lightning and switching impulses, an electrical surge can occur in a power supply system. During an electrical surge, a large transient voltage will be produced in the electrical network and system. This causes overvoltage stresses on electrical equipment that comes under the voltage travelling path. Any equipment breakdown will be detrimental to the whole system. Hence, all electrical equipment in the power supply system must be protected against electrical surges to ensure reliable electricity. A high voltage metal oxide arrester (MOA) is generally used in power system for surge protection.

In MOA, metal oxide blocks placed near the high voltage end are highly stressed by the surrounding electric field. In other words, the electric field along the metal oxide varistors has non-uniform distribution. This can shorten the lifetime of the varistors at the high voltage end. Hence, improvement must be made to make the electric field distribution to be more uniform [1]. One of the ways to make the electric field distribution uniform is by installing a grading ring on the surge arrester.

Several works have been done in the past to obtain uniform the electric field distribution surrounding MOA. In [2], the electric field was evaluated by COMSOL Multiphysics which is a finite element method (FEM) based software. Then, using MATLAB software, differential evolution (DE) and particle swarm optimization (PSO) were performed to optimize the outer radius and the vertical height of grading ring. In [3], the adequacy of the grading ring configuration proposed by the manufacturer for a 624 kV MOA was evaluated. An optimized dimension of the grading ring was presented by considering all the influencing factors.

A work in [4] proposed a method combining 3D FEM and circuit analysis to analyze the potential distribution of a surge arrester for 1000 kV ultra-high voltage air-insulated substation. An optimum grading ring design and parallel capacitors arrangement were proposed to maintain the potential distribution coefficient around 5 %. In [5], 2D axial-symmetry models of high voltage capacitor and surge arrester bushings were developed using COMSOL Multiphysics software to evaluate the electric field distribution. The effects of the bushing permittivity, electrical conductivity, width, length and metallic interface on the electric field distribution were investigated.

In [6], a 3D model geometry of 11 kV ZnO surge arrester was developed using finite element analysis (FEA) to evaluate the leakage current. The surge arrester parameters being optimized were the glass permittivity, silicone rubber permittivity and width of ground terminal. In [7], a 132 kV surge arrester was developed using COMSOL Multiphysics software to investigate the effects of different surge arrester parameters on thermal distribution under normal condition and overvoltage condition. By varying the arrester length, bushing thermal conductivity, bushing width, glass width and ZnO width, their influences on thermal distribution were studied.

A work in [8] simulated a set of medium line surge arresters using COMSOL Multiphysics, EMTP-RV and

PSCAD software to study their discharge energy capabilities during fast-front surge events. In [9], a non-ceramic insulator string model with corona ring was modelled in FEA software to evaluate the electric field distribution. The outer diameter, inner diameter and vertical height of corona ring were varied to study their effect on the electric field distribution.

II. Methodology

Fig. 1 shows the 2-dimensional axial-symmetry model of 150 kV MOA with grading ring in COMSOL Multiphysics software respectively. The models were simulated to obtain the surrounding electric field distribution. The grading ring parameters are shown in Table I. The relative permittivity of the 150 kV MOA materials is shown in Table II.

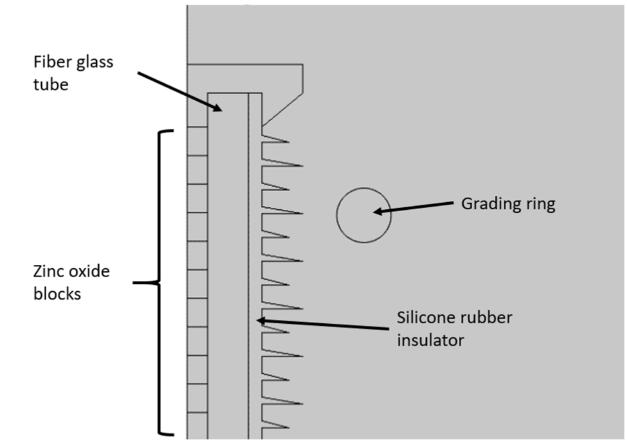

Fig. 1. Structure of the MOA with grading ring model

TABLE I. Dimensions of the Grading Ring

Parameter	Dimension
Outer diameter	600 mm
Vertical height	300 mm
Inner radius	40 mm

TABLE II. Relative Permittivity Used for the Materials

Material	Relative permittivity
Air	1
ZnO	60
Fiber glass	4.6
Silicone rubber	3.9
Aluminum	1000

The Electrostatics sub-module under the AC/DC module in COMSOL Multiphysics software was used to compute the electric field distribution. The equation used to calculate the electric field is given by [10-12]

$$\vec{E} = -\nabla V \quad (1)$$

where E is the electric field and V is the electric potential.

For boundary conditions, the top part of the MOA was connected to a high voltage. For the MOA model with grading ring, the grading ring was also set to high voltage as it is also connected to the top part of the MOA. In contrast, the bottom part of the MOA and the outer boundary of the hemispherical air were grounded.

To obtain the optimum design of grading ring for each of the surge arrester model, the objective function is to minimize the electric field magnitude using Gravitational Search Algorithm (GSA). The number of maximum iterations and the population size for all optimizations were fixed at 100 so that they are comparable. Each optimization was run for 10 times and the best results were chosen.

GSA optimization began with random generation of potential solutions known as masses in the problem space. Based on the fitness function, the gravitational constant and inertia masses were updated. Total force on masses in all direction and acceleration of each mass were calculated. Then, the velocity and position for all masses were updated. As the process was iterated, the weaker solutions moved toward the better solutions. When the stopping criteria or the maximum iterations were reached, the heaviest mass or the best solution was found. Table III shows some parameters used in GSA optimization. Fig. 2 shows the flowchart of GSA used in this work.

TABLE III. Parameters of GSA

Parameter	Value
Initial gravitational constant	100
Alpha	10
Elitist check rate	1
Rpower	1
Iteration	100

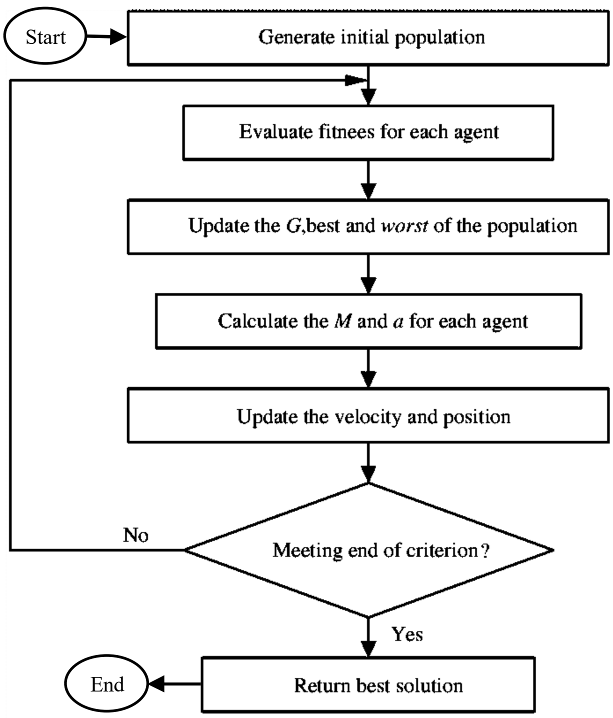

Fig. 2. Flowchart of GSA

III. Results and Discussion

Fig. 3 shows the electric field distribution at high voltage end of the MOA without grading ring. Using 'Cut Line 2D' in COMSOL Multiphysics software, the electric field across the MOA was extracted. From Fig. 4, it can be seen the electric field distribution across the MOA is not uniform. The electric field is highest at point slightly after 0 mm of the reversed arc length axis. It gradually decreases when moving away from the high voltage terminal of the MOA. This means that the metal oxide blocks in the vicinity of the high voltage terminal are experiencing higher electric field stress.

The point with the highest electric field in the MOA was used for evaluation of the electric field magnitude in all following simulations. The electric field at the point was found by using 'point evaluation' in COMSOL Multiphysics software. In this case, the electric field magnitude at this point is 714588 V/m.

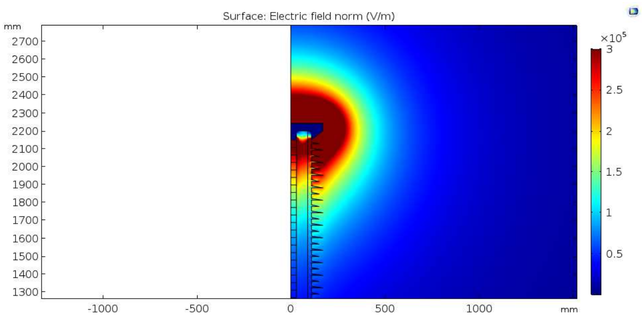

Fig. 3. Electric field distribution of MOA model without grading ring

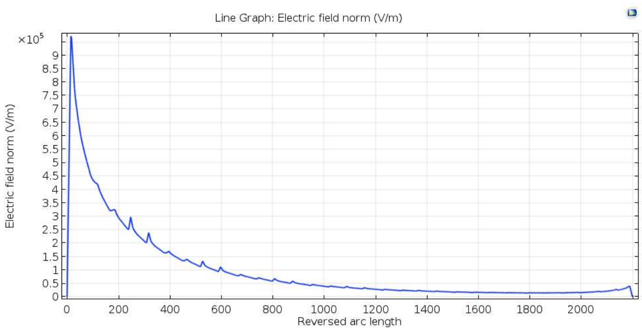

Fig. 4. Electric field magnitude of MOA model without grading ring

From Fig. 5, it can be seen the grading ring distorts the electric field distribution at the high voltage end of the MOA model. The electric field stress on metal oxide blocks at the high voltage end of the MOA has also been greatly reduced. Fig. 6 shows that the electric field is still highest at the point slightly after 0 mm of the reversed arc length axis. The electric field first decreases abruptly to its minimum point at around 100 mm of the reversed arc length axis. Then, it increases rapidly until about 250 mm of the reversed arc length axis before decreasing gradually over the rest of the MOA.

By installing the grading ring, the electric field magnitude at point 0 mm of the reversed arc length axis is almost halved, which is from 714588 V/m to 392575 V/m. The percentage of reduction for the electric field magnitude is 45.06 %. This indicates that the high electric field surrounding the high voltage end of the MOA can be minimized by proper geometry size of the grading ring.

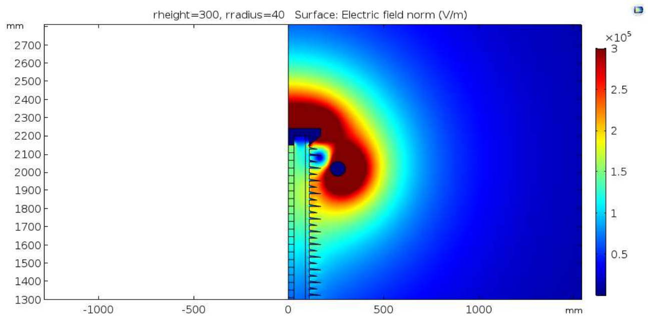

Fig. 5. Electric field distribution of MOA model with grading ring

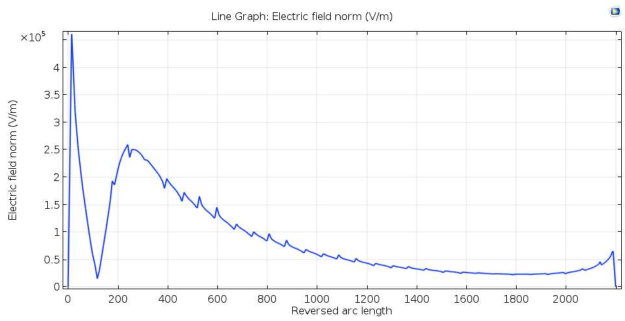

Fig. 6. Electric field magnitude of MOA model with grading ring

To minimize the electric field magnitude at point 0 mm of the reversed arc length axis, the outer diameter, inner radius and vertical height of grading ring were optimized using GSA optimization. It was found that the electric field is lowest at 104579.01517 V/m when the outer diameter is 605.955624 mm, the inner radius is 59.102416 mm and the vertical height is 205.176181 mm. Table IV shows the optimization results of GSA, participle swarm optimization (PSO), genetic algorithm (GA) and simulated annealing (SA) optimization while Fig. 7 shows the convergence curve.

Based on the results, it can be seen GSA optimization yields the lowest electric field. Of all the optimization methods, GSA optimization has the least number of iterations to converge while PSO has the shortest total running time. The results indicate that GSA optimization is the most suitable method among all optimization methods for having more advantages than the others.

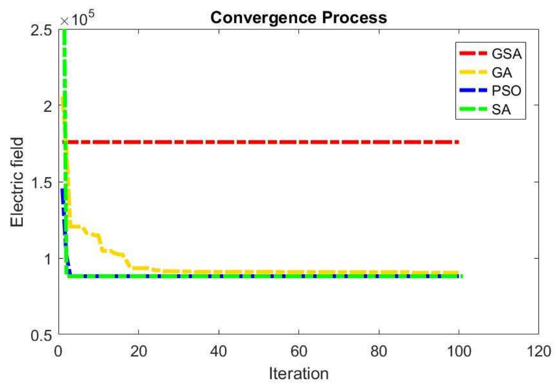

Fig. 7. Convergence curve of GSA, GA, PSO and SA

TABLE IV. OPTIMIZATION RESULTS OF GRADING RING DESIGN

Parameter	GSA	GA	PSO	SA
Diameter (mm)	605.35	600.09	600.00	600
Radius (mm)	32.67	30.01	30.03	30.03
Height (mm)	201.42	200.01	200.00	200
Field (x10^5 V/m)	2.608	2.772	2.771	2.771
Convergence iteration	1	70	4	100

IV. CONCLUSIONS

Using COMSOL Multiphysics software, a model of high voltage metal oxide arrester (MOA) was successfully developed to study the surrounding electric field. From the results of MOA with and without grading ring, it was found that the high electric field at the high voltage end of the MOA can be minimized by installing a grading ring. The outer diameter, vertical height and inner radius of grading ring were varied to study their effect on the electric field distribution. The results show that the inner radius and the outer diameter should be large while the vertical height should be short for low electric field. However, the electric field will stay constant when the outer diameter exceeds a certain threshold.

To identify the most suitable method for optimum grading ring design, results of different optimization methods including gravitational search algorithm (GSA), genetic algorithm (GA), particle swarm optimization (PSO) and simulated annealing (SA) were compared. It was found that GSA is the most suitable method for designing an optimum grading ring for surge arresters compared to the other methods. This is due it yields the lowest electric field and requires the smallest number of iterations to converge.

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