Electromagnetic & Electrostatic study in High Voltage Switchyard

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Abstract: Safe electromagnetic radiation levels for long term exposure of humans have been specified. The project reported in this paper is to check whether the limits specified are exceeded in a 765 kV, 2000 MW switchyard. A commercial package COMSOL has been used to simulate the electromagnetic field model of the switchyard. This involved geometric model, finite element analysis and numerical solution. It is seen through simulation that the magnetic field is within the regulatory limits. The electric field, however, exceeded the limit in certain locations. A grounded wire placed at appropriate locations helped to reduce the electric filed below the limit.

Keywords: Electric field, Magnetic field, Finite element analysis, Numerical solution, COMSOL.

1. Introduction

Constant exposure of humans even to low frequency electromagnetic radiation may be hazardous. Hence exposure limits have been specified for electrical and magnetic fields at the power supply frequencies. The project reported in this paper is to check whether the limits specified are exceeded in a 765 kV, 2000 MW switchyard endangering the long term health of the human operators working in the yard.

Several studies have been made on the electromagnetic fields in substations of Very High Voltages. Due to the complexity of the geometric structure of the electric lines and equipment, most of the studies have resorted to simulation tools to determine electromagnetic field inside the substation [1-10]. Finite element analysis is one of the popular tools used for determining the electromagnetic radiation levels in the areas concerned. Also, many of the studies assume symmetry of the structure along one dimension to reduce the problem to a two dimensional study. However, in this paper, an attempt is made to simulate the three dimensional structure of the field distribution simplifying only on the basis of tower structures, auxiliary equipment representation and symmetry of the transmission line layout geometry.

The main contribution of the paper is as follows: (i) provide a workable finite element analysis based 3D simulation of the electrical and the magnetic field distributions in a switchyard of 765 kV. (ii) the simulation results of the electromagnetic field are verified against selected field measurements and (iii) provide a simple solution to keep the radiation levels within the regulatory limit.

The rest of the paper is organized as follows. Section 2 presents the detailed methodology followed for simulation of the power system using the elements of a commercial package called COMSOL. Section 3 provides the main results and discussions. Section 4 concludes the paper.

2. Simulation Methodology

2.1 Approach Used

Due to the complexity of the geometry of the switchyard layout, a practical approach to the solution of the problem is to carry out finite element modelling (FEM) analysis using the commercial package COMSOL (Basic pack plus AC/DC module). To make the problem tractable, physical modelling of the switchyard is simplified.

2.2. Geometry Model

We took advantage of the symmetry of the switchyard geometry to reduce the problem complexity. For the case of electric field computation, it is found that it is sufficient to consider two parallel bays of 39m/14m height conductors for modeling purposes. For the case of the magnetic field , however, to keep the size of the problems within the computing capability of the system at hand, it is found necessary to limit our analysis to nearly one third (at the right or left end) of a single bay of 39m/14m height transmission lines. The solution of the mid –one third portion of the bay is considered less critical in terms of magnetic field values.

In order to avoid the minute gaps that arise when two cylindrical objects touch each other, as when the drop lines meet the transmission lines, resulting in inverted or bent meshes and a consequent numerical instability of the solution, the conductors are geometrically modelled as rectangular blocks so that the drop lines sit on each other without any gap on the joined surfaces. The cross-section of the transmission and drop lines are approximated to be 0.04m square. The effect of such approximations on the results is nil since the field values at distances of 12 m or more will not be affected by changes in the geometry as above of the order of mm.

Transmission towers along the transmission lines are modelled as two metallic pillars at ground potential at appropriate locations as per the system drawing. Also, circuit breakers, isolators and other equipment below the transmission lines are modelled as metallic objects positioned on the ground at appropriate locations to the given height as per the drawing.

Fig. 1 shows the geometrical structure of the transmission lines, towers and the auxiliary elements, such as, circuit breakers etc used in the simulation study.

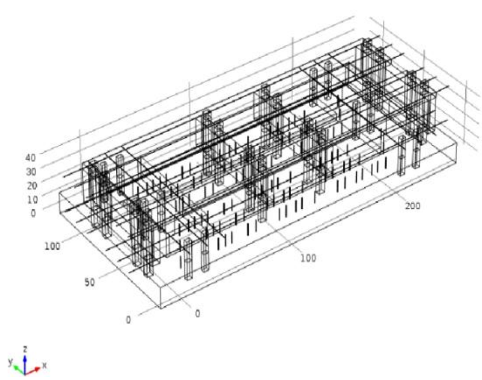

Figure1. Switchyard configuration as simulated

2.3 Material Specification:

The different parts of the geometry are identified with the material used. Conductors are identified with Aluminium, towers and objects on the ground, such as, Circuit breaker etc. are identified with material Steel. The space encompassing the switchyard is identified with Air.

2.4 Meshing

Meshing is a process by which the space of interest is filled with meshed elements in the form of tetrahedral. In view of the large diversity in the length of conductors, cross section of conductors, as well as the height of the transmission lines and towers, it was found necessary to house various geometrical spaces into virtual boxes which, while not being part of the geometry, help in building an efficient meshed geometry. Growth rate, maximum and minimum mesh sizes, allocation of different sizes to different virtual control boxes etc are the different factors that are used to tune to get a good meshed domain with a good quality index with a minimum number of meshes. Typical number of meshes encountered in our solution ranged from 3 million to 5 - 6 million. Fig.2 shows the meshed form of Fig 1 useful for finite element analysis of EM field distribution.

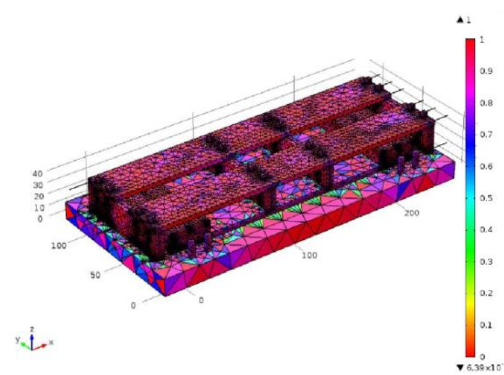

Figure 2. Switchyard configuration - meshed

2.5. Mutiphysics Model :

With the switchyard modelled as a finite element space, it is now necessary to excite it using a voltage or current source. For this purpose the coupling of electric circuit with electric current physics is used for the study of electric field. In the case of magnetic field, coupling of magnetic field and electric circuit physics is used. For electric field, the 3-phase voltage source applied has a magnitude computed as follows.

(765 kV) * (√2/√3) = 625 kV peak at 50 Hz

For the magnetic field simulation we used a current source which is computed as follows

{660MW/ph) (765k V/√3} (√2) =2113 A peak at 50 Hz

At 50 Hz, the electric and magnetic fields are essentially decoupled and can be separately studied.

2.6 Study :

In this phase, the different solvers could be run to find solution to the EM field inside the volume of the space occupied by the switchyard. We used many linear iterative solvers to arrive at the EM field solution. The number of degrees of freedom involved in the solution varies depending on the number of meshes involved and whether an electrical field or a magnetic field study is considered. Generally the number of degrees of freedom ranged from about 4 million to 9 million in numbers. This corresponds to the dimension of the unknown vector in a linear system of equation approximation of the solution sought. Solution time varied from a few hours to more than 24 or 48 hours in many cases. Many times the iteration was stopped when the solution reached an error of the order of 10^{-2}.

3. Results and Discussion :

The results can be displayed in many forms. For the purpose of the study at hand, the most appropriate display corresponds to the field distribution along the horizontal cross- section of the switchyard at a height of about 1.8 m above ground (corresponding to the typical height of a human operator). The electric field is measured in terms of kV/m. The magnetic field is expressed in terms of mG (milli Gauss). The field distribution is presented in colour with different colours corresponding to different levels of the field values. It is possible to point to different locations on the switchyard space to find out the EM field at that location specified in terms of its x,y,z coordinates.

3.1 Electric Field :

Fig. 3 shows the electrical filed distribution at a height of 1.8 m above ground level. The electric field in many locations (shown by arrows) exceeded the prescribed limit of10 kV/m as per regulations. To rectify this situation, 4 grounded wires per bay are placed at a height of 8 m above ground across the span of 30 m of the 14m/39m height transmission lines symmetrically (2 on either side) about the centre line of the bay where higher field strengths were detected. By placing the grounded wires as specified, the simulation showed that it was possible to bring down the electric field below the limiting value of 10kV/m at all the locations where the field exceeded the limit originally. Fig.4 shows the electric field obtained through simulation at a plane 1.8 m above ground with the 8m ground wire in place.

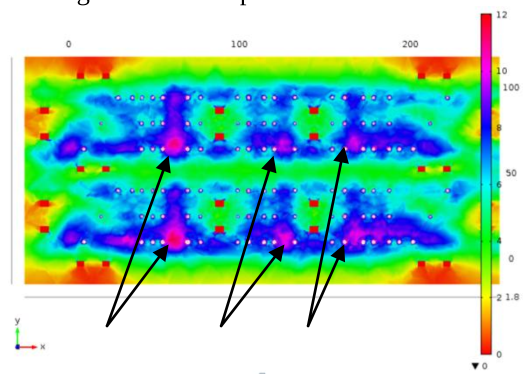

Figure 3. Electric field (in kV/m) distribution in switchyard 1.8m above ground. No ground wires.

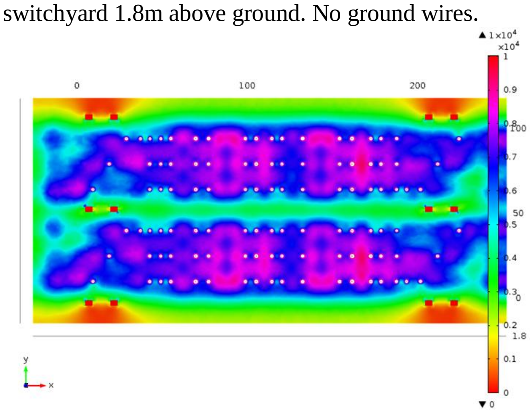

Figure 4. Electric field (in kV/m) 1.8m above ground with grounded wires inserted at 8m above ground.

3.2 Magnetic Field :

Fig. 5 shows the magnetic field distribution at a plane parallel to the ground plane and at a height of 1.8 m above ground level. From Fig. 5, it is seen that the value of the magnetic field along the plane mentioned is always below 10 mG. The regulatory limit is far above this value at 5000 mG. So, clearly, for the current levels provided no risk is perceived through magnetic field.

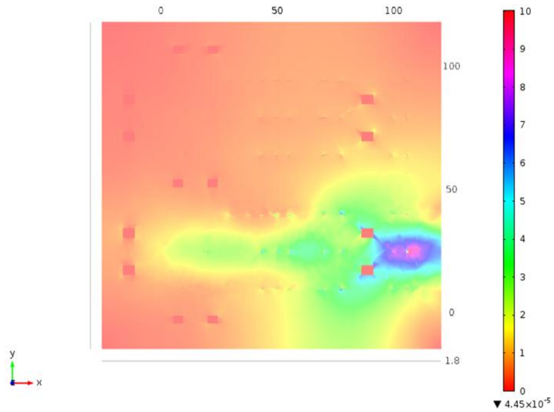

Figure 5. Magnetic flux density (mG) 1.8m above ground level.

4. Summary and Conclusions

The electromagnetic field study of the switchyard extending over a length of about 250 m, breadth of about 200m and height of about 40 m is not an easy problem. Finite element analysis of the electromagnetic field is a practical solution. Due to the large variation between the cross-sectional dimensions of the conductor and length of the conductor, the meshed elements are large in number running into several millions. Also, to keep the number of meshed elements at an affordable range, it was necessary to simplify the modelling of towers as two vertical pillars at a given distance apart only thus neglecting the detailed geometry of the towers as well as the insulation supports involved.

For the electric field the number of degrees of freedom involved is nearly double the number of meshed elements. As for the magnetic field computation, the number of degrees of freedom to be solved could be several times the number of meshed elements.

Given the complexity of the problem as above, we need to take advantage of the symmetry of the switchyard geometry to reduce the problem complexity. For the case of electric field computation, it is found that it is sufficient to consider two parallel bays of 39m/14m conductors for modeling purposes. The rest of the electric field solution follows by symmetry. For the case of the magnetic field , however, to keep the size of the problems within the computing capability of the system at hand, it is found necessary to limit our analysis to nearly one third (at the right or left end) of a single bay of 39m/14m transmission lines. Solution of the other one third of the bay follows by symmetry. The solution of the mid –one third portion of the bay is less critical in terms of magnetic field values since the number of current carrying conductors (causing the magnetic field) at the middle one-third portion is only 12 compared to 15 current carrying conductors at the end portion of the bay.

In conclusion, it is found that the magnetic field in the switchyard is far below the level at which it is considered harmful to human operators in the switchyard. On the other hand the electric field could be at levels near or above the regulatory levels allowed for continuous exposure of humans. It is then possible to mitigate the electric field effect by suspending grounded thin conductors at a height of, say, 8 m above ground at the critical regions.

The EM field simulation results were also compared with field measurements made at selected points on the ground .It is generally found that the measurements tend to support the field values obtained through simulation.

5. References

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