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Assessment of earthing system location for wind turbines using finite element method

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ABSTRACT

A new proposal for the assessment of earthing system location used for wind turbines is presented. This proposal depends on the simulation of the electric field as well as the calculation of current density at the ground surface above the earthing system and distribution inside the soil when the wind turbine is exposed to high voltage. The electrical potential simulation around the earthing system of wind turbine using ring earth electrode with and without auxiliary vertical rods was also studied. Accurate calculations and simulation of the electric field are prerequisite for the simulation of current density. The electric field distribution is obtained by calculating the electric potential in three-dimensional domain surrounding the earthing system using Finite Element Method. The boundary conditions satisfy both Dirichlet's and Neumann's equations. The simulated electrodes are energized with one per unit voltage to be available for different types of applied potential. The resistance of the earthing system is calculated. This simulation model shows reasonably close agreement which gives confidence in predicting the assessment of the earthing grid location which is around 66.6% out of the total depth length of the affected domain. Different types of soils were checked to satisfy this ratio of the location assessment. The results showed that the vertical component of electrical field intensity and current density were improved at the assessment location of the earthing grid.

1. Introduction

Renewable energy is the new trend to meet the world requirements from the electrical power. It represents an alternative energy source to overcome the pollution of fuel energy and energy crisis. One of the most important types of renewable energy is the wind turbine due to the high power obtained from it. This power can be controlled from wind turbine shape and height. Wind turbine is often struck by lightning and is usually placed in higher and isolated location with high soil resistivity [1]. So, earthing system is important to protect wind turbine from lightning or system faults. On one hand, the earthing system consists of surge protection, lightning receptor points, conductors and grounding system for each wind turbine [2], as well as high protection to it from power system faults that provide high current or voltage. On the other hand, earthing system provides a low impedance path to high currents to prevent over-voltages and potential gradient rise that may cause damage to electrical equipment or human and animal lives [3,4]. During the transient conditions of the wind power system, earthing system can be used as a common reference to all electrical equipment in the system [5,6]. Its resistance equals 10 Ω before connecting to any other systems [7].

The shape of earthing electrodes takes different forms such as simple surface, meshed electrodes, cable with exposed metal sheath and rod electrodes [8]. Firstly, simple surface electrodes in the form of a ring or a single ended strip are located horizontally in the soil. Secondly, meshed grid electrodes are placed horizontally at a certain depth. Thirdly, cable with metal static sheath behaves as a strip-type driven earth electrode. Lastly, rod driven electrodes buried at a depth greater than 1 m and usually from 3 m to 30 m [8]. The disadvantage of horizontal earth electrode is that it has a limited ability to reduce the earth potential rise but vertical driven rod is the simplest and most economical form of earthing electrode [9]. The optimum length was determined experimentally and differed from one model to another [9]. Ring earth electrode with auxiliary vertical driven rods can reduce the earthing system resistance due to the parallel connection between the rods [10]. Whenever the depth of the buried ground rod is increased, the earth surface potential will decrease [11]. Also, the position of

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maximum ground surface potential which varies with the depth of the earthing system during ground faults or lightning strikes was investigated with scale models in an electrolytic tank [12].

Finite element method (FEM) is one of the numerical method techniques that is used for finding approximate solutions which satisfy the boundary conditions of such problem using partial differential equations [13,14]. FEM has many advantages over other methods that it can consider complex construction of soil and configurations of the earthing systems regardless of the size, length, type and shape of the electrodes [14].

A simplified ideal wind turbine foundation will be used [15] which is consisted of a reinforced bar structured by a copper frame. This foundation can be connected to earthing system through copper wires. The earthing system is consisted of a combination of a ring earth electrode with auxiliary vertical driven rods [15].

In this paper, the optimum location of wind turbine earthing system is presented. This location depends on the optimum value of the vertical component of the electric field simulation at the ground surface and the current density calculation inside the soil surrounding the earthing system. Also, the electrical potential, electrical field and current density distribution due to the combination of the ring earth electrode with and without auxiliary vertical rods for wind turbine as recommended in IEC TR 61400-24:2002 [15] are presented. The effect of increasing the grounding grid depth is investigated for both of the vertical component of field simulation and current density calculation. The value of the whole grounding system resistance due to the different types of soils is determined. FEM electrostatic calculations with a wind turbine foundation and various electrode configuration are performed using the partial differential equation toolbox under MATLAB library toolbox.

2. Method of analysis

2.1. Electric field distribution

The electric field intensity, E, can be calculated by using the value of the potential distribution in the required medium from the gradient equation;

$$E = -\nabla V \tag{1}$$

where, V is the electrical potential distribution.

So, the electric potential distribution due to ring electrode subjected to electric charge can be obtained as,

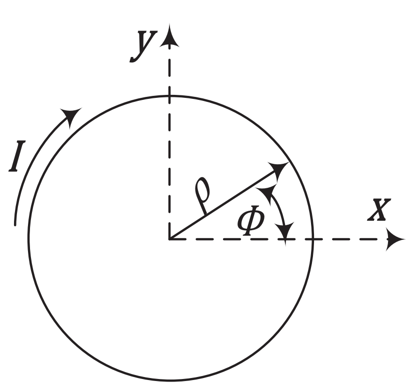

Fig. 1. Schematic diagram of two-dimensions of ring electrode energized with electric current.

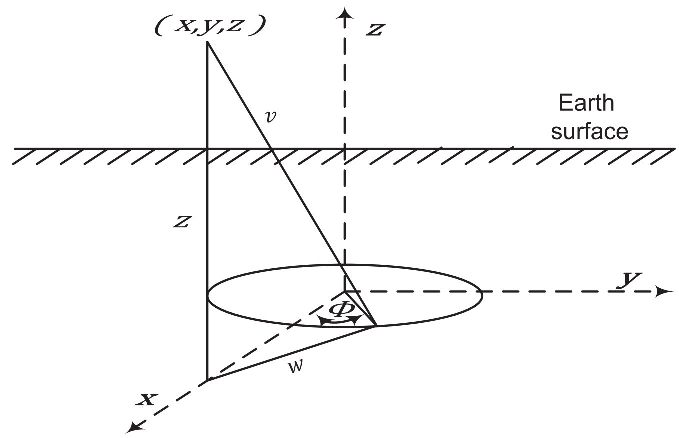

Fig. 2. The three-dimensions of ring electrode.

$$V = \int_{\rho}^{\infty} E(\rho)d\rho \tag{2}$$

where, ρ represents the radius of the ring electrode in m, and can be analyzed in two components of $x\!-\!y$ plane, see Fig. 1.

The electric field intensity can be obtained also from the value of current density as,

$$E = \frac{J_e}{\sigma} \quad V/m \tag{3}$$

where, J_e is the electrostatic current density in A/m^2 and σ is the soil conductivity of the medium.

The electrostatic current density due to the leakage current, $I_{leakage}$, which will cover the area of the earth electrode, which represented as the surface area of sphere, can be determined as:

$$J_e = \left(\frac{I_{leakage}}{4\pi\rho^2}\right) \quad A\big/m^2 \tag{4}$$

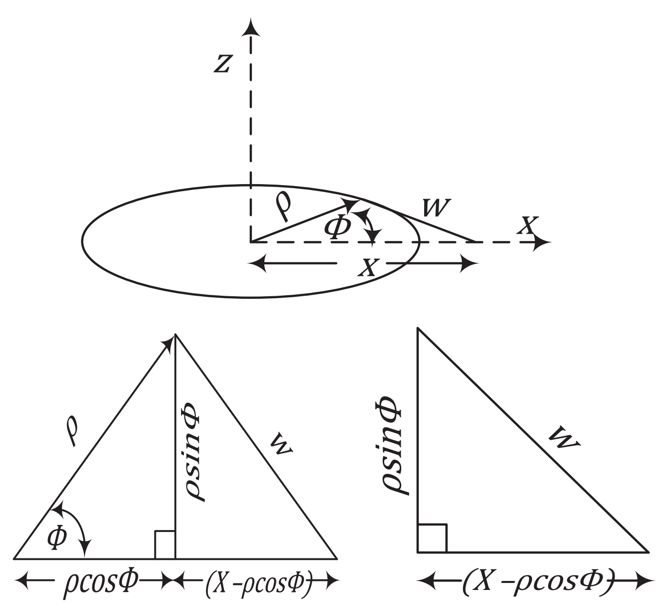

Fig. 3. The two-dimensions of ring electrode and analysis of its components.