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A Proper Design of Wind Turbine Grounding Systems under Lightning

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Abstract**—**Lightning protection systems (LPS) for wind power generation is becoming an important public issue. A serious damage of blades, accidents where low-voltage and control circuit breakdowns are frequently occur in many wind farms. A grounding system is one of the most important components required for appropriate LPSs in wind turbines WTs. Proper design of a wind turbine grounding system is demanding and several factors for the proper and effective implementation must taken into account. In this paper proposed procedure of proper design of grounding systems for a wind turbine was introduced. This procedure depends on measuring of ground current of simulated wind farm under lightning taking into consideration the soil ionization. The procedure also includes the Ground Potential Rise (GPR) and the voltage distributions at ground surface level and Touch potential. In particular, the contribution of mitigating techniques, such as rings, rods and the proposed design were investigated.

Keywords**—**WTs, LPS, GPR, Grounding System, Mitigating techniques.

I. Introduction

WITH a rapid growth in wind power generation, lightning hazard to wind turbines (WTs) has come to be regarded with more attention. Due to their great height, distinctive shape, and exposed location, WTs are extremely vulnerable to lightning stroke. After a WT is struck by lightning, high lightning current flows through the WT and causes considerable damage to electrical equipment inside the WT structure and wind turbine nacelle results stop of the generator operation and probably expensive repairs [1].

In order to decrease downtime, repairs and blade damaged. Protecting the blade is very important and well-designed lightning protection is a necessity for this equipment so Modern wind turbine blades are made of insulating materials such as glass fiber reinforced plastic (GFRP) as a common material or wood epoxy. The lightning protection of wind turbine blades can be classified as receptor, metallic cap, mesh wire, and metallic conductor as reported in IEC-61400-24 standards.

In general, the problem of lightning protection of wind turbine blades is to conduct the lightning current safely from the attachment point on the blade to the hub and then to the ground.

However another serious problem known as "back-flow surge" which not only causes damages to the wind turbine that has been struck but also the other turbines that have not. The back-flow surge phenomenon has been defined as the surge flowing from a customer's structure such as a communication tower into the distribution line. High resistivity soil often makes Surge Arresters (SAs) at tower earthing systems operate in reverse and allow backflow of surge current to the grid. The phenomenon of surge invasion from a wind turbine that is struck by lightning to the distribution line in a wind farm is quite similar to the case of "back-flow surge" [2].

Due to significant influence on the wind farm behavior under lightning, a grounding system is one of the most important components required for appropriate LPSs in WTs and wind farms. The design of a grounding system of a wind turbine is demanding and you need to take into account several factors for the proper and effective implementation [3]. In this paper proposed procedure for wind turbine grounding systems design introduced with the help of the software package CYMGRD and ATP-EMTP. Conventional and proposed Grounding systems are compared in terms of ability to reduce potentially hazardous touch voltages. To check validity of proposed procedure for lightning protection Computation, characteristics and hazards of back-flow surge in wind farm are analyzed using onshore wind farm as an example under Conventional and proposed Grounding system.

II. Wind Turbine Grounding System

A typical grounding system of an individual wind turbine consists of a ring electrode installed around the foundation and bonded to the metal tower through the concrete foundations, as can be seen in Fig. 1.

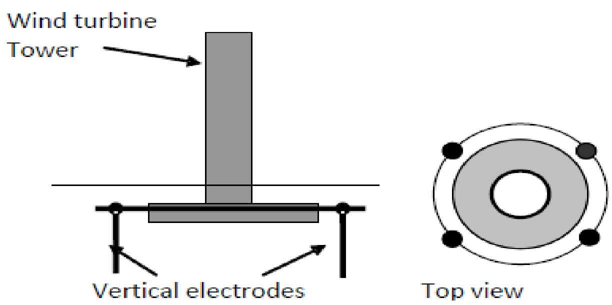

Fig. 1 Typical wind turbine grounding layout [1]

Each individual turbine earthing system is required to have an earth resistance of 10Ω or less, as specified in IEC 61024 – 1998 and TR61400-24, 2002 [1].

Vertical rods and additional horizontal electrodes are often used in conjunction with the ring electrode to achieve this

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value of earth resistance. Some alternative earthing arrangements are shown in Fig. 2 [1].

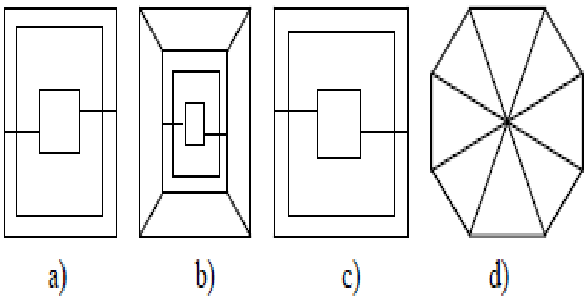


Fig. 2 Alternative grounding arrangements [4]-[6]

As it is normal that varying types of electrodes are combined in practical use, it is difficult to estimate correctly a grounding resistance value of an arbitrary electrode with a complex shape. Under a lightning impulse, it is not satisfactory to consider the steady value of the earth resistance only, it is also important to consider transient voltage [7]. So numerical calculations including the Finite Element Method FEM in CYMGRD method are important to calculate the grounding electrode and design an accurate grounding system for LPS.

III. Description of the Investigated Onshore Wind Farm

Fig. 3 shows layout of onshore wind farm composed of two identical wind power generators. Boost transformers for the generators are installed in vicinity of the wind turbine towers. All boost transformers are connected to the grid via grid-interactive transformer by overhead distribution line. Surge arresters are inserted to the primary and secondary sides of the boost and grid-interactive transformers.

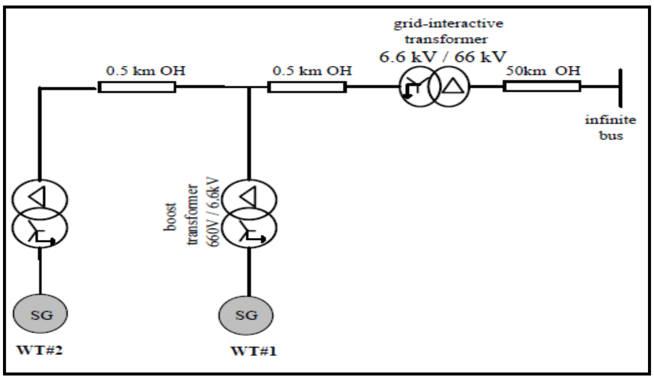
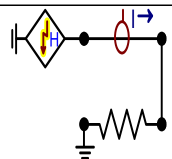
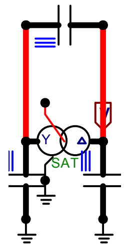
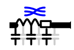
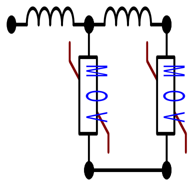
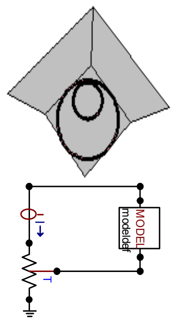


Fig. 3 Wind farm model [2]

IV. Modeling of the Electric Components of the Onshore Wind Farm Using ATP/EMTP

In this section, the detailed high frequency modeling of the electric components of the onshore wind farm using the ATP/EMTP is demonstrated. These components include Transmission line (TL), transformers, power system grid and surge arresters. Table I show different component and simulation models used in ATP/EMTP.

TABLE I
Different Components of Wind Farm and Simulation Models

Component	Simulation Shape	Data Used
Lightning Current		51kA-2/631μs winter lightning in japans [2]
Synchronous Generator- Y Connected		Voltage (line rms) 0.660 [kV] Rated power 1.0 [MVA] Leakage reactance 0.1 [H] Frequency 60.0 [Hz]
Transformer (Boost, Grid-Interactive)		Connection method Y / Δ , Y / Δ Voltage (line rms) 0.660/6.6 [kV], 66.0/6.6 [kV] Rated power 1.0 [MVA], 10.0 [MVA]
Line		Positive / zero phase inductance [mH/Km] 0.83556/2.50067 Positive / zero phase capacitance [nF/Km] 12.9445/6.4723
Surge Arresters		440kV SA with L_1 and L_0 are equal 0.07μH [8], [9]
Conventional Grounding System		Ring only#12 Diameter at 1 meter depth

V. Results and Discussion

In this section an extensive analysis of various ground systems for a wind turbine tower, 3m in diameter, with the help of the software package CYMGRD was introduced. The wind turbine is considered to have a grounding strip, of 3m diameter galvanized copper buried at a depth of 0.5m. The analysis is carried out with a maximum ground current of 1000A and soil resistivity of 100 Ohm-m. The analysis is performed according to IEEE Std 80-2000 for a person weighing of 70kg [10]. The analysis includes the reinforcement of the foundations of the grounding system, which is a part of the system grounding. The ring geometry used is a round one and additional bars or additional ring at greater depth can be used.

The conventional shape of grounding grid configuration is considered, shown in Table I. With the given grid configuration, ground resistance (R) is determined to be 4.82 Ω. GPR is 5000 V. Fig. 4 shows Potential distributions, the touch, step and surface potential distributions along the grounded area, from left-bottom corner to right-upper corner of grounding grid design. It is clear that the maximum permissible touch potential can be as high as 255 Volt.

Step potential distribution is under maximum permissible step potential (355 Volt). On the other hand, the touch potential in the site is not safe, because its value is higher than that of the maximum permissible touch potential. Fig. 5 gives a three-dimensional distribution of the touch potential. This figure shows that the site is in dangerous situation from the view of touch potential. Therefore, the grounding grid design must be improved.

For enhancing the design of the grounding grid, Two Rings one has 12meter diameter at 1 meter depth, and the other has 16 meter diameter at 1.5 meter depth are used with additional four electrodes. Fig. 6 shows the maximum permissible touch potential, which it can be as high 255 Volt, step potential distribution is under maximum permissible step potential (355 Volt). On the other hand, touch potential in the site is safe, because its value is lower than that of the maximum permissible touch potential. Fig. 7 shows the three dimensional distribution of the touch potential. In this figure the site is safe from the touch potential view. Therefore, it can be observed that the proper design is achieved under 1000A ground current can be take occurs.

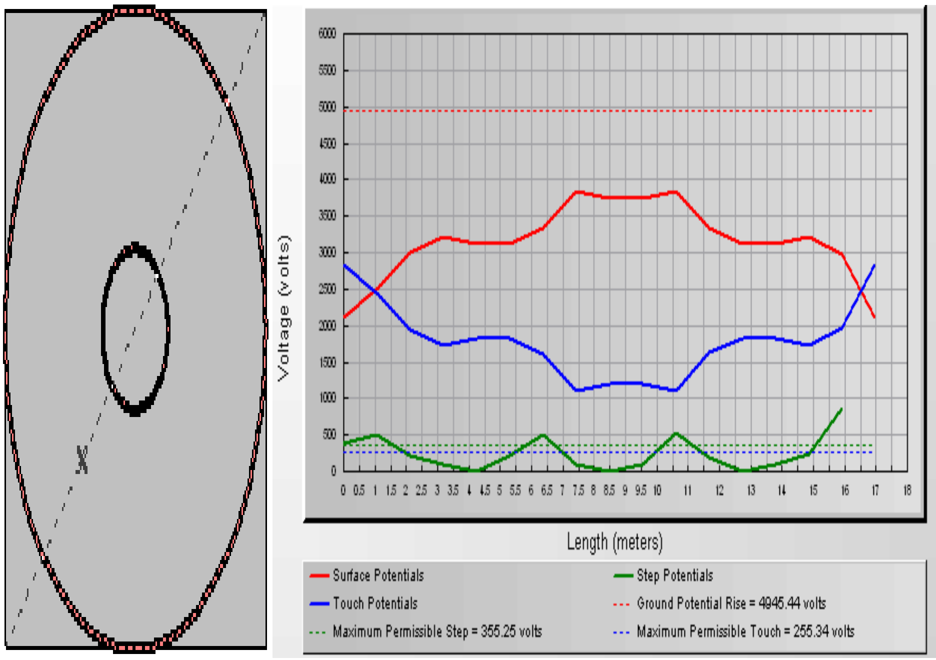


Fig. 4 Potential distributions of conventional grounding design

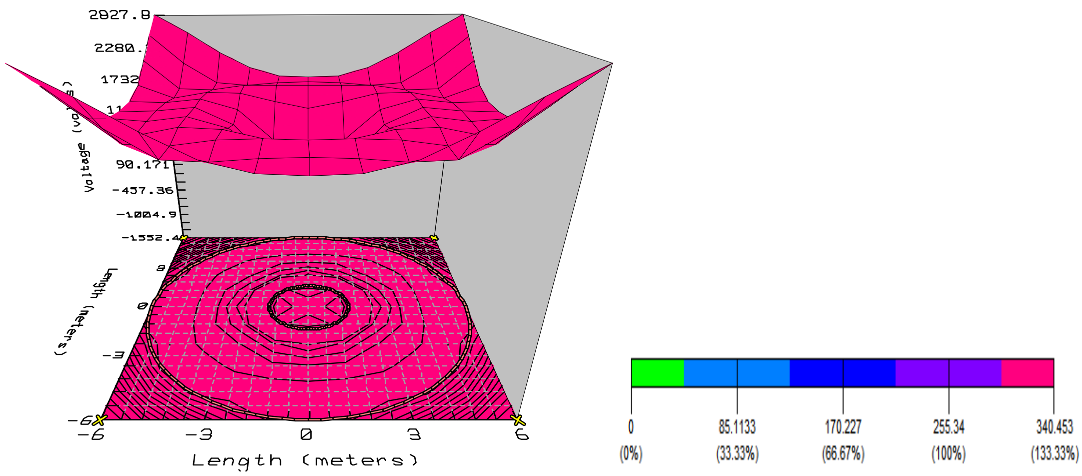


Fig. 5 Touch potential distribution of conventional grounding design

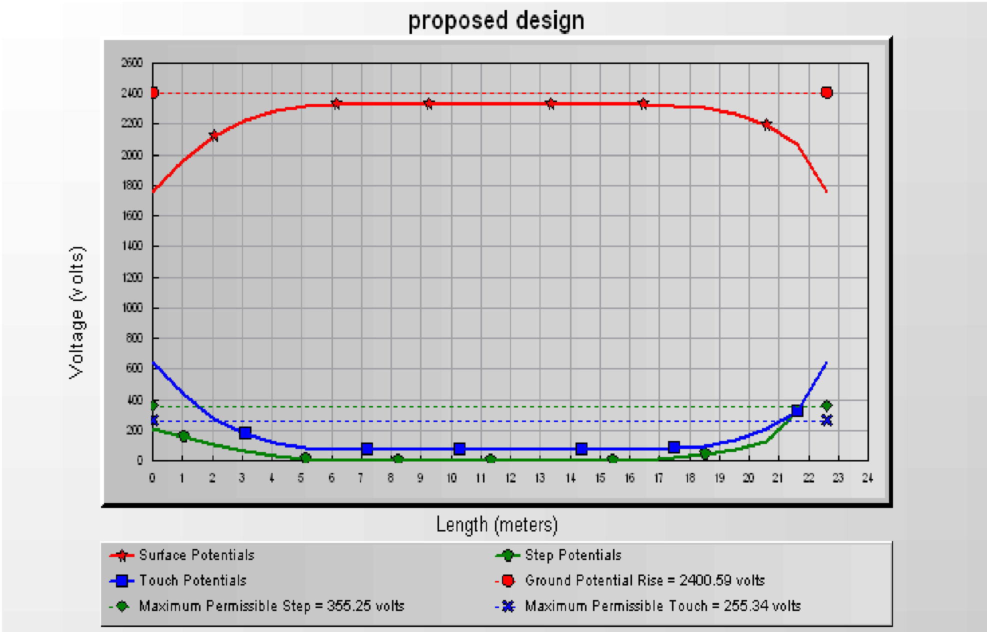


Fig. 6 Potential distributions of improved grounding grid design

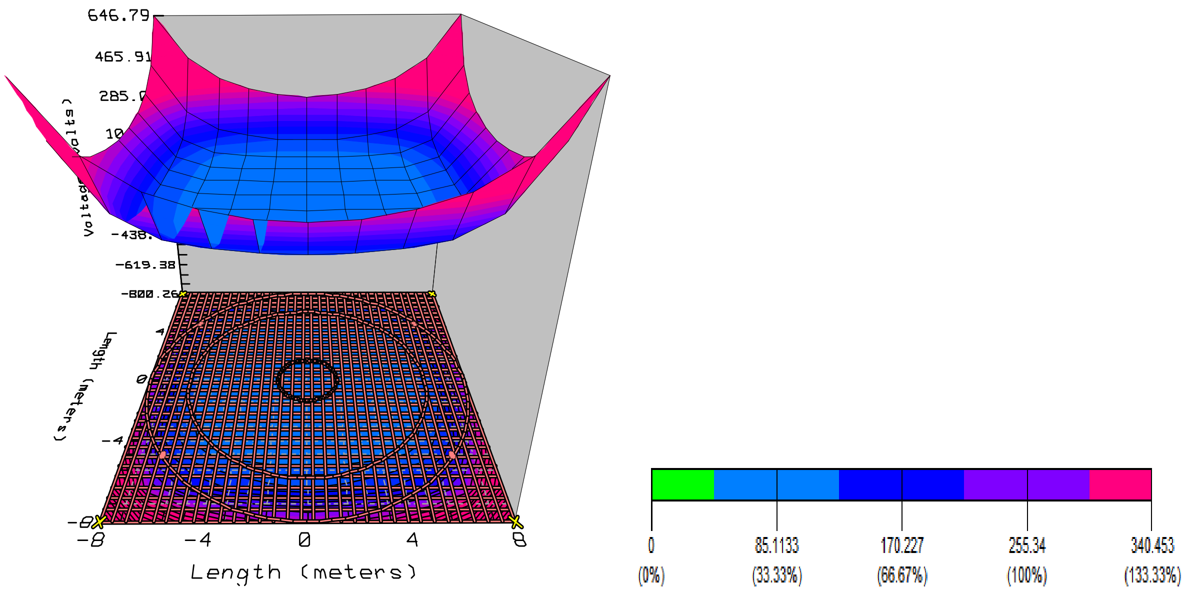


Fig. 7 Touch potential distribution of improved grounding grid design

VI. Proposed Procedure of Wind Turbine Ground Design under Lightning Impulse

In this work proposed method introduced for designing proper and safely grounding grid design under lightning impulse, 51kA 2/631µs, struck WT#1 as shown in Fig. 8. Fig. 9 shows Flow chart and the procedure followed for proper grounding grid design under lightning.

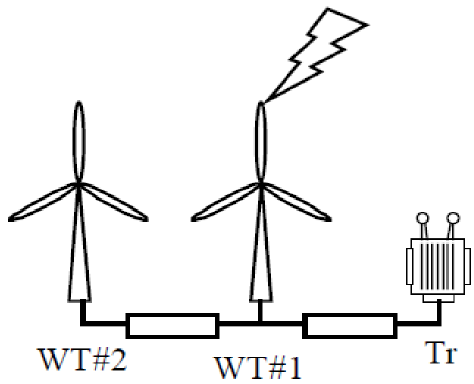


Fig. 8 Lightning hit WT#1 [3]

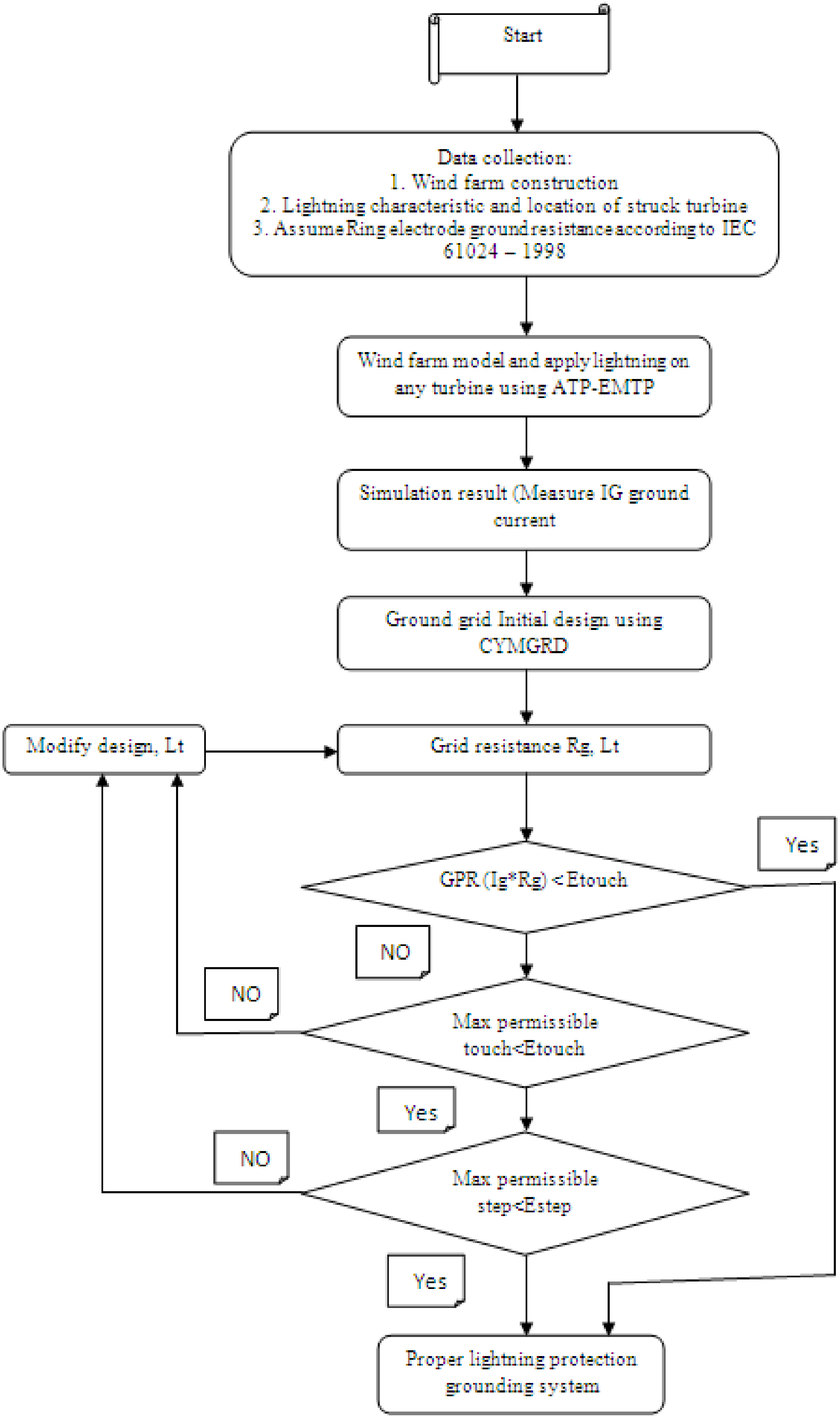


Fig. 9 Procedure for proper lightning protection

Fig. 10 shows the proposed arrangement of grounding grid of wind turbine in case of 51kA 2/631µs lightning impulse. There are 12 rods in this design and three rings with radius of 6m, 8m and 10m respectively and foundation from steal conductor constructed in an area of 15*15m.

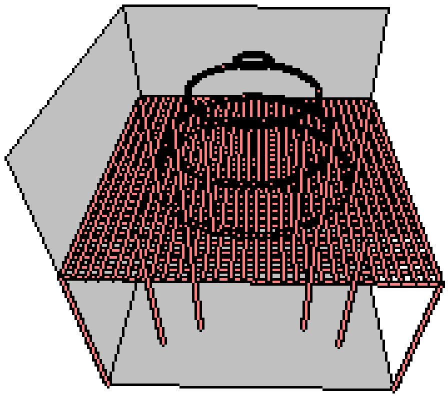


Fig. 10 Proposed grounding arrangement under 51kA 2/631µs

Fig. 11 show potential distributions on proposed ground grid due to lightning strokes on WT.

It is clear that the maximum permissible touch potential is calculated as 255 Volts, step potential distribution is under maximum permissible step potential (355 Volts). On the other hand, touch potential in the most regions in site is safe because value of touch potential is lower than maximum permissible touch potential for most of the points.

Fig. 12 shows the three dimensional distribution of the touch potential. In this figure, the site is safe from the touch potential view. Therefore, it can be observed that the proper design is achieved under 51kA 2/631µs lightning impulse strike WT. So the proper lightning protection of wind farm was achieved by the proper ground grid design. The proper ground grid design is achieved under identification of the worst lightning strokes in site of wind farm by using flow chart in Fig. 9.

Fig. 13 shows a comparison between the voltage at secondary side of boost transformer and GPR at lightning struck turbine when using grounding system including ring electrode only and our proposed design. The results show that the overvoltage reduced by about 95% and GPR decrease by about 97% when using proposed design of grounding system. This can attributes to the fact that, the proposed grounding grid cover large area of ground.

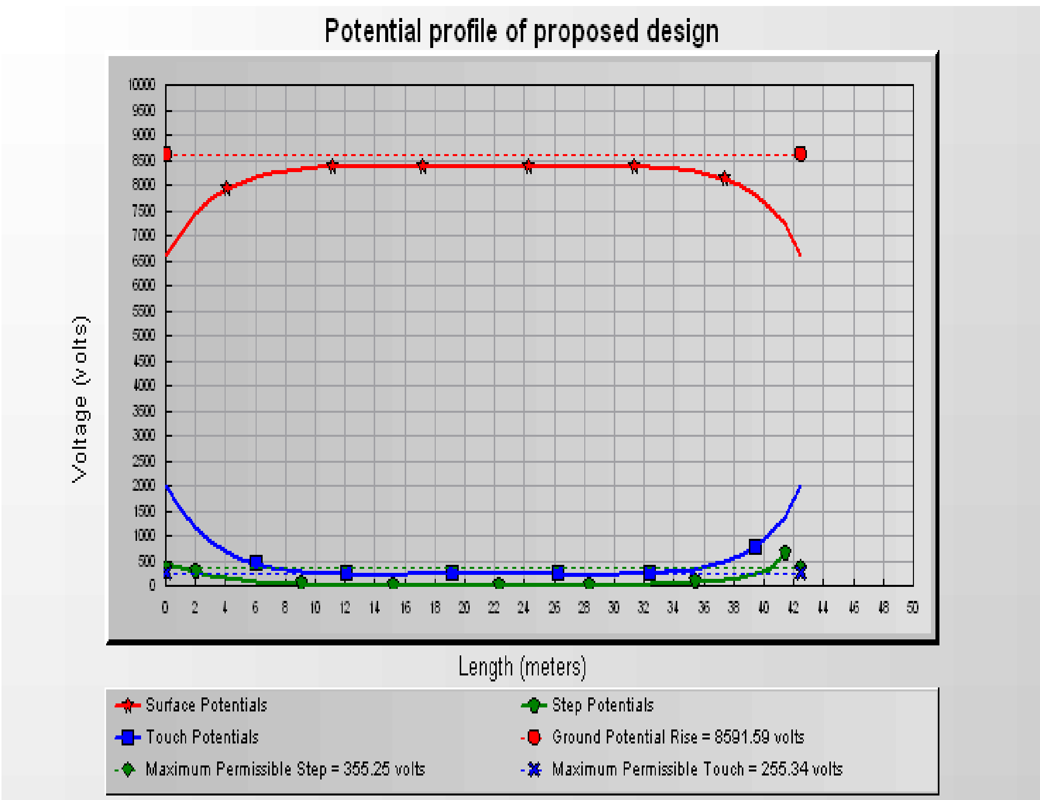


Fig. 11 Potential distributions by using CYMGRD

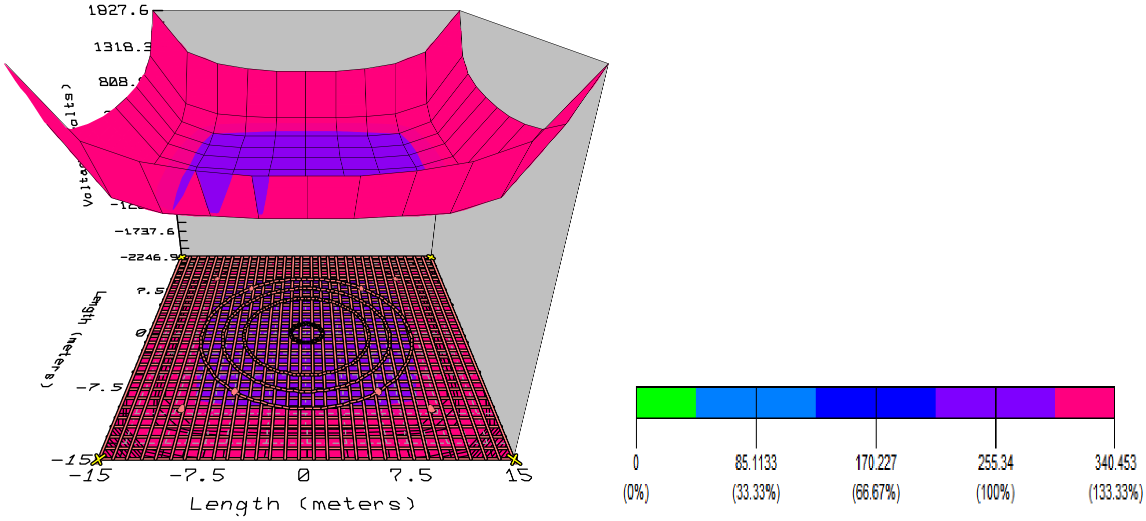
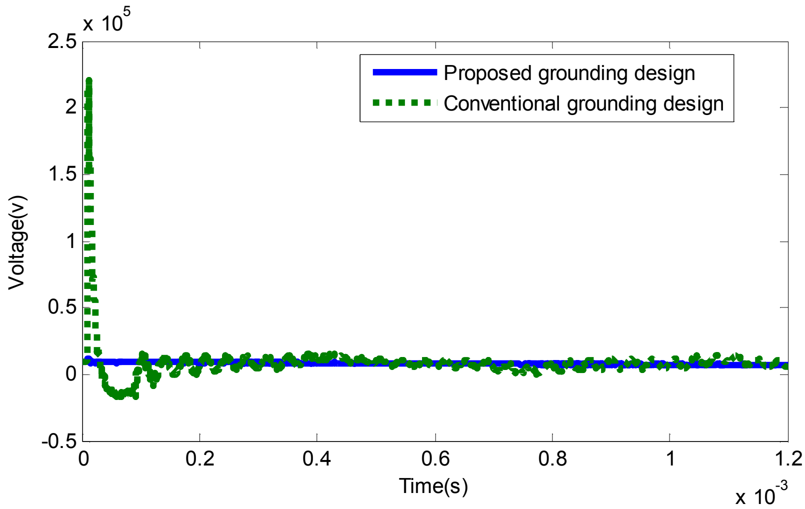
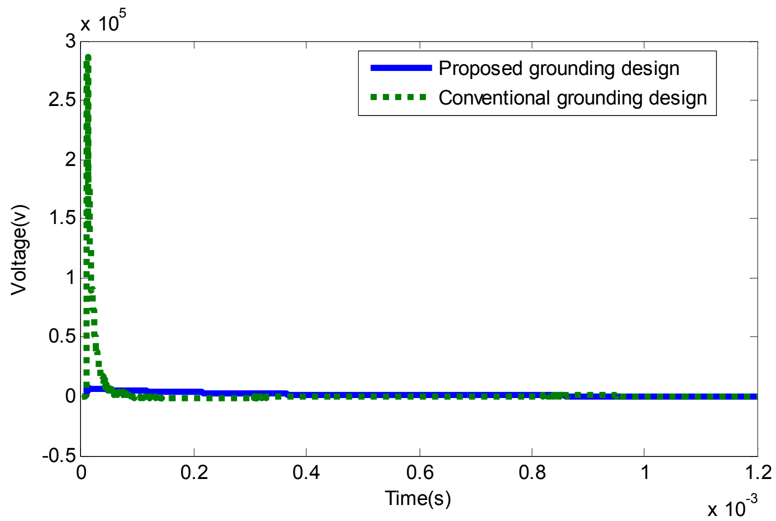


Fig. 12 Touch potential distribution of proposed grounding grid design



(a) Voltage waveforms Comparison at WT#1



(b) GPR waveforms Comparison at WT#1

Fig. 13 Overvoltages, GPR at lightning struck turbine under different grounding arrangements

VII. CONCLUSION

In practical use a combined types of electrodes in grounding grid is widely applicable. In fact, it is difficult to estimate correctly a grounding resistance value of an arbitrary electrode with a complex shape. So numerical calculations including the Finite Element Method FEM are important to calculate the grounding electrode resistance and design an accurate grounding system for LPS.

In this paper, a proper design improvements for grounding grid, which have a high earth resistance and small area for grounding grid.

Also, proposed procedure of proper design of grounding systems for a wind turbine with the help of the software package CYMGRD and ATP-EMTP was introduced. Conventional and proposed Grounding system enhancements are compared in terms of their ability to reduce potentially hazardous touch potentials. Computation, characteristics and hazards of back-flow surge in onshore wind farm are analyzed under Conventional and proposed Grounding system. The results show that the overvoltage is reduced by about 95% and GPR is decreased by about 97% when using the proposed design of the grounding system

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