WIND FARM EARTHING

Maria Lorentzou*, Ian Cotton**, Nikos Hatziargyriou*, Nick Jenkins**

INTRODUCTION

A windfarm, as any other electrical system, must be earthed to provide a low impedance connection between the electrical equipment and the general mass of the ground, to provide a reference potential for electrical equipment in order to ensure the effective operation of protective devices, and prevent excessive overvoltages and potential gradients that may cause damage to equipment or threaten human life.

Although the same grounding system is normally used for protection against both power system faults and lightning strikes, the response to either energisation source is dramatically different owing to the high frequency components contained in lightning current. Lightning current is considered to have an average rise time of 5.5μs and a time to half value of 75μs with a peak current of 30kA [1]. This fast rise time results in high frequency components being injected into the grounding system. The grounding system inductance, significant in relation to the resistance for a large grounding system, causes these high frequency components to increase the total grounding impedance owing to the change in inductive reactance.

Standard methods to determine the impedance of a grounding system based on simple formulae are unsuitable for windfarms owing to the large distances they span. This paper examines the use of computer modelling to assess the suitability of windfarm grounding systems for protection against power system faults and lightning strikes. The transient behaviour of practical earthing system designs are presented using the general purpose program EMTP (Electro Magnetics Transient Program) [2] and a specialist grounding software, CDEGS (Current Distribution, Electromagnetic fields, Grounding and Soil structure analysis) [3].

TYPICAL WINDFARM EARTHING METHODS

The grounding of a single wind turbine is normally achieved by placing a ring electrode around the foundation and bonding it through the foundation to the turbine tower. The foundation reinforcement bar is also connected directly or via the turbine tower to the ring electrode and will be effective in acting as a ground electrode since the surrounding concrete can be considered to have a resistivity equal to that of the surrounding soil (fig. 1). However, in relevant calculations it is normally ignored to provide a worst case analysis of the grounding system.

Vertical rods or strip electrodes (horizontal electrodes) are often used in conjunction with this ring electrode to achieve a certain value of ground resistance. A resistance of 10Ω or less (before it is connected to any other system) is stated in international standards/recommendations as being suitable for lightning protection purposes.

A wind turbine typically contains an induction machine generator supplying a grounded star transformer winding at approximately 700V or less (e.g. 630 V or 380 V). The high voltage side of the local turbine transformer is wound in delta and is connected to the windfarm distribution cable. The windfarm cable system is then normally connected to a star transformer winding or equivalent at the windfarm substation. The individual wind turbine grounds are therefore usually connected by the metallic screen or armour of the main power cable running between the turbines. This has the effect of reducing the overall site ground impedance to a low value, often 1-2Ω. Where the windfarm is sited in

* National Technical University of Athens, 42 Patission Street, 10682 Athens, Greece
** The Manchester Centre for Electrical Energy, UMIST, PO Box 88, Manchester, M60 1QD

an area of high soil resistivity, each turbine ground may be connected by a strip electrode in addition to the connection provided by the power cable screen/armour (fig.2).

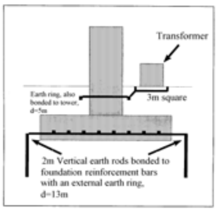

Figure 1

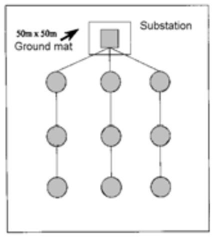

Figure 2

Lightning strikes to a wind turbine will raise the local ground potential resulting in large differential voltages between the power cable phase conductors and armour/screen as well as the high voltage winding on the wind turbine transformer and the grounded case/low voltage winding. This differential voltage may be able to break down either the cable or transformer winding insulation and damage that piece of equipment. The lower the grounding impedance, the lower the voltage rise produced by the lightning strike leading to a lower likelihood of insulation breakdown.

EXAMPLES OF PRACTICAL WINDFARM EARTHING SYSTEMS

Single Turbine

The response of the earthing system of a small (100 kW) wind turbine situated on the Greek island on Lemnos for a lightning strike calculated by EMTP and CDEGS is shown in Figs. 3 and 4, respectively.

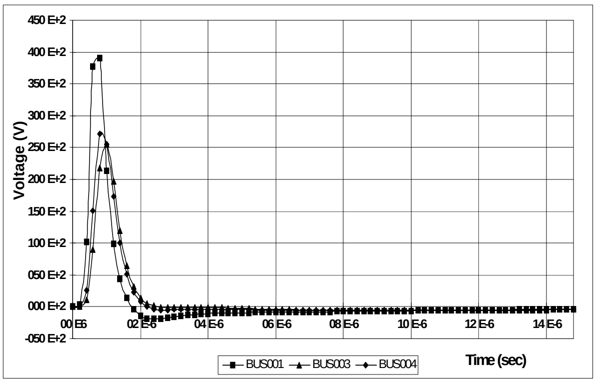

Figure 3: Calculation of response using EMTP (transmission line model)

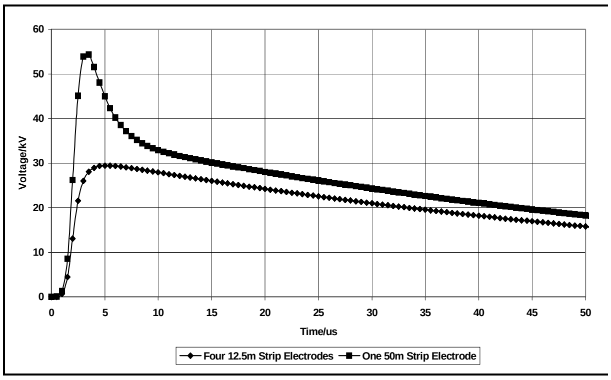

Figure 4: Effect of short strip electrodes (lower plot) in comparison to longer lengths (upper plot) on reducing the maximum lightning voltage rise using CDEGS

The computed ground resistance of the above system is 5.8Ω when the grounding system is situated in 100Ωm soil (a low soil resistivity). An energisation current of 1kA at 50Hz results in a maximum voltage of 5.8kV as expected. Similarly, the injection of a 5.5/70μs lightning wave with a peak current of 30kA results in a peak voltage of 174kV, the value expected for a purely resistive grounding system.

When a 50m long conductor is attached to the turbine base, the resistance is now calculated as 1.2Ω. The same injection of 30kA peak lightning current as before results, however, in a peak voltage of 54kV. This would suggest a grounding resistance of 1.8Ω. This difference is caused by the high inductive reactance seen by the high frequency components of the lightning wave. This has been produced by the inductance present in such a distributed grounding system.

If the 50m electrode had been split into four 12.5m sections and attached to the four corners of the grounding system a lower ratio of inductance to resistance is achieved. The resistance of this arrangement is 0.98Ω and the peak lightning voltage is 29kV, the value expected when injecting the current into a pure resistance. By using four short strip electrodes as opposed to one long strip electrode, the grounding design has been improved.

Two Interconnected Wind Turbines

As previously shown, the use of the earthing system resistance to estimate the GPR at a point following a lightning strike is inaccurate. This is more clearly shown in the case of two windturbines connected with strip electrode. As a further example of this consider a system in 1000Ωm resistivity soil consisting of two turbine bases situated a distance of 100m apart with the grounding systems connected by strip electrode. The computed resistance of the network is 18.59Ω and the maximum voltage rise for an injection of 1A at 50Hz is 18.59V.

An injection of a lightning current with peak current of 30kA results in a maximum voltage of 868kV at the injection point (fig.5). This can be compared to a voltage of 558kV that would be expected if the same current has been injected into the 18.59Ω resistance. The voltage waveform produced at the base of the first wind turbine is shown in Fig. 5 along with the waveform expected had the same current being injected into a pure resistance. Note that the inductance increases the peak voltage and changes the time to peak.

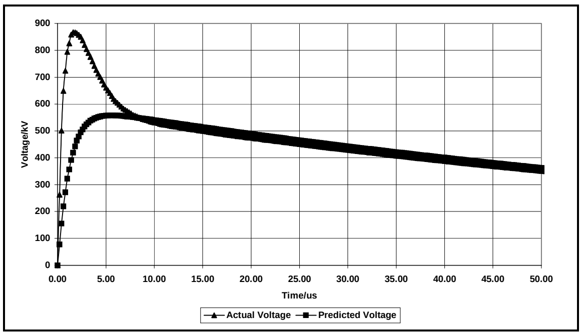

Figure 5 - Voltage waveform following lightning current injection into resistance only (lower plot) compared with impedance (upper plot)

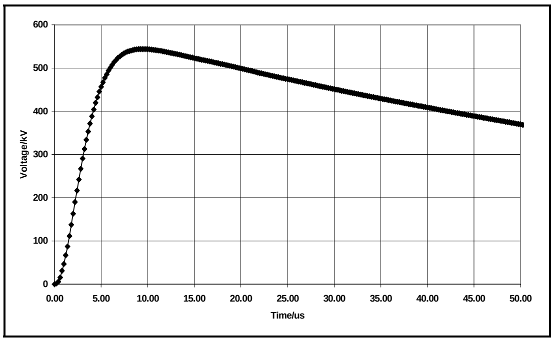

Figure 6 - Voltage at the turbine remote from the injection point.

If the windfarm substation is assumed to be at a remote point and the high voltage system is grounded there, an overvoltage of 868kV will be present between the high voltage transformer winding and the locally grounded case/low voltage winding possibly leading to damage. The ground potential at the second wind turbine, 100m away will also rise to a value over 500kV due to the injection of lightning current, as shown in. The slower time to peak and smoother waveform than that seen at turbine one is another consequence of the relatively high level of inductive reactance present in the system.

ACKNOWLEDGEMENTS

The work was partially supported by the European Commission, under DG XII Non-nuclear energy Programme, contract nr. JOR3-CT95-0052

REFERENCES

[1] M A Uman, 'The Lightning Discharge', Academic Press, 1987
[2] EMTP Theory Book, BPA, 1986.
[3]F P Dawalibi et al, 'Transient Performance of Substation Structures and Associated Grounding Systems', IEEE Trans. on Industry Applications, Vol. 31, No. 3, May/June, 1995.