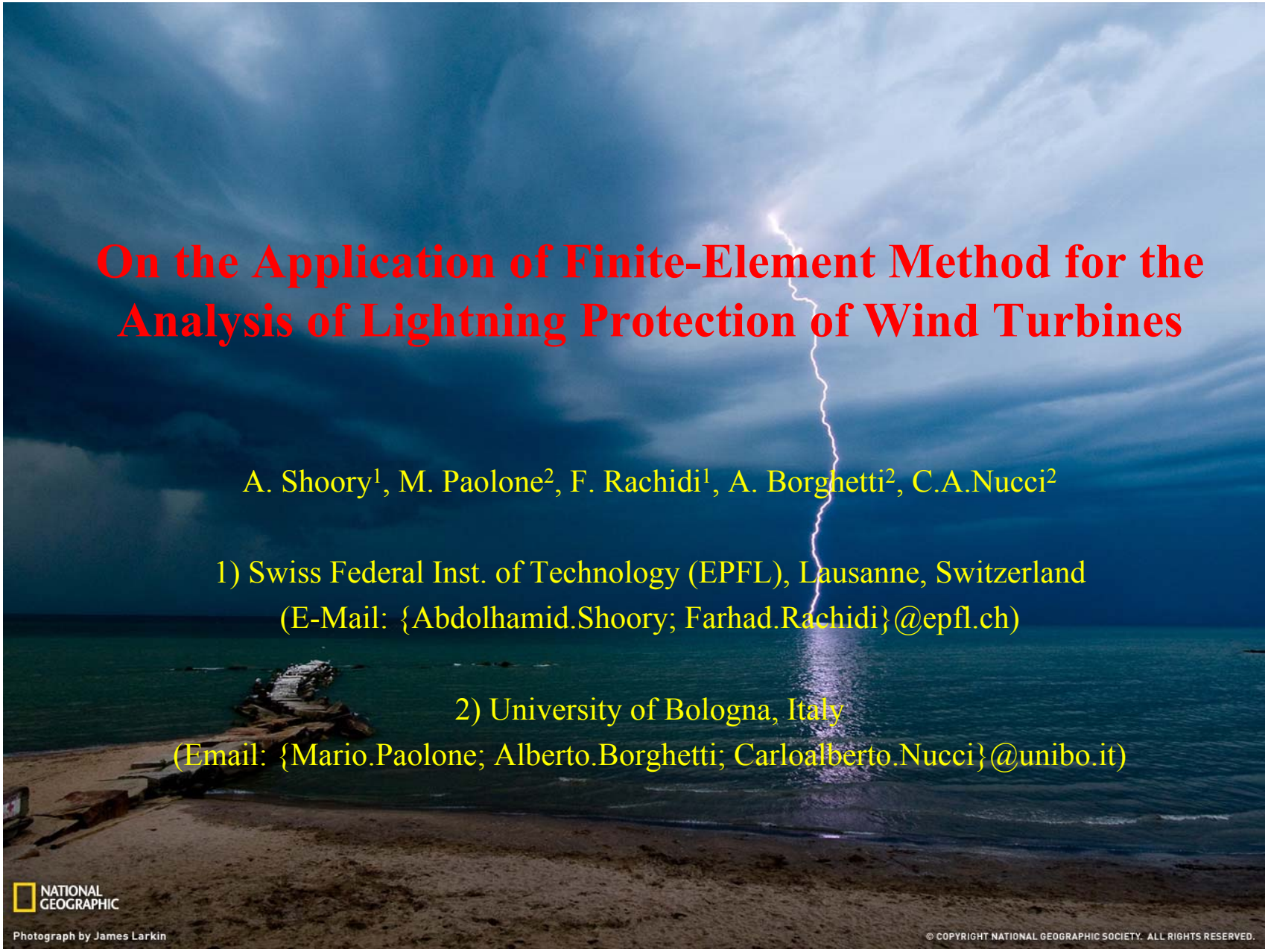


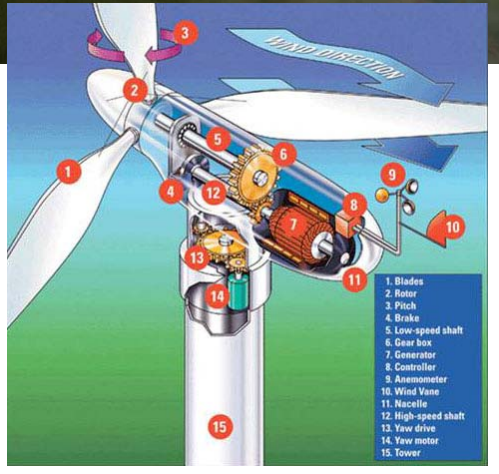
On the Application of Finite-Element Method for the Analysis of Lightning Protection of Wind Turbines

A. Shoory[1], M. Paolone[2], F. Rachidi[1], A. Borghetti[2], C.A.Nucci[2]

1) Swiss Federal Inst. of Technology (EPFL), Lausanne, Switzerland
(E-Mail: {Abdolhamid.Shoory; Farhad.Rachidi}@epfl.ch)

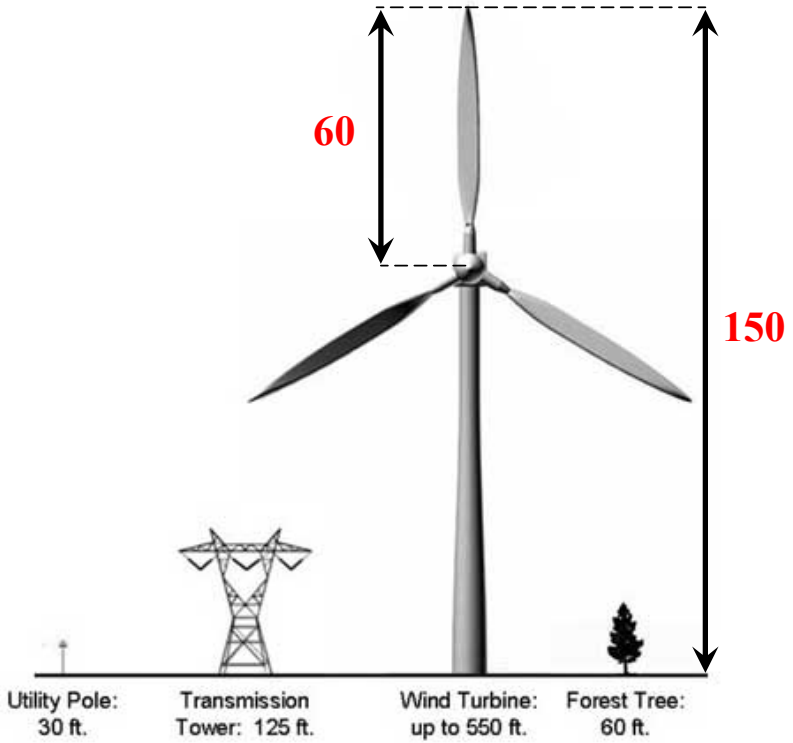
2) University of Bologna, Italy
(Email: {Mario.Paolone; Alberto.Borghetti; Carloalberto.Nucci}@unibo.it)

Wind Turbines and Lightning



- Between 4% and 8% of European wind turbines are damaged by lightning every year [*Rachidi et al 2008*].
- Lightning protection of traditional wind turbines are addressed in related standards [*IEC 62305-1 & 62305-4, 2006*].
- Modern wind turbines are also **more complex**.

Tall Modern Wind Turbines

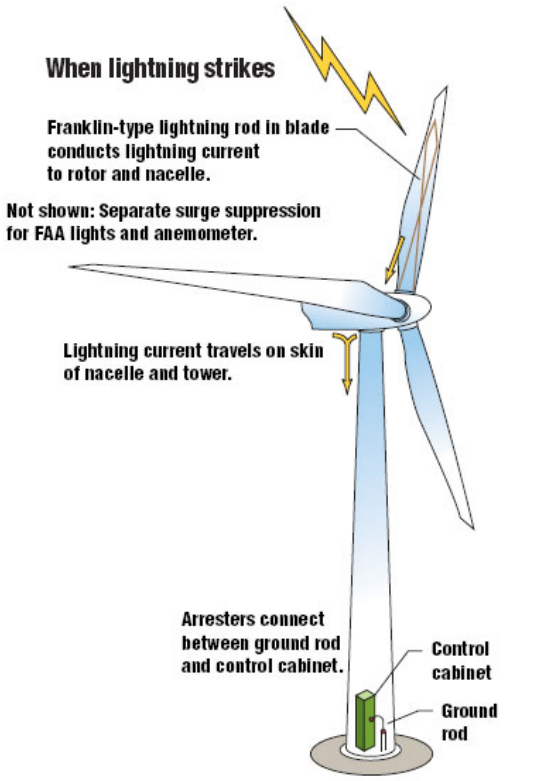


- Modern wind turbines are **higher** and are then **more vulnerable to lightning**.

Composite Materials in Modern Wind Turbines

- carbon-reinforced-plastic (CRP) laminates are being extensively used to reinforce the blades.
- Lightweight, strong, good fatigue characteristics.

CRPs and Lightning Protection

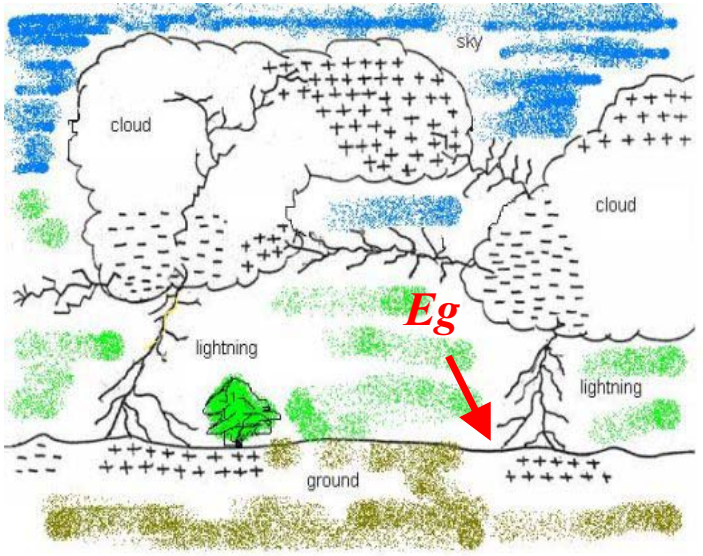


- CRPs are assumed to be as electrical conductors [*IEC 61400-24*].
- It is recommended to bond them to other conducting components for lightning protection [*IEC 61400-24*].

Issues to be Responded

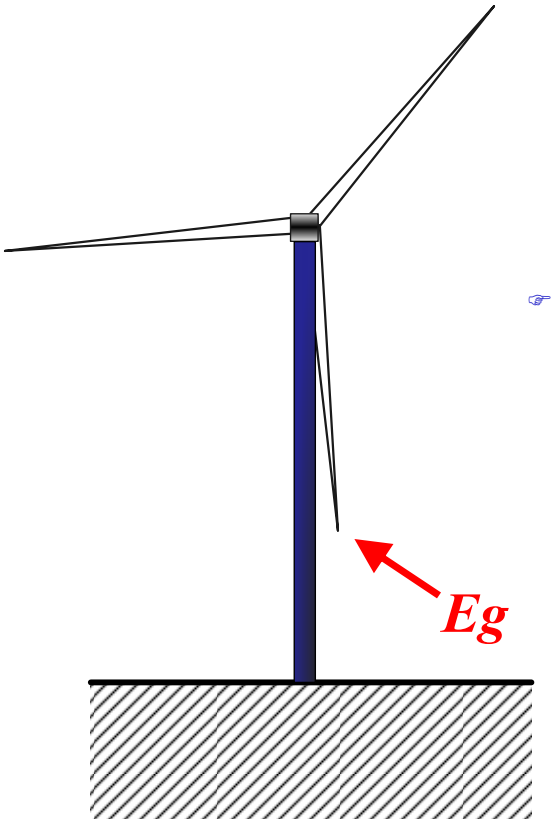
- Are CRP components able to conduct lightning current without being damaged?
- Should the bonding between CRP and LPS be made?

Static Electric Fields Under Thunderclouds

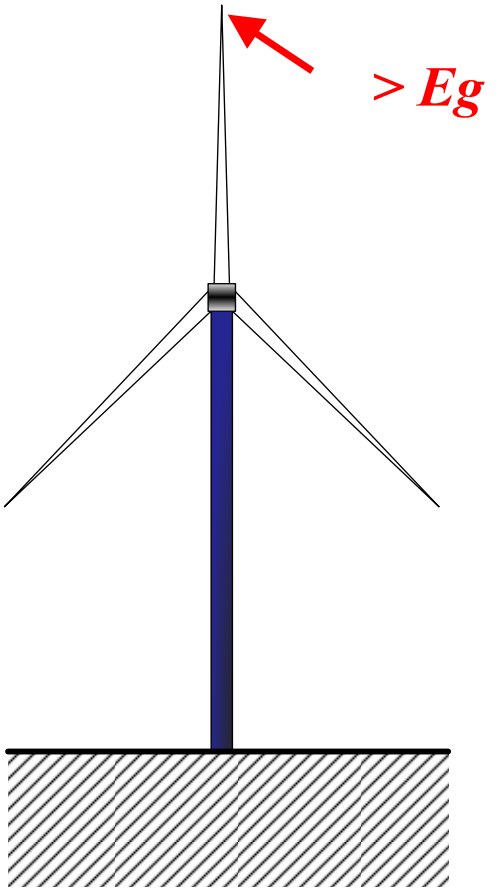


- $E_g = -5$ to -15 kV/m

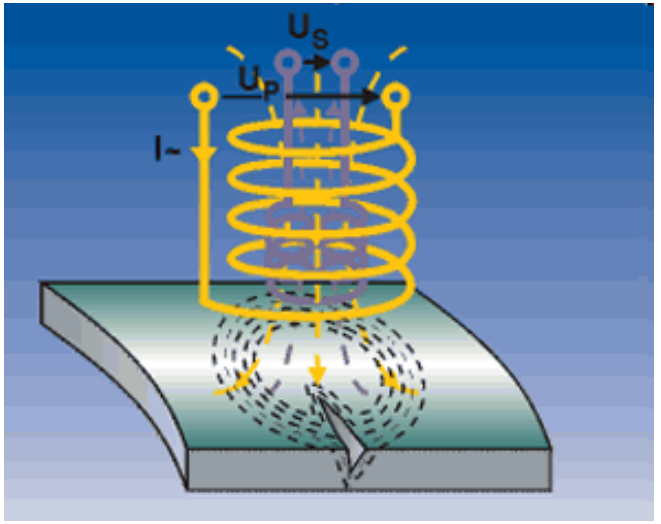
CRPs and Static Electric Fields



- Field enhancement and variation of electric field at the tip of the blades

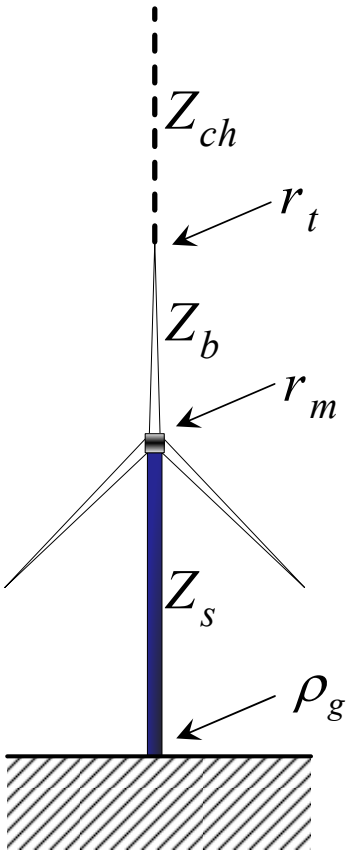


CRPs and Eddy Currents



- The mechanical stress resulting from the energy dissipation in CRP laminates due to the circulation of eddy currents is another problem [*Rachidi et al 2008*].

Wind Turbine and Lightning Currents

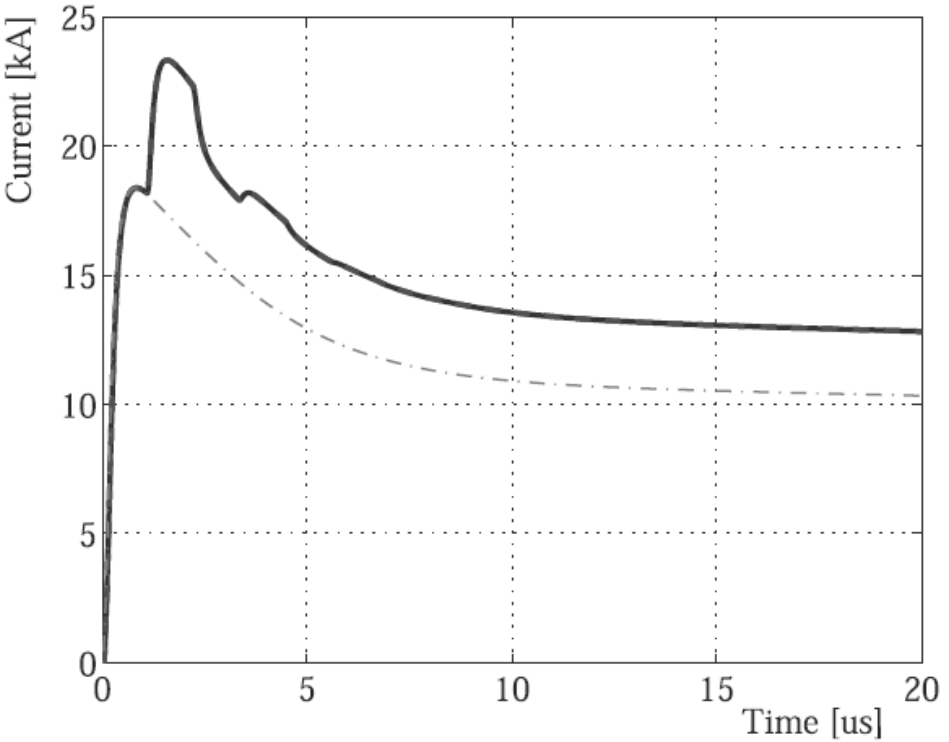


- The injected lightning currents by return strokes into the turbines are affected by reflections at the **top**, **bottom**, and **junction of the blades with the static base** of the turbine [*Rachidi et al 2008*].

- The reflection coefficient are functions of **electrical** and **geometrical** parameters of blades, hub, base, etc.

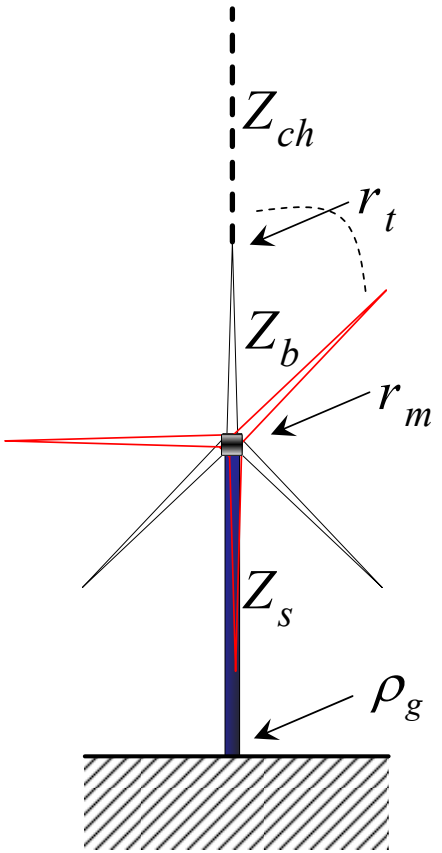
Reflections at Extremities of Tall Structure

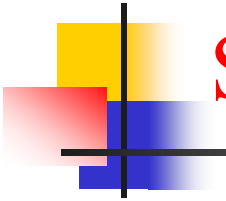
- Disturbed and undisturbed current at the top of a 168 m tower [*Bermudez et al., 2003*]



Rotation of Blades

- The angle can vary from one stroke to another within a flash and introduces another level of complexity.

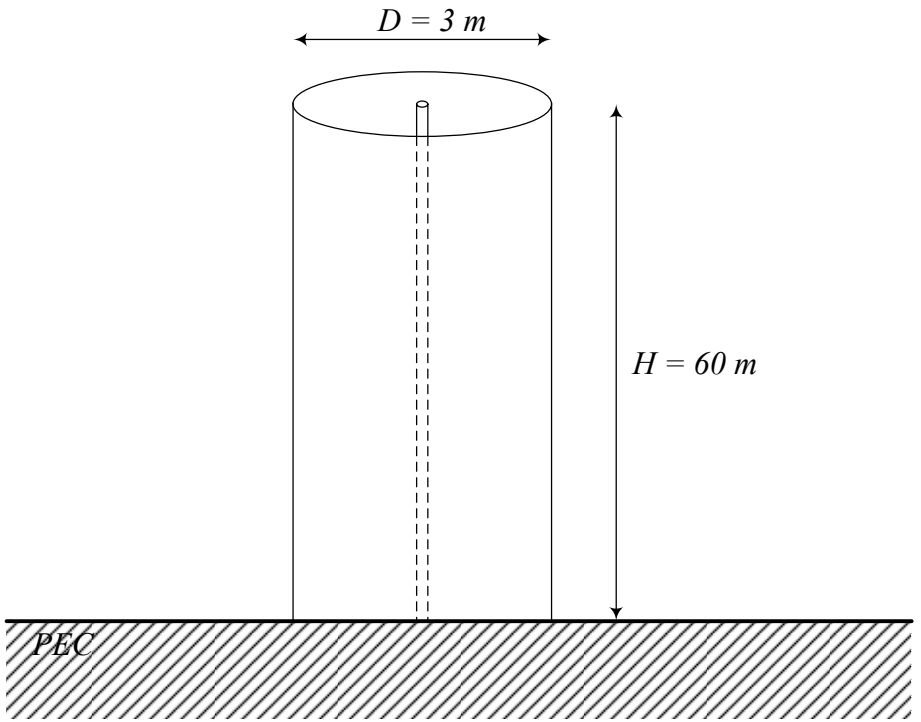




Simulation Requirements

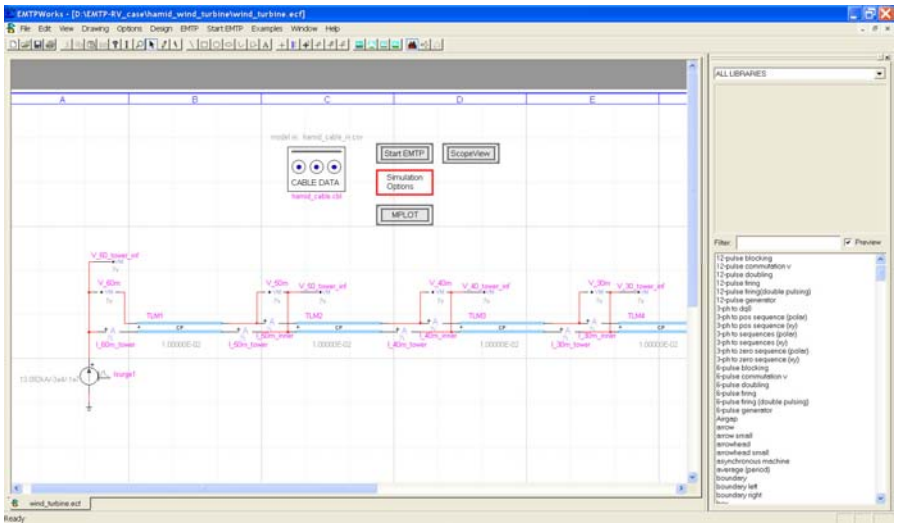
- Complex electromagnetic wave propagation due to the presence of **different conducting materials**.
- **Heating of composite** materials due to the circulation of high eddy currents.
- **Mechanical stress** due to the circulation of eddy currents.

Case Study



- The complex structure of the wind turbine is simplified to a model consisting of two concentric conducting cylinders.
- The outer represents the base and the inner represents one of the cables (0.02 m radius).
- For simplicity, blades are not included in the model.
- Both base and cable are connected to the ground.

EMTP

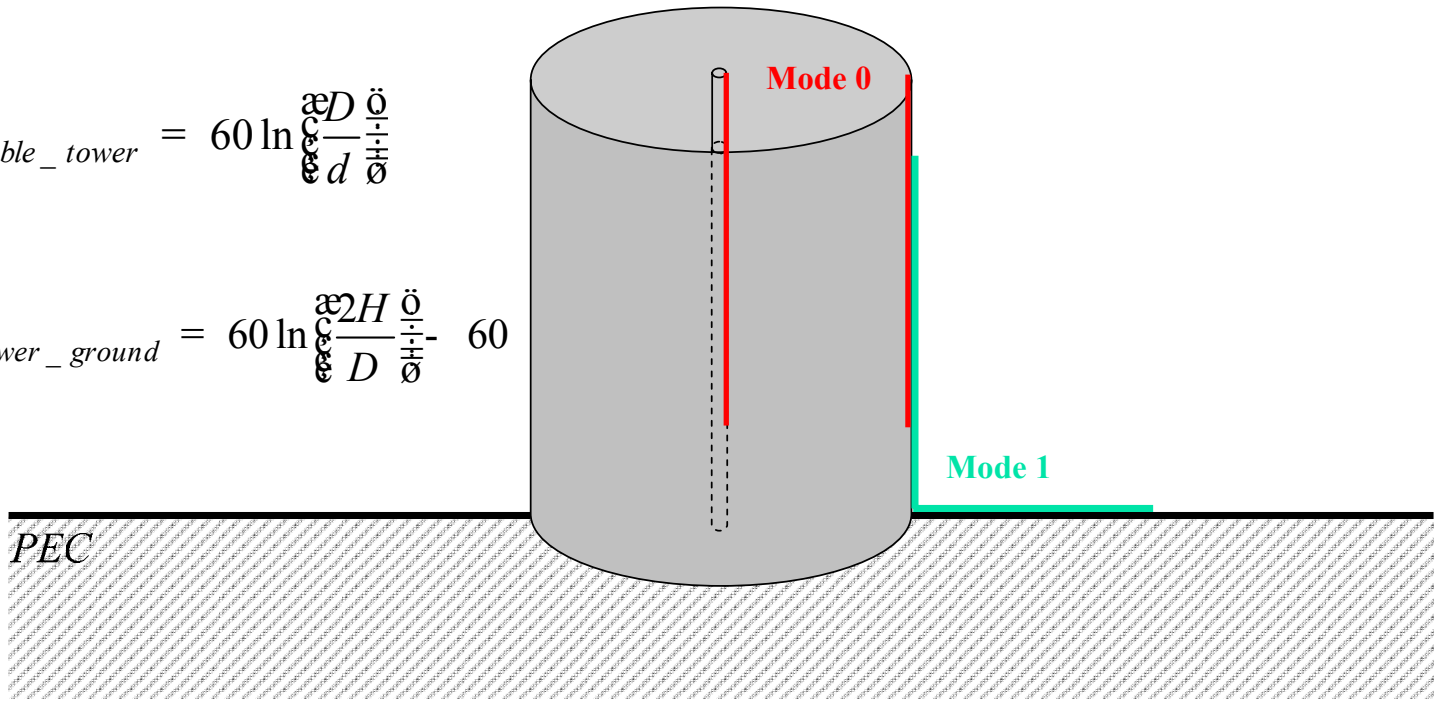


- EMTP, based on transmission line equations, solves the transient wave propagation phenomena.
- EMTP is computationally efficient (☺).

Modeling Using the EMTP

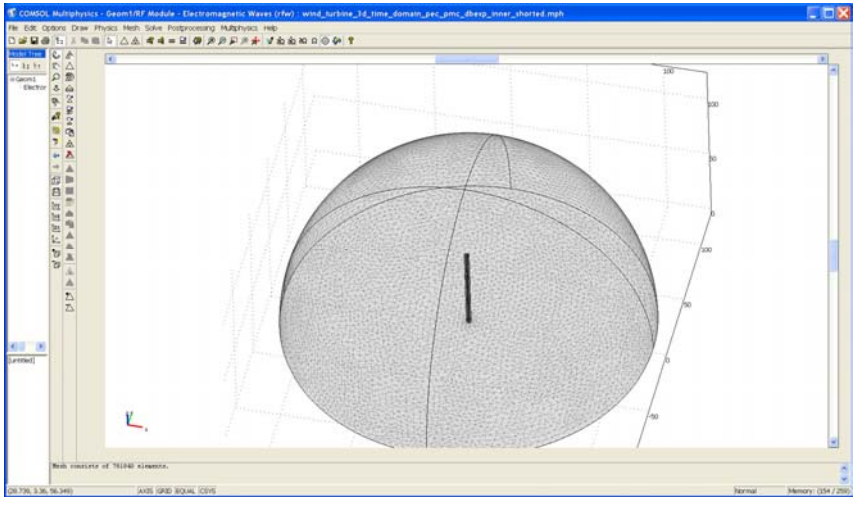
$$Z_{cable\_tower} = 60 \ln\left(\frac{D}{d}\right)$$

$$Z_{tower\_ground} = 60 \ln\left(\frac{2H}{D}\right) - 60$$



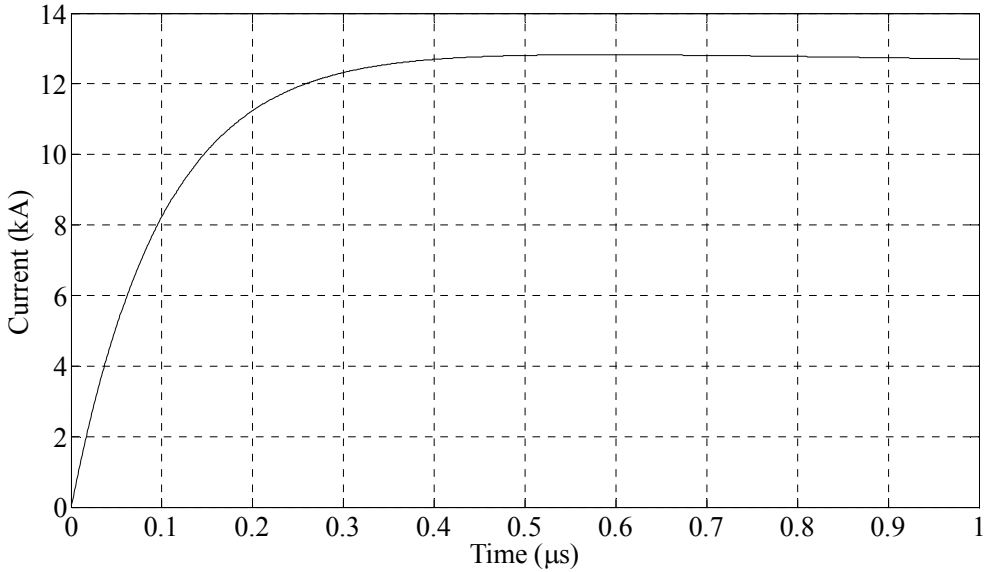
COMSOL

- COMSOL solves the transient wave equations in a complex structure using the FEM-TD.
- It solves different aspects of physics like electro-thermal interaction within a single solution.
- COMSOL is computationally very expensive (☹).

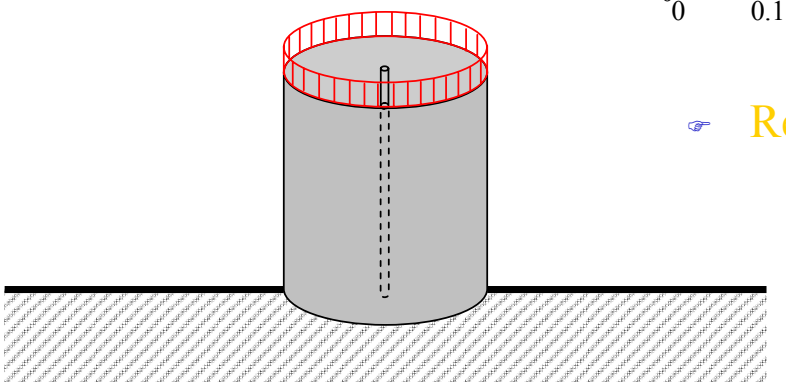


Excitation

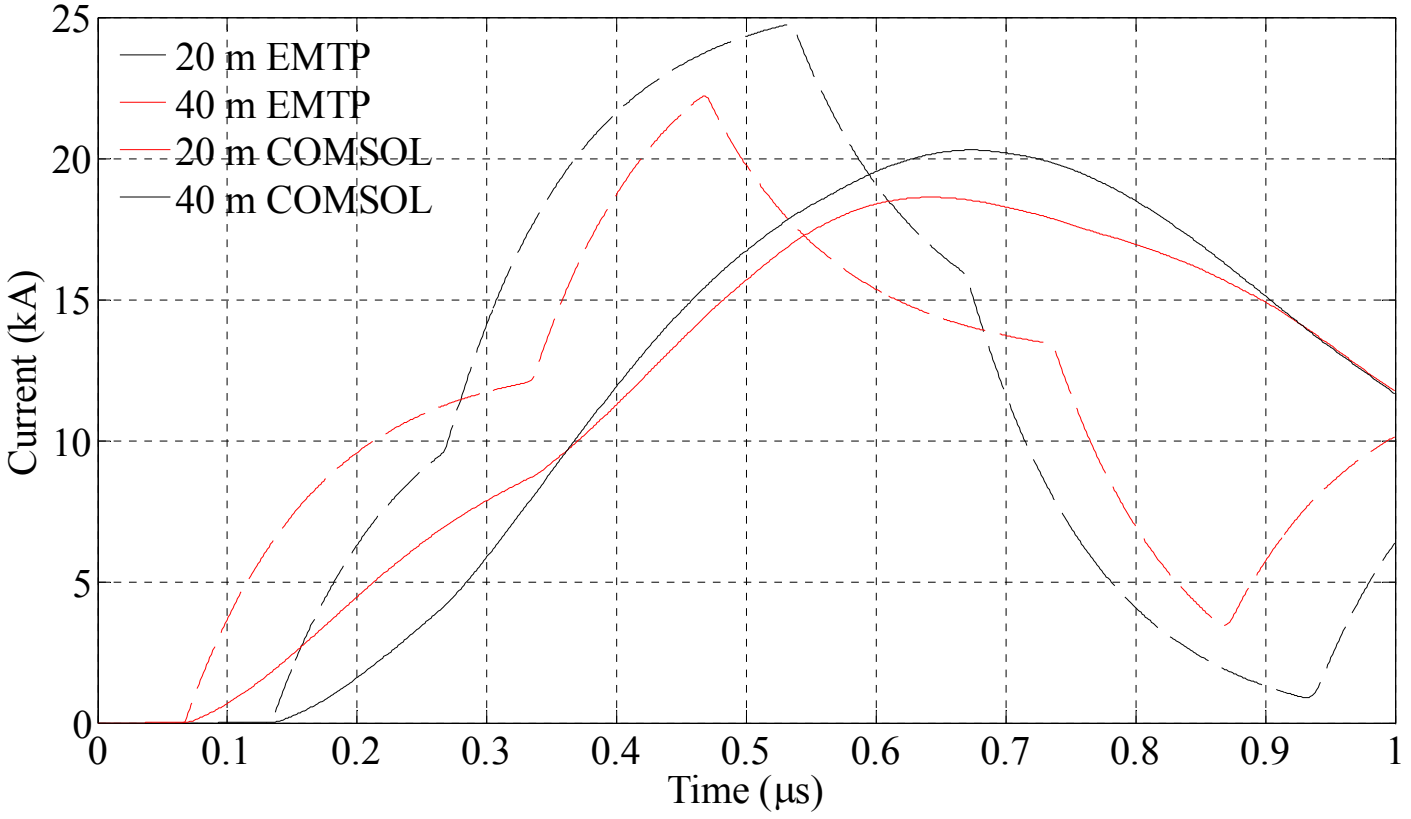
- A current source at the top of the base represents the lightning current injection.



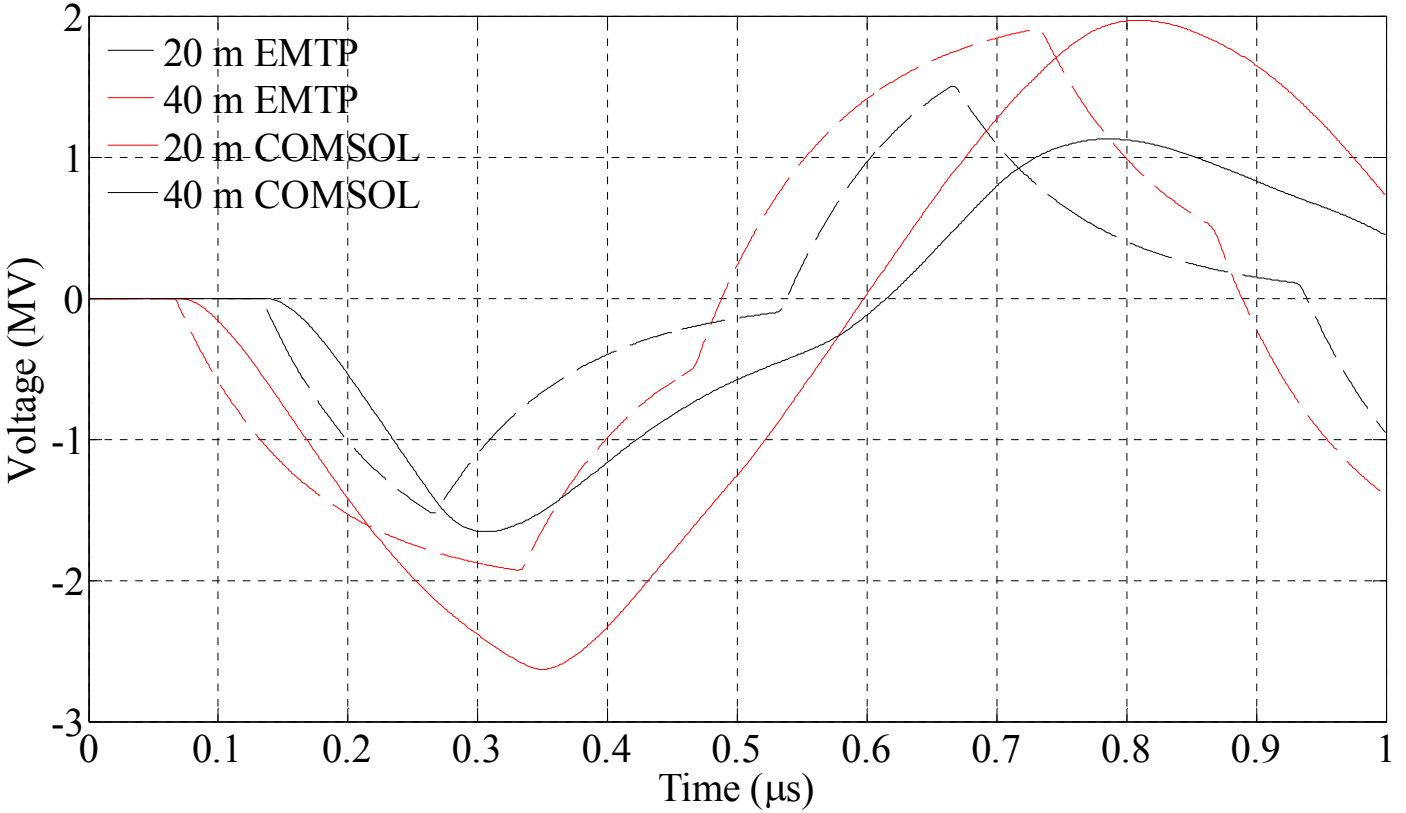
- Representing subsequent return stroke current



Current Along the Base



Voltage Between Inner Cable and Base

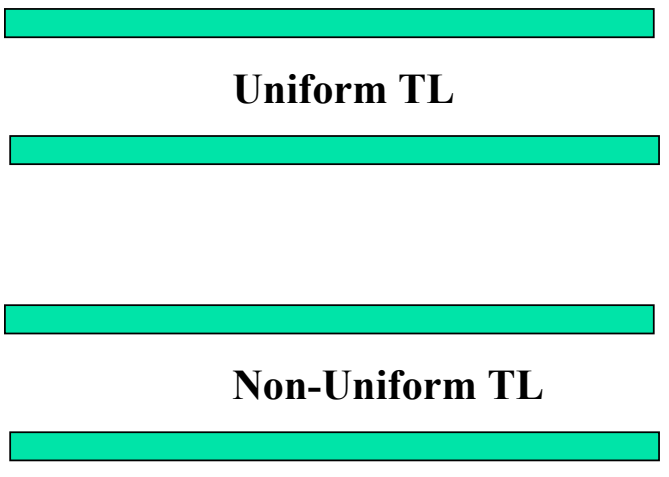


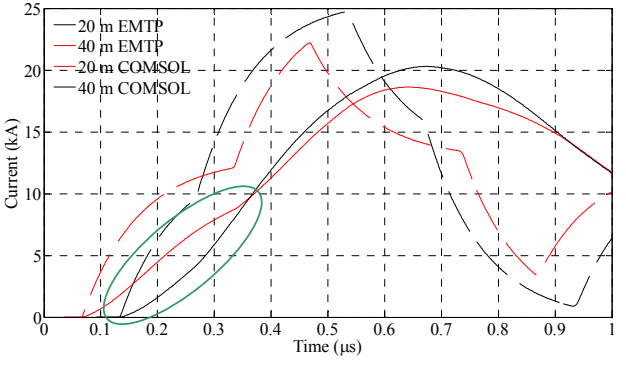
Remarks (☺)

- There are some differences in the amplitudes of the currents and voltage waves predicted using COMSOL and EMTP
- If Concern is current and voltage peak, EMTP can be probably used with some modifications.

Remarks (☺😐☹) Dispersions

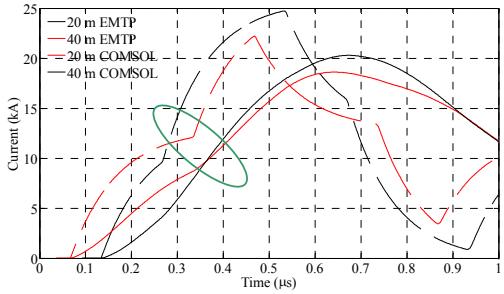
- Voltage and current waves predicted by COMSOL are strongly suffering from dispersion.

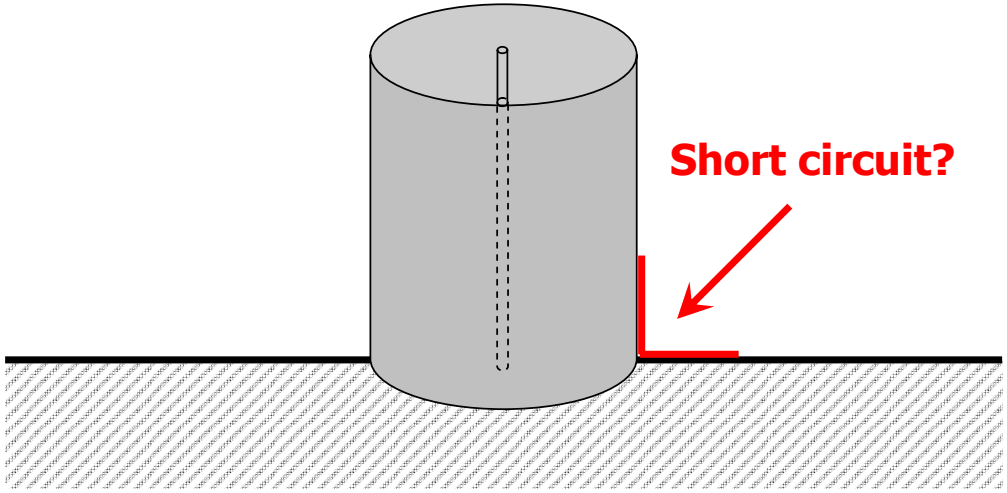


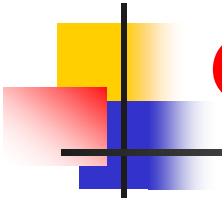


Remarks (☺😐☹)
Ground Reflections

- Is the junction between the mast and ground a real short circuit junction as assumed in the EMTP model?
- What is the value of reflection coefficient at ground [*Bermudez et al, 2003*]?

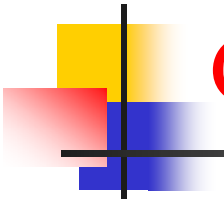






Conclusions (1)

- Interaction of lightning with modern wind turbines is a multiphysics phenomena.
- The whole multiphysics problem should be solved in a single solution.
- EMTP and similar techniques are inadequate in modeling of such a multiphysics problem.



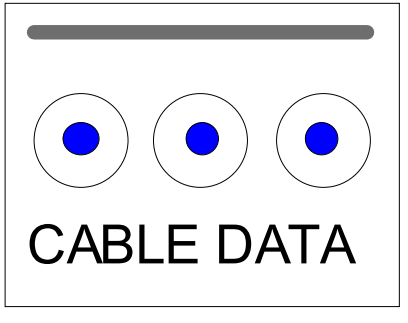
Conclusions (2)

- If the peak of base current is the main concern, EMTP can be used with some modifications.
- Some clarifications are needed to explain the wave propagation in such a complex problem e.g., the ground reflection coefficient and dispersion phenomena.

EMTP Model

- Single core underground cable (Cable) is used to model the two concentric conductors.

model in: hamid_cable_rv.csv



hamid_cable.cbl

EMTP Model

- Transmission line is modeled using the constant parameter (CP) line model.