Windmills WIPL-D EM Simulations

Introduction

WIPL-D is a well-known **commercial tool for fast and accurate full wave EM simulation**. The underlying numerical method is the Method of Moments (MoM) based on unique higher order basis functions (HOBFs) which **allows mesh elements to extend up to 2 lambdas, in contrast to widely used low order methods** where the mesh size is typically a fraction of a lambda. Other distinguished features, such as usage of **quad mesh elements** (instead of commonly used triangular elements), efficient usage of **CPU and GPU resources**, profound knowledge and extensive experience of WIPL-D Team in regard to demanding EM simulations, make WIPL-D suite the ultimate product for EM simulations of electrically large structures.

Typically, EM simulation complexity is measured in total number of mesh elements. However, a more natural term for MoM simulations is the unknown. To compare WIPL-D Pro with competing products, a number of unknowns should be multiplied 3-10 times. As a result, **WIPL-D is able to simulate structures which are hundreds of wavelengths large**. Prediction of number of unknowns is simple. Surface of object in square wavelengths should be multiplied by 30 for metallic objects or by 60 for dielectric surfaces. **In the majority of simulations, the number of unknowns can be reduced locally**, i.e. at the parts of the model insignificant for EM simulations.

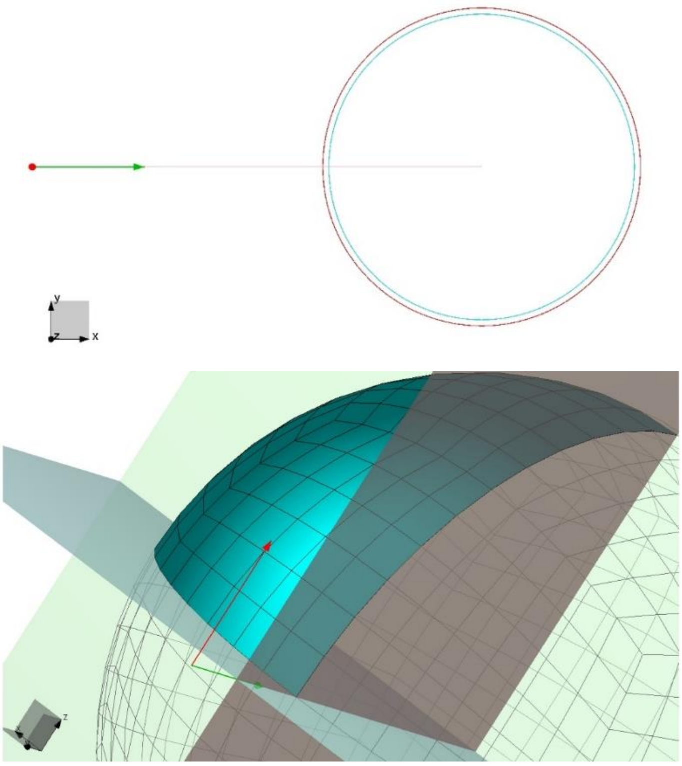
A large windmill tower could be considered as an unimaginable subject for EM simulations, but it remains within the reach of WIPL-D as it can be used even there for accurate 3D full wave EM simulations. Models of windmills or similar structures are usually provided **as CAD files in a standard format that can be imported into WIPL-D Pro CAD.** A variety of features is available to easily **repair the models and simplify the model** to avoid details insignificant for EM simulations. Finally, the **automated meshing** is executed using in-house developed quad meshing. The quad mesher takes into account small details and curvatures. It accurately resembles original geometry, using quad patches as large as possible (2 lambdas for HOBF and 10 lambdas for Ultra HOBF).

However, even heavily reduced due to many unique features of the program, the size of EM problem for such structures is still very large and challenging. **A windmill typical geometry requires 3 parts for simulation: mast, nacelle and blades**. In majority of cases, the result of interest is near behind coated large windmill, the so-called **shadow region**.

The first and most basic approximation can be to consider either nacelle or mast as infinite cylinders and to simulate their cross section in **WIPL-D 2D Solver**. Such simulations are not demanding, can be run at a **standard PC** in just a couple of seconds or minutes.

2D Solver Simulations

Simplified scenario assumes that nacelle of wind turbine is assumed to be sphere. The aim is to illustrate the effects of using a coating material over a metal surface. Such simulation can be 2D or 3D problem. The problem can be solved in **WIPL-D Pro 2D EM solver** (as infinite cylinder) or in **WIPL-D Pro 3D EM solver** (as sphere). On one side, 2D solver simulation is fast, with simulations performed in seconds, but on the other side, a full wave 3D EM simulation includes all the EM effects and therefore is more accurate.



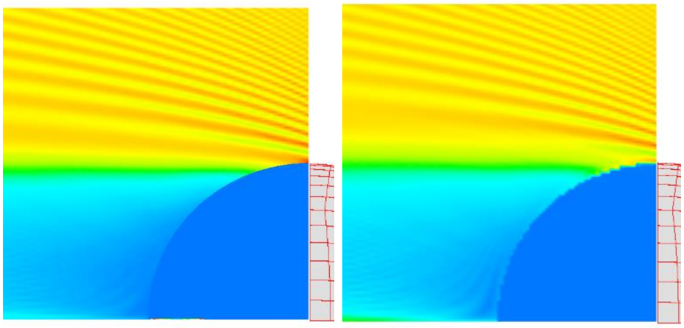
2D (up) and 3D (below) models of nacelle

Two simulations are carried out to demonstrate high efficiency of WIPL-D MoM implementations. **The first is PEC sphere and the second is PEC sphere coated with thin sheet of resistive material.**

The simulation is carried out as RCS problem of 5 m diameter PEC sphere. This is simpler problem, compared to sphere covered with 1 mm thick coating layer. Material is dielectric with permittivity 2-j2. **The result of interest is near field in the zone immediately behind the sphere, but in principle, field can be evaluated at any distance from the sphere** (shadow region). The effects of coating are most imminent at the diffraction edge.

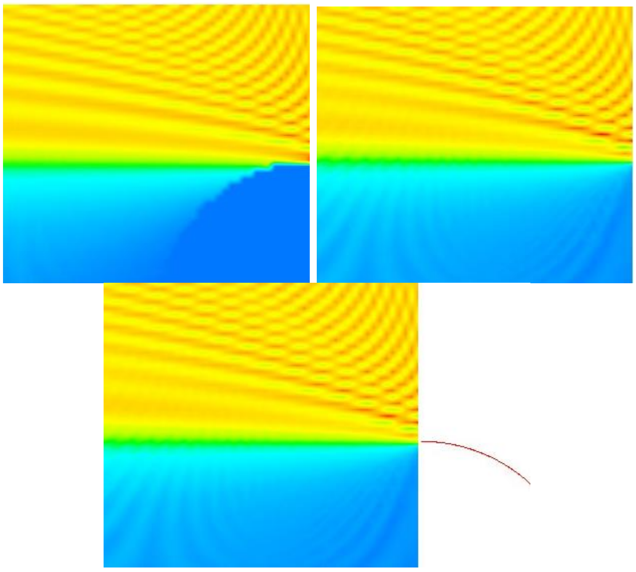
The first set of results is obtained using 3D solver. These include the near field behind large sphere for PEC and coated case. The requirements are low. PEC sphere model is simulated with approximately 30,000 WIPL-D unknowns, coated sphere model around 90,000. 3 symmetry planes are applied, which reduces number of unknowns 8 times.

The simulation times are minimal, **a couple of minutes for PEC sphere**, while **coated model is solved in 1 hour** (on **any desktop PC equipped with inexpensive GPU card** such as Nvidia GTX 1080 Ti).



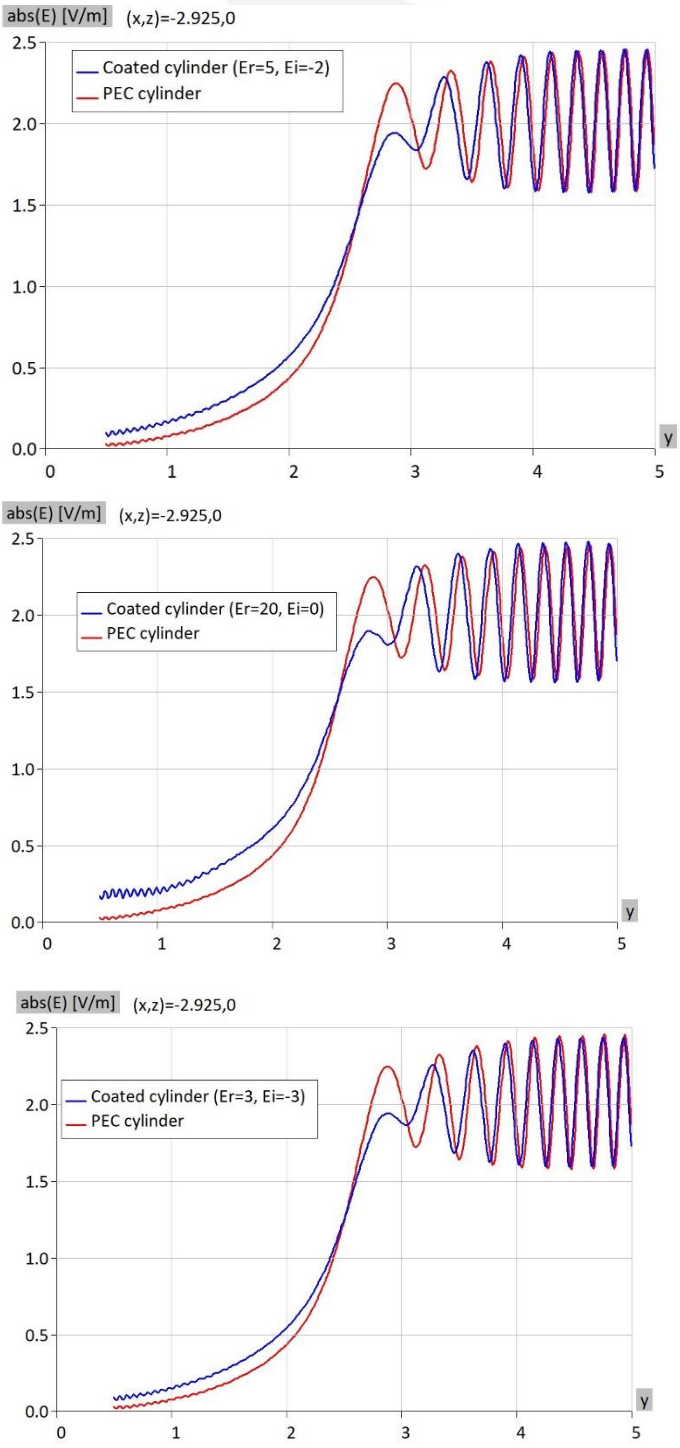
Near field behind PEC (left) and coated (right) sphere

The 2D solver simulations are practically trivial. They last a couple of seconds and require less than 5,000 (4,225 unknowns for dielectric with Er=20). The first near field is the same as for the 3D solver. From top to bottom, left to right: PEC sphere, coated with 1 m thick Er=20, and at the end 1 mm thick 3-j3.



2D Solver results for three different scenarios

Since the simulations are practically instantaneous, we simulate near field right behind the sphere with three different materials.



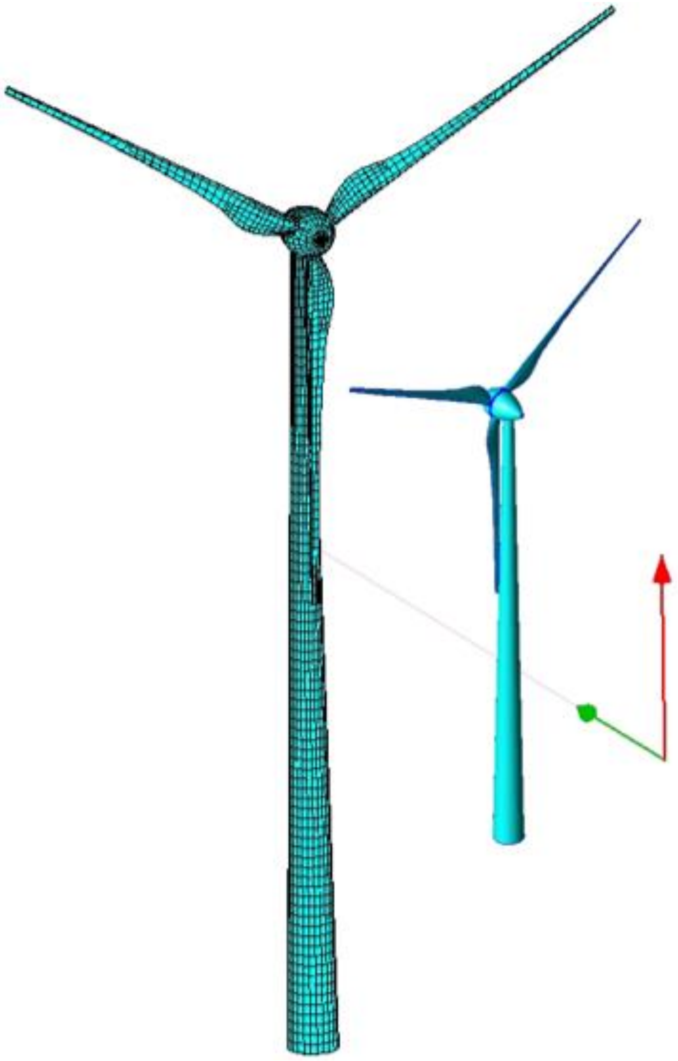
Near field behind coated sphere for 3 different materials

MoM and DDS Simulations

The next step is more difficult as it aims towards full scale windmill simulations. The figure below shows **realistic CAD model of large windmill**, as well as model meshed for simulation at 3 GHz. To simplify, we first simulate mast only.

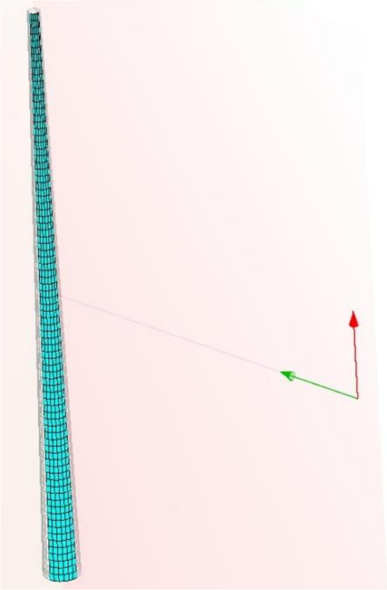
The first set of simulations are quick MoM simulations. Since full-wave MoM simulations are tremendously demanding, we focus to **wind turbine mast at 3 GHz**. The simulation is run by using full-wave higher order MoM solver.

Application of 2 symmetry planes reduces number of unknowns significantly to 230,000. Reduction of reference frequency, which is set up using a single click, shrinks the number of unknowns further, down to 140,000. Thanks to all of the reductions applied, the simulation times are ultra-short, around 30 minutes. In this case the full model has 230,000 unknowns are requires the simulation time around 1 hour. **The hardware of the workstation used for computations is as follows**: Intel® Xeon® Gold 5118 CPU @ 2.30 GHz (2 processors, 12 cores each) with 192 GB RAM and four NVIDIA GeForce GTX 1080 Ti GPU cards. The GPU cards are used for matrix inversion. The other operations are performed on CPU. The GPU cards require 5 SSD 2 TB discs for exploiting major part of their compute power.



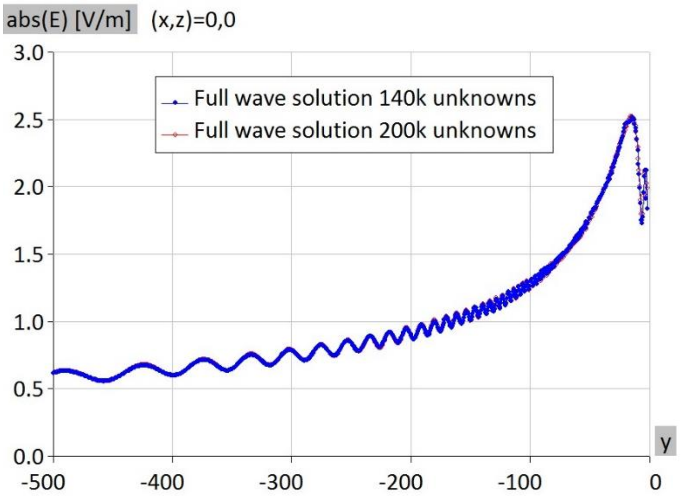
Realistic wind turbine. From left to right: the model meshed at 3 GHz and the CAD model (not to scale)

A quarter of the meshed mast is shown next.



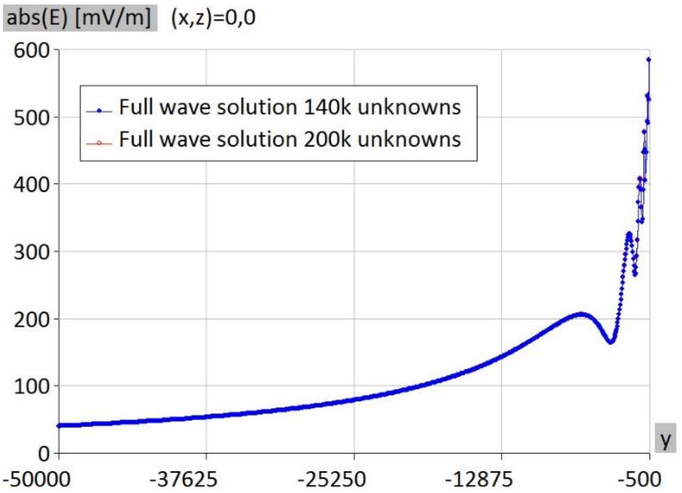
Wind turbine mast at 3 GHz, by using 2 symmetry planes

The result of interest is near field in the shadow region 25 m above ground (the mast is over 50 m high). Scattered field 500 meters behind the mast is shown next. The graph is zoomed-in to show that reduction of reference frequency has no effect.



Near field behind PEC mast, full wave MoM solution

An interesting result is near field at the height corresponding to half of the substrate mast (25 m), at distances up to 50 km away from the mast. This is the same simulation as before, but in extended range.

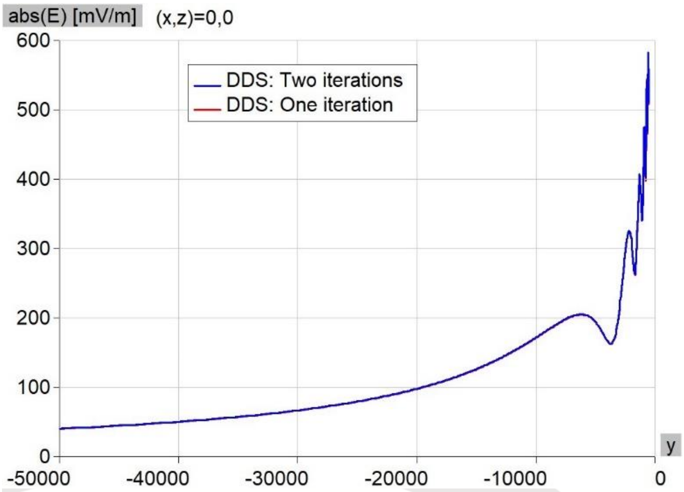


Near field at the middle of PEC mast, up to 50 km away in the shadow zone, full wave MoM solution

The coated wind turbine is almost an order of magnitude more challenging simulation. The simulation times would become impractically long, so we switch to **Domain Decomposition Solver (DDS).** It has an advantage in this and similar cases as it scales much better with frequency than traditional MoM. **DDS is an iterative solver** approaching the accuracy of MoM solution.

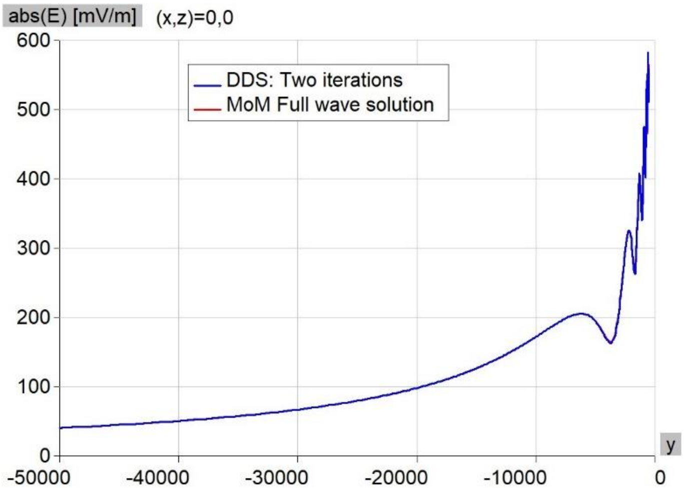
To **demonstrate DDS accuracy**, we first simulate PEC mast and compare the results with MoM. Since the ultimate goal is non symmetric windmill simulation, we focus on 3 GHz mast with single symmetry plane. We test the convergence and accuracy by comparing results with the full wave solution

With single symmetry plane, simulation requires 460,000 unknowns for the full model and 280,000 with the reduced referent frequency. The hardware platform is the same as before (with 24 cores and 192 GB RAM). The simulations times are short, first iteration lasts 7.3 minutes, while the second lasts 5.6 minutes. To compare, MoM traditional simulations lasts 6,294 seconds (105 minutes) and requires exactly 276,744 unknowns.



Near field behind middle of PEC mast, 50 km behind in the shadow zone. DDS solution in two iterations

The previous figure shows that the solution is valid after the second iteration, although even the first iteration is sufficiently accurate. This is a rare situation where we can compare iterative asymptotic solver and full wave EM MoM simulator. **The agreement is excellent.**

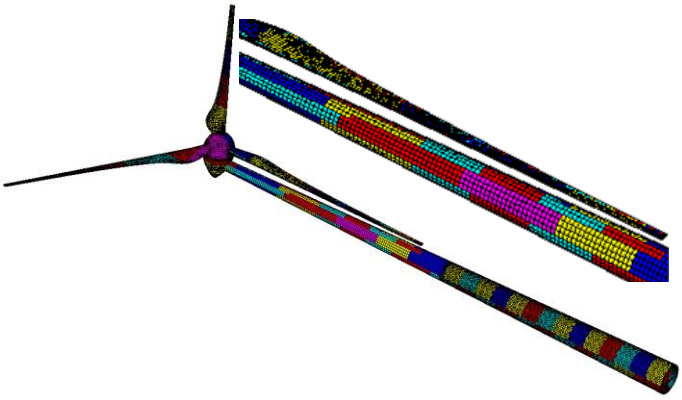


Agreement of DDS solution (after two iterations) and full wave MoM simulation serving as reference; PEC mast

PEC and Coated Full Scale Windmill in DDS

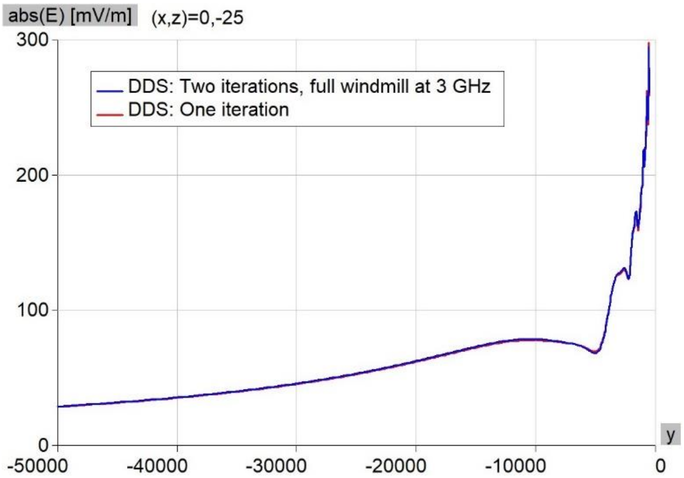
Since **the accuracy of DDS solver is verified**, we can proceed to the ultimate goal, that is calculation of a near field 50 km behind wind turbine when it is coated with a dielectric layer. **At 3 GHz, entire wind turbine is simulated by using WIPL-D DDS solver.** Number of unknowns is reduced according to previous tests by using single click reduction of reference frequency.

The first step is, of course, full model of PEC wind turbine with mast, blades and nacelle meshed at 3 GHz. 64 DDS groups are shown in the following image. The mesh is extremely dense.



Meshed PEC turbine, exported to DDS to group very dense mesh. Part of mast and blade zoomed-in (DDS groups)

To summarize, **required number of unknowns is 914,970. Simulation times are: the first iteration 45.2 minutes, the second 44.5 minutes. Hardware is the same as before: 2x12 cores CPU, 192 GB RAM.**

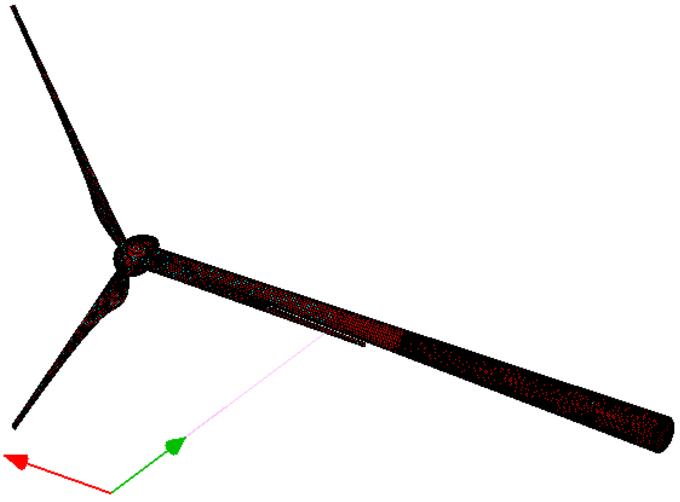


Near field 50 km behind full PEC windmill, simulated in WIPL-D DDS, almost 1 million unknowns

Again, **accurate result is obtained after two iterations**. The estimated run time for the MoM solver is impractical from the engineering point of view and it is estimated to two days.

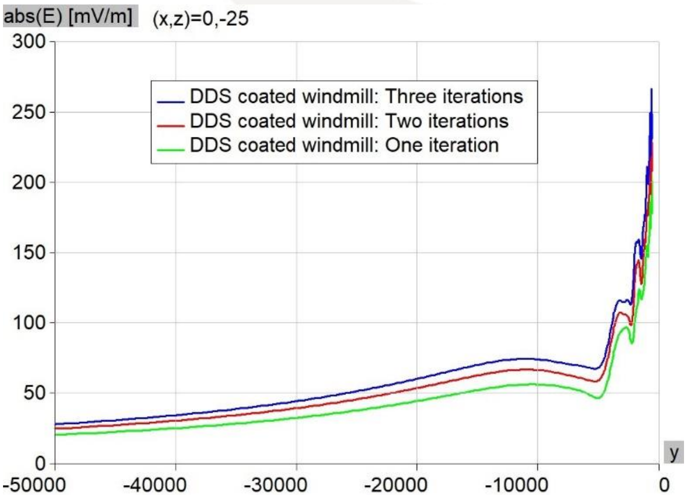
The last piece of the puzzle is **full windmill covered with generic dielectric layer** (1 mm thick, Er=2-j2). The model contains over 25,000 plates (PEC windmill). The mesh elements are grouped and thickness is added in single click via Copy\Layer manipulation. The next figure shows final model. With mast being over 50 m high and dielectric only 1 mm thin, two very close layers cannot be distinguished at the figure. Total number of mesh elements is doubled to over 50,000.

The number of unknowns rises to 2,744,370.



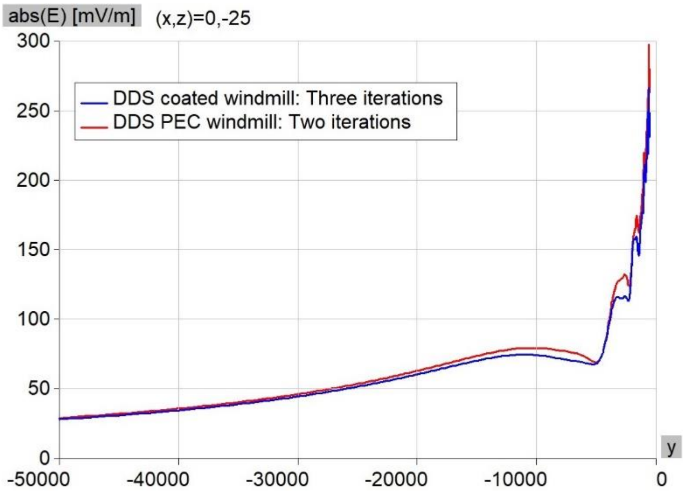
Coated windmill at 3 GHz. Dense mesh, dielectric and metallic surface visually overlap due to mast size and thin coating

The convergence is slower than for the PEC case.



Convergence of the 2.7 million unknowns dielectric coated windmill in DDS solver

At the end, scattered field of PEC and coated case is shown next.



Comparison of coated (2,7 million) and PEC (900K) case

Conclusion

The WIPL-D implementation of MoM is an ideal candidate for RCS simulations of electrically large structures. A number of features leads to this: **unique quad mesh applying higher order basis functions, CAD tool providing the optimum mesh, efficient implementation at CPU/GPU platforms and number of methods to reduce number of unknowns at EM insignificant model parts**.

The code is pushed to the limits for the case of wind turbines. The main challenge represents the electrical height of the mils which is very large at frequencies of interest, and presence of resistive dielectric layers. The usual result required for the case of wind turbines is **near field in the shadow zone**.

The application note offers an unconventional combination of three simulation methods. The first method is **WIPL-D 2D solver** allowing simulation of infinite cylinders, both, coated or PEC, in seconds. This is a good approximation for modeling of either windmill mast or nacelle.

In the next step, the **DDS solver** is used as high frequency method for electrically large structures. The **accuracy of the tool for the particular case is verified** first by simulating PEC mast and comparing results with the **default MoM full wave simulation**. The result of interest is near field up to 50 km behind 50 m tall mast, at the height of 25 m. The iterative DDS method yields accurate solution after two iterations.

The final goal is simulation of entire wind turbine coated with single dielectric resistive layer. The simulation frequency is 3 GHz. Such a simulation is impractically large for MoM as in that case resulting million unknowns simulation lasts around 2 days on a workstation with 2 CPUs with 12 cores, plenty of RAM, four inexpensive Nvidia GTX cards and 5 fast SSD discs. On the other hand, using the same machine, the DDS requires only as many cores as possible. The same applies to RAM. **The simulation time is now a couple of hours for PEC windmill and 1-2 days for the coated case (nearly 3 million unknowns).**

Table 1. Simulations overview.

Model	Number of unknowns	Simulation time
5 m diameter infinite cylinder (PEC or coated)	Under 5,000 [2D solver]	A few seconds
5 m diameter PEC sphere	27,840 [MoM]	5 min
5 m diameter PEC sphere coated with 1 mm 2-j2	88,548 [MoM]	<1 hour
Quarter of 50 m tall PEC mast	140,000 [MoM]	30 min
Half of 50 m tall PEC mast coated with 1 mm 2-j2	276,744 [MoM and DDS]	105 min [MoM] 7.3+5.6 min [DDS]
Full 50 m tall PEC windmill	914,970 [DDS]	45.2+44.5 min
Full 50 m tall PEC windmill coated with 1 mm 2-j2	2,744,370 [DDS]	19.8h + 21.5h + 25.6h