March 7, 2018

TECHNICAL NOTE: GIRAFFA
Generalized i/o-format for adapting optimization frameworks for windfarm-applications

Introduction

In windPRO 2.9 and 3.0 input-output interface formats were implemented to allow execution of high-resolution CFD calculations on remote high-performance computer clusters (HPC), see Sørensen [1] or Svenningsen et al [2]. In windPRO 3.2, we implement an interchange format to allow for 3rd party optimization models. These (optimization) models can then be executed from a subset of data exported from a windPRO project. It is our intension to use this format also in HPC-applications to significantly speedup the optimization calculations - and to allow for more constraints to be evaluated (such as structural loads or COE).

Figure 1: Sample Project: Illustration of an Optimization Setup.

The GIRAFFA IO format follows the same approach as we did for the CFD, namely including the following:

- A request file format from windPRO (or any other client) to an optimization model
- A result format from the optimization model to deliver its results to windPRO (or any other client)

The request and results files are meant to carry basic and needed data only. It is assumed that the 3rd party optimization model will prompt for any missing data – and furthermore give the user access to additional model options as well as documentation and reporting. The GIRAFFA format allows the model to supply a pdf-report for documentation as part of the optimization setup and execution (which we highly recommend).

1. Optimization Request Format

The purpose of the optimization request format is to export relevant data to define:

- Meta data such as coordinate system and client information
- The terrain for the site (as map-files)
- The climate for the site (as wrg/rsf file, siteres file, flowres file)
- Areas of interests
- Excluded/Restricted areas
- Turbine data, such as power curves and thrust curves
- Neighboring wind farms
- An initial layout

An "Optimization Request" file is a compressed zip-file that has the extension ".optireq". A number of files reside inside the ".optireq" file, each needed to execute the optimization. The main file in the ".optireq" file is call "OptimizationRequest.xml", which – as the name indicates is an XML-file that describes the request. In the following the contents and options of the XML-file will be described.

The overall structure of an optimization request XML file is shown in the Figure 2. A detailed description of each of the node is also available below. A preliminary version of the XML Schema Definition can be found in the download links as well as an example of an ".optires" file:

Request XSD: http://www.emd.dk/files/flow/GIRAFFA_OptiRequest.xsd
SampleFile: http://www.emd.dk/files/flow/OptimizationRequest_Sample20170515.optireq
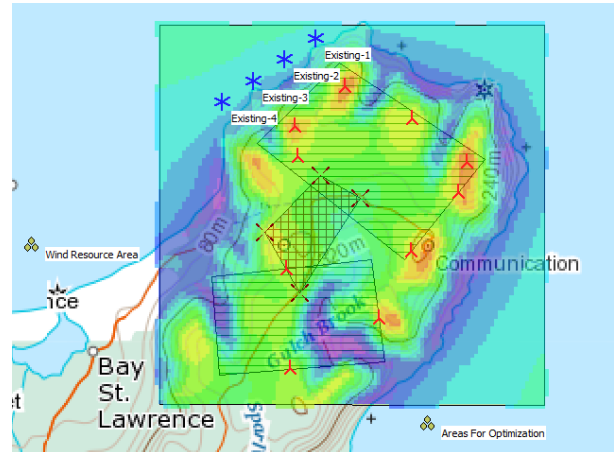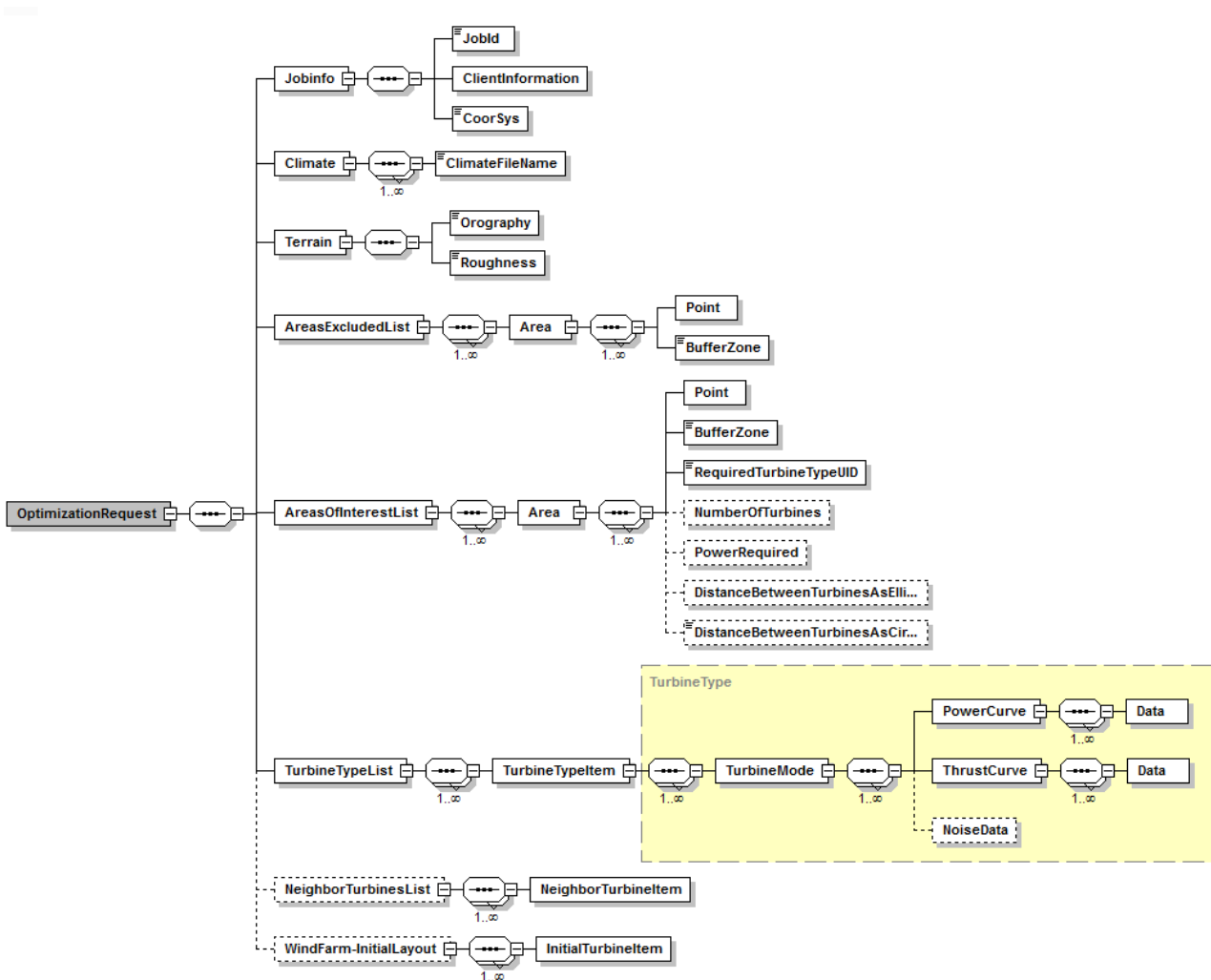
Figure 2: Outline of Optimization Request Format (XML Schema Definition)

1.1 JobInfo

The first part of the XML is the JobInfo node. This part contains meta data that the optimization model is expected to copy - without modification - to the result file. An example of the first part of a flow request XML file:

```xml
<JobInfo>
    <JobId>89f3fe4b-1b62-476e-a99a-7eb70c4bf5f6</JobId>
    <ClientInformation Name="windPRO" Version="3.2.999" UserName="mlt@emd.dk"/>
    <CoorSys Type="WINDPRO">3: 20: 10: 0, UTM (north)-WGS84 Zone: 20</CoorSys>
</JobInfo>
```

1.2 Climate

The climate node holds filename-links to the wind- and climate parameters for the site area – with an option of also adding additional descriptive site-parameters, such as turbulence, temperature and wind-shear. There is also the option of adding results taken directly from a flow model (like WAsP-CFD). Such results must be added as FLOWRES files, see Sørensen [1]. The location of the climate file(s) is within the zip-files (assumed to be in the root folder). Possible file types are "RSF", "WRG", "SITERES" and 'FLOWRES'. For advanced optimizations with multiple climate parameters, we recommend the *.siteres format, see references [3, 4].

```xml
<Climate>
    <ClimateFileName Type="RSF">CapeBreton_Canada_Res_50_Hub_80.0_100.0_120.0_0.rsf</ClimateFileName>
    <ClimateFileName Type="SITERES">CapeBreton_Canada_SiteResults.siteres</ClimateFileName>
    <ClimateFileName Type="FLOWRES">CapeBreton_Canada_FlowResults.flowres</ClimateFileName>
</Climate>
```

1.3 Terrain

The terrain node holds filenames for the terrain-description (roughness model and digital elevation

model). The location of the terrain file(s) is within the zip-file (assumed to be in root-folder). Possible file types are "MAP" format or "XYZ" grid.

```xml
<Terrain>
    <Orography Type="MAP">ContourLines_10m.map</Orography>
    <Roughness Type="MAP">ROUGHNESSLINES_CapeBreton.map</Roughness>
</Terrain>
```

1.4 AreasExcudedList

The AreasExcludedList node defines the horizontal areas where turbines cannot be erected. If a buffer-zone has been applied to the polygon data, then it is reported as an attribute (BufferZoneApplied).

```xml
<AreasExcludedList>
    <Area Name="NorthernArea Excusion Zone" BufferZoneApplied="0">
        <Point x="695925" y="5210593"/>
        <Point x="696466" y="5210302"/>
        <Point x="695708" y="5209031"/>
        <Point x="695208" y="5209813"/>
    </Area>
```

1.5 AreasOfInterestList

The 'AreasOfInterestList' node defines the horizontal areas where turbines can be erected. It is a requirement to add the 'RequiredTurbineTypeUID' as an attribute for each area – in order to link turbine-type to area of interest. A number of optional attributes exists in order to allow for detailed control of the optimization constraints. A complete list of the required and optional attributes is shown in the Table 1 below.

```xml
<AreasOfInterestList>
    <Area Name="Northern Area Inclusion Zone 1" BufferZoneApplied="0" RequiredTurbineTypeUID="0ea1adb6-2604-48e2-b21c-5f261a98d02
        <Point x="696125" y="5212070"/>
        <Point x="698106" y="5210877"/>
        <Point x="697076" y="5209506"/>
        <Point x="695078" y="5210981"/>
    </Area>
    <Area Name="Northern Area Inclusion Zone 2" BufferZoneApplied="0" RequiredTurbineTypeUID="0ea1adb6-2604-48e2-b21c-5f261a98d02
        <Point x="694534" y="5209206"/>
        <Point x="696637" y="5209501"/>
        <Point x="696860" y="5208158"/>
        <Point x="694669" y="5207908"/>
    </Area>
</AreasOfInterestList>
```

Attribute Name	Type	Use	Comment
RequiredTurbineTypeUID	string	Required	Unique identifier for link to WTG
Name	string	Optional	Name of area
BufferZoneApplied	double	Optional	Has buffer zone been used, then >0
NumberOfTurbinesMinimum	integer	Optional	Min. number of WTGs in area
NumberOfTurbinesMaximum	integer	Optional	Max number of WTGs in area
PowerRequiredMinimumMW	double	Optional	Min required power in area.
PowerRequiredMaximumMW	double	Optional	Max required power in area
DistanceBetweenTurbines_Ellipse_MajorAxis	double	Optional	Distance between WTGs
DistanceBetweenTurbines_Elipse_MajorAxisAngleFromNorth	double	Optional	Angel for major axis
DistanceBetweenTurbines_Ellipse_MinorAxis	double	Optional	Distance between WTGs

Table 1: Attributes for Areas of Interests (polygons)

1.6 Turbine Type List

This node is implemented as sequence of 'TurbineTypeItem's – as outlined in the Figure 3 below. The intension is to extract a relevant subset of turbine data to be used in the optimization exercise (such as hub-height, rotor diameter, modes, power- and thrust-curves).
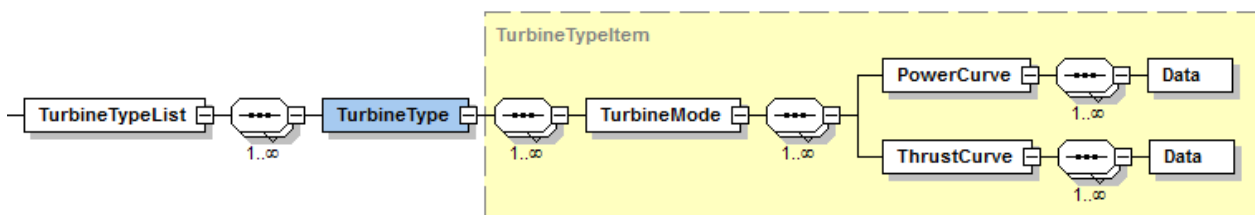

Figure 3: TurbineTypeItem – Definition.

A truncated example of the TurbineTypeList Implementation is found in the code snippet below. Please note that the format allows for multiple 'modes', typically to be used when turbines is running in noise curtailment modes.

```xml
<TurbineTypeList>
    <TurbineType TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}" HubHeight="100" RotorDiameter="70">
        <TurbineMode ModeID="0" StopWindSpeed="25" AirDensity="1.225">
            <PowerCurve>
                <Data windSpeed="3.00" power="0.0"/>
                <Data windSpeed="4.00" power="14.0"/>
                <Data windSpeed="5.00" power="85.0"/>
                <Data windSpeed="6.00" power="187.0"/>
                ....
            </PowerCurve>
            <ThrustCurve>
                <Data windSpeed="4.00" CT="1.082"/>
                <Data windSpeed="5.00" CT="0.934"/>
                <Data windSpeed="6.00" CT="0.825"/>
                <Data windSpeed="7.00" CT="0.804"/>
                ....
            </ThrustCurve>
        </TurbineMode>
    </TurbineType>
</TurbineTypeList>
```

1.7 NeighborTurbinesList

An optional list of any neighbor turbines (any existing turbines) within the area – that should be considered as part of the optimization algorithm (typically to include the wake effects). The neighbor turbines are intended to be 'static' elements only. The sequence of NeighborTurbineItems contains turbine positions, IDs, GUID link to TurbineTypeItems as well as turbine-modes. A code snippet/example is shown below.

```xml
<NeighborTurbinesList>
    <NeighborTurbineItem NeighborUID="Existing-1" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}" x="695800" y="5212402" Turbi
    <NeighborTurbineItem NeighborUID="Existing-2" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}" x="695396" y="5212108" Turbi
    <NeighborTurbineItem NeighborUID="Existing-3" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}" x="694922" y="5211813" Turbi
    <NeighborTurbineItem NeighborUID="Existing-4" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}" x="694588" y="5211518" Turbi
</NeighborTurbinesList>
```

1.8 InitialLayoutList

The InitialLayoutList is an optional list of an initial layout of the turbines within the area of interest. These turbines are to be included in the optimization. The structure is very similar to the 'NeighborTurbinesList', with many of the same attributes, please see the snippet below.

```xml
<InitialLayoutList>
    <InitialTurbineItem InitialWTGUID="New-1" x="6191000" y="5213122" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}"
    <InitialTurbineItem InitialWTGUID="New-2" x="6191000" y="5213122" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}"
    <InitialTurbineItem InitialWTGUID="New-3" x="6191000" y="5213122" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}"
    <InitialTurbineItem InitialWTGUID="New-4" x="6191000" y="5213122" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF85AD5C}"
</InitialLayoutList>
```

2. Optimization Result Format

The Optimization Result format (*.optires) is a compressed zip file that contains an XML file and documentation file. An outline of the format is shown in Figure 4.
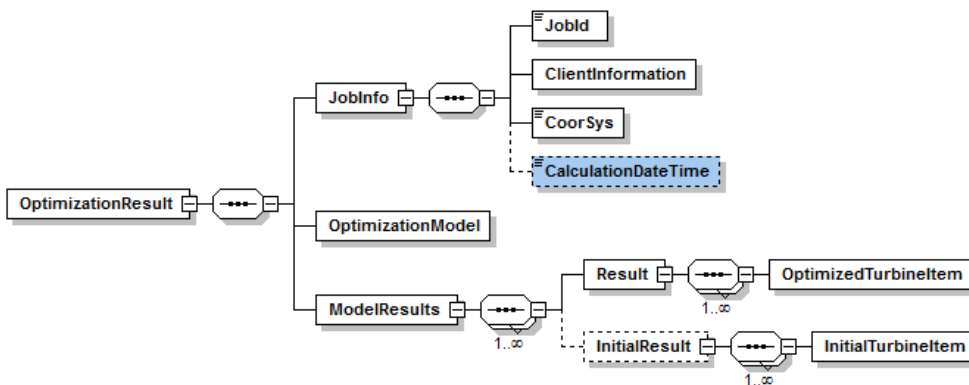

Figure 4: Outline of Optimization Result Format (XML Schema Definition).

A preliminary version of the XML Schema Definition can be found in the download link below, while an example of an ".optires" file is also available

Optimization Result XSD: http://www.emd.dk/files/flow/GIRAFFA_OptiResult.xsd
SampleFile : http://www.emd.dk/files/flow/OptimizationResult_Sample20170515.optires

2.1 JobInfo

Like the optimization request file the first part of a result file is the meta information in the JobInfo tag.

```
<JobInfo>
    <JobId>89f3fe4b-1b62-476e-a99a-7eb70c4bf5f6</JobId>
    <ClientInformation Name="windPRO" Version="3.2.999" UserName="mlt@emd.dk"/>
    <CoorSys Type="WINDPRO">3: 20: 10: 0, UTM (north)-WGS84 Zone: 20</CoorSys>
    <CalculationDateTime>2017-05-15T12:12:00</CalculationDateTime>
</JobInfo>
```

If the result file is produced from a model that was started with an optimization request file, then the JobId, CoorSys and ClientInformation tags are simply copied from the request XML to the result XML. If there is no corresponding request file for the result the JobId and ClientInformation nodes can be left out of the result XML. The CoorSys node can also be left out if the coordinate system is not known, but once the result is used in windPRO the user will be asked to define the coordinate system, so if the optimization model has the coordinate system information it should be put in the XML. In the current version there are two ways to define the coordinate system:

- WINDPRO: This type is a string that represents the coordinate system in windPRO and it is normally used in flow request files from windPRO and hence then copied to the result
- EPSG: This type allows the flow model to write the coordinate system as an EPSG code

As an option, it is possible to add a calculation time-stamp to the CalculationDateTime node.

2.2 Optimization Model

The OptimizationModel node holds data on the optimization model, that it its name and the version.

```
<OptimizationModel Name="FarmOpt" Version="1.0"/>
```

2.3 ModelResults

Results from the optimization modelling are stored in the ModelResults node. As an option it holds also an evaluation of any initial layout (e.g. wake losses and turbine yields) – as well as potentially a number of optimized layouts (in prioritized order). Positions of each turbine location and their in-park performance is given within the 'OptimizedTurbineItem' nodes.

```xml
<ModelResults>
  <Result Name="CapeBreton-OptimizedLayout 2017-05-15" OptimizationPriority="0" OptimizationDocumentation="CapeBreton_OptimizationResult.pdf" ParkYield_InMWhPerAnnu
    <OptimizedTurbineItem OptimizedWTGUID="{4bd10bed-ff26-4310-8881-4ee42c76fdfe}" x="697863" y="5210829" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF8
    <OptimizedTurbineItem OptimizedWTGUID="{e6a4ef94-ddf4-4594-a999-5b1d5fb45732}" x="695563" y="5211229" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF8
    <OptimizedTurbineItem OptimizedWTGUID="{40fb7e37-0307-4964-ae40-a74a08a058c1}" x="697113" y="5211379" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF
    <OptimizedTurbineItem OptimizedWTGUID="{1e0791a9-54b3-41bf-80e1-2f1ea2e47c1c}" x="696213" y="5211779" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF8
    <OptimizedTurbineItem OptimizedWTGUID="{ba356ddd-ec39-4f4d-a9ae-bc5cbcbf896e}" x="696763" y="5208729" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF8
    <OptimizedTurbineItem OptimizedWTGUID="{48249a92-18d9-4657-a28a-2a9591ba86eb}" x="697163" y="5209629" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF
    <OptimizedTurbineItem OptimizedWTGUID="{9b3f8444-45b5-4c14-8b6c-67c446bc8bd3}" x="697763" y="5210829" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF
    <OptimizedTurbineItem OptimizedWTGUID="{a2cf977f-3983-456a-ada5-0b68f71cda1d}" x="697863" y="5210429" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF8
    <OptimizedTurbineItem OptimizedWTGUID="{ccef8fc4-8786-4aa3-8f58-fb9b9a2b1382}" x="695613" y="5208029" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF8
    <OptimizedTurbineItem OptimizedWTGUID="{cbdb426c-dc5f-4aaa-9f23-9d19622fde2f}" x="695513" y="5209329" TurbineTypeUID="{CD75A30E-8559-49DE-821C-9FBEBF8
  </Result>
</ModelResults>
```

3. References

[1] Sørensen T.G.: *Generalized Flow request and result format (version 1.4),* EMD A/S, 2016-10-25, available at: http://www.emd.dk/files/flow/EMD_technote_Generalized_Flow_Request_Result.pdf
[2] Svenningsen et al: *WAsP-CFD Validation Report, EMD International*, 2013-07-10, available at: http://help.emd.dk/knowledgebase/content/TechNotes/TechNote_4_WAsPCFD_EMD_ValidationReport.pdf
[3] Site Results Format – Sample file, available at: http://www.emd.dk/files/flow/SiteResults_Sample20170515.siteres
[4] Thøgersen, M.L. & Sørensen T.G.: SITERES - Generalized gridded results format for wind farm site and climate parameters, EMD A/S, 2016-05-16, available at: http://www.emd.dk/files/flow/EMD_technote_SITERES_20170515.pdf

4. Document History

2017-05-15: First draft with review completed (MLT+TGS)
2018-03-07: Review