OULUN AMMATTIKORKEAKOULU

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FLOWCHART OF THE CONSTRUCTION PHASE OF A WIND FARM

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Tämän opinnäytetyön toimeksiantajana toimii VSB Uusiutuva Energia Suomi Oy. Opinnäytetyön tarkoituksena oli tutkia ja kartoittaa maatuulipuiston rakentamisvaiheen keskeisiä sopimuksia ja työvaiheita. Tavoitteena oli tutkia ja koota kattava tietoperusta, jotta opinnäytetyön tilaajayritykselle oli mahdollista luoda tuulipuiston rakennusvaihetta ohjaava vuokaavio.

Opinnäytetyö koostuu kolmesta osuudesta. Ensimmäisessä osiossa käydään läpi tuulivoimaa yleisellä tasolla, tutustutaan VSB:n Juurakon tuulipuistoon ja tarkastellaan kolmea eri pitkäaikaista sähkönostosopimusta eli PPA-sopimusta. Toisessa osiossa käydään maatuulivoimalan rakentamisvaihe läpi vaihe vaiheelta. Kolmannessa osiossa käydään läpi opinnäytetyön tilaajayritykselle luotu vuokaavio.

Empiirinen osio eli opinnäytetyön tutkimusosio suoritettiin käyttäen toimeksiantajan luovuttamaa materiaalia, koskien toimeksiantajan rakentamisvaiheessa olevaa Kalajoen Juurakon tuulipuistoa. Laajemman tietoperustan koostamiseen käytettiin lisäksi kirjallisuutta tuuli- ja rakennusprojektien rakentamisvaiheista, yleisiä Euroopassa käytettäviä standardeja ja sopimusehtoja sekä eri työvaiheille tehtyjä suunnittelu- ja työohjeistuksia.

Tutkimuksissa havaittiin tuuliprojektien sisältävän kaksi päärakentamisurakkasopimusta, jotka sisältävät kaikki suunnitteluun ja rakentamiseen liittyvät tehtävät. Nämä kaksi päärakentamisurakkasopimusta ovat tuulipuiston infrastruktuurin rakentamis- ja voimalatoimitussopimukset. Haasteita tutkimustyöhön aiheutti aiheen laajuus ja sen kokoaminen mahdollisimman kattavaksi ja selkeäksi kokonaisuudeksi. Tutkimustyön avulla laadittiin opinnäytetyön tilaajayritykselle toimiva ja selkeä tuulipuiston rakennusvaihetta ohjaava vuokaavio.

Asiasanat: Tuulipuisto, vuokaavio, tuulipuiston infrastruktuurin rakentamissopimus, voimalatoimitussopimus, Juurakon tuulipuisto, PPA-sopimus

ABSTRACT

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This thesis was commissioned by VSB Uusiutuva Energia Suomi Oy. The purpose of the thesis was to study and survey the key agreements and work phases of the construction of a wind farm. The aim was to study and compile a comprehensive knowledge base, which made it possible to create a flowchart to guide the construction phase of the wind farm.

The thesis has three parts. The first part reviews wind power at a general level, VSB's Juurakko wind farm and three different long-term power purchase agreements, i.e., PPAs. The second part reviews the construction phase of the wind farm step by step. The third part reviews the flowchart created for the thesis commissioner.

The theory and research part of the thesis, were performed using the material provided by the commissioner, concerning the Kalajoki Juurakko wind farm, which is under construction. In order to compile a better knowledge base, common literature on the construction phases of various wind and construction projects, general standards and contract terms used in Europe, as well as design and work instructions for the various work phases were used.

During the research, it was found out that the wind projects included two main building contracts covering all design and construction-related works. The two main building contracts are the Balance of Plant Agreement and Turbine Supply Agreement. Challenges to the research work were caused by the scope of the topic and its compilation into the most comprehensive and clear entity possible. The research work was comprehensive enough to create the desired flowchart for the commissioner as a final product.

Keywords: Wind farm, Flowchart, Balance of Plant, Turbine Supply Agreement, PPA

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LIST OF ABBREVIATIONS

BoP	Balance of Plant
CapEx	Capital expenditures, are funds used by a company to maintain physical assets such as property, buildings, and technology.
DEM	Digital Elevation Model, is a one model of a laser scanning.
DSM	Digital Surface Model, is a one model of a laser scanning.
ECM	Engineered Crane Mat, a foundation option for a crane hardstand.
FEM	Finite Element Method, used for foundation design.
GW	Gigawatt, 1 billion watts.
HV	High Voltage
IEC	International Electrotechnical Commission
kN	Kilonewton, 1 thousand Newtons.
MIP	Mixed-in-place
MV	Medium Voltage
MW	Megawatt, 1 million watts.
OE	Owner's Engineering
OHL	Overhead lines
PPA	Power Purchase Agreement
TSA	Turbine Supply Agreement
SCADA	Supervisory Control and Data Acquisition, is a wind turbine's control system.
YSE	Rakennusurakan yleiset sopimusehdot, General conditions for building contracts.
V	Volt, is the unit for electric potential, electric potential difference (voltage) and electromotive force.
WTG	Wind turbine generator, is a device that converts the wind's kinetic energy into electrical energy.

1 INTRODUCTION

The prevailing climate change is driving the world towards renewable energy sources. One of the best renewable energy sources is wind. The wind is everywhere, and it can be exploited in many ways touching only a little bit of nature.

The first part of the thesis reviews general information of the wind power, VSB's Juurakko wind farm and the market-based wind projects. Market-based wind projects are the reason why the popularity of wind power has grown in Finland in recent years.

The second part of the thesis studies what construction phase of a wind farm includes. The construction phase is reviewed through step by step. There are two main building contracts, Balance of Plant Agreement (BoP) and Turbine Supply Agreement (TSA). These contracts are opened, and the important plans, works and events contained in them are reviewed.

The third part of the thesis reviews the flowchart, which is the final product of the thesis.
The object of the thesis is the VSB Uusiutuva Energia Suomi Oy's first wind farm in Finland. Wind farm will be built in Juurakko, Kalajoki, and its production will begin in 2022. A total of 7 wind turbines will be built in the wind farm and the total power production is max. 40 MW. (1.)

The commissioner of this thesis is VSB Uusiutuva Energia Suomi Oy. VSB is one of the leading European full-service suppliers in the renewable energy industry. VSB is headquartered in Dresden, Germany. VSB's main business is the international project development and realization of wind and solar farms. VSB also manages operation, commercial and technical use of the wind and solar farms. Since 1996, VSB has commissioned 655 wind farms. VSB and associated companies employs over 300 people. VSB arrived in Finland in 2015 and VSB Uusiutuva Energia Suomi Oy was founded in 2016 in Oulu. (2.)

The aim is to study and get acquainted with the processes of the wind farm's construction phase and to create a flowchart for the client to guide operations. Making a flowchart requires knowledge and understanding of the different stages of a wind farm project, so the goal is to become familiar with the whole project. (3.)

2 WIND ENERGY

Wind's kinetic energy is used to produce electricity. Wind energy can be generated into electrical energy using wind turbine or other conversion systems. Wind hits the blades of the wind turbine and the kinetic energy makes them rotate, which converts the kinetic energy into mechanical energy. This rotation turns an internal shaft connected to a gearbox, which increases the speed of rotation. That spins the generator that produces electricity. (4; 5, p. 10.)

Wind power is easily usable as a form of energy and modern technology wind turbines are a real solution to displacing fossil fuels in electricity generation. In just a short 5-8 months, a wind turbine generates the same amount of electricity as it takes to extract its raw materials and to manufacture, transport, build and dismantle it. The technical life of wind turbines is about 25–30 years. (6.)

2.1 Wind farm

A wind farm is a group of wind turbines in the same area used to produce electricity. There are two types of a wind farms, onshore and offshore wind farms. Finland is a perfect country to build wind farms because it is sparsely populated. Weather in Finland is good for wind farms because its climate is moderately windy and extreme conditions are rare. Only extreme weather condition in Finland is very low temperature on winter. For that reason, there are blade warming technology in wind turbines. (7.)

2.2 Juurakko wind farm

VSB Group's first Nordic wind farm will be built in Juurakko, Kalajoki, Finland. The wind farm is located about seven kilometres from the Gulf of Bothnia coastline and about ten kilometres northeast of Kalajoki city centre. (1; 8.)

The turbine supplier for the construction of the wind farm is the European company Nordex Group. Nordex's seven N163 / 5.X wind turbines will be installed in the farm, with a total power capacity of max. 40 MW (figure 1). (1; 8.)

FIGURE 1. Nordex windmill (8)

The wind turbine model is Nordex's latest technology and has a capacity of 5,7 MW. One 6 MW wind turbine can produce the electricity needs of about 5,500 households (6). The turbine has a hub height of 148 meters and a rotor diameter of 163 meters. (8; 9.)

The wind farm BoP contractor is Suomen Maastorakentajat. About 800 cubic meters of concrete is used to cast the foundations of one windmill. The wind farm's internal cable will be excavated for about six kilometres and the external cable for about 9 kilometres. New roads will be built for about 3 kilometres and existing roads will be modified for 6,5 kilometres. (9.)

The Juurakko wind farm is connected to Fingrid Oy's Jylkkä's substation, which is located about five kilometres from the wind farm along a bird's eye view. The Jylkkä's substation is undergoing expansion work, which will be completed during 2022. When completed, the substation will be Finland's most significant connection point for wind power production. (9.)

The wind turbines will be transported by ship to the port of Raahe, from where they will be transported to the wind farm area in the spring of 2022. The installation of wind turbines will begin after the transport and the wind farm will be ready for production in autumn 2022. (9.)

2.3 Market-based wind projects

Market-based wind projects do not receive any state subsidies. First purely market-based wind project was built in Finland in 2018. In market-based wind projects, there are three different types of a financing solutions. The first solution is a power purchase agreement, and it means that big electricity user makes long electricity buying agreement, 10 - 20 years, with wind power company. (10, p. 10.)

The second solution is a Mankala principle, where Mankala companies produce electricity and sell it to their shareholders at production cost instead of making profit. Shareholders can use the electricity they receive themselves or sell it further. Mankala principle enables investors and companies to invest in wind production. (11, p. 9 - 10; 12.)

In the third solution a large electricity user buys the property rights of the wind project from the wind producer company. Wind producer company builds the wind farm and when it is completed, its ownership will change. The technical and commercial management remains with the wind producer company. (13.)

3 CONSTRUCTION PHASE

This part of the thesis reviews the various phases of wind farm construction. Construction phase is depending on the multiannual development and permitting processes. These processes precede the construction phase. The construction phase is progressing systematically from tendering process to the agreements and then from design to construction. Development and permitting processes create a stable base for construction phase of the wind farm. Development phase analyses and measurements confirms that the chosen area is good for wind farm. For example, wind measurements are the most important factors enabling wind energy production in this area. (14; 15, p. 39 - 49; 16, p. 17 - 21.)

In the permitting phase, vital studies and permits are made for the wind farm. Once all permits have been legally confirmed, the wind project can proceed to the construction phase.
Construction phase of a wind farm is multistage and includes several design and construction works that are done simultaneously. (15, p. 39 - 49; 16, p. 17 - 22.)
There are four construction phases:

1. tendering
2. agreements
3. design
4. construction (14).

3.1 Tendering

Construction phase begins with the assembly of the construction work team. Construction work team's first task is to create preschedule of the construction phase. The duration of the construction phase is most dependent on the number of wind turbines. (14.)

The first key decision of the phase is to choose, how the tendering process will be carried out. Construction contractors will be selected in the tendering process. The purpose of the tendering process is to ensure that the best possible result is obtained for the investment. The winner of the tendering process is the contractor, who finds the consensus and best meets the needs of the customer – with the best value for money. The final investment decision will be made after the tendering process. (14.)

This thesis examines two different tendering processes and those are named as process A and B. In both processes, the designs, plans, and materials required for the tendering process are compiled into a "tendering package", that can be delivered to the selected companies. The project owner is responsible for the designs, plans and materials of the tendering process. If no specialist can be found under the project owner to make the designs and materials for the tendering package, a pre-tendering process will be made for these. (14.)

Tendering process A will be carried out with a preliminary ground study, plans and material. Tendering process B will be carried out with main and execution designs and complete ground study. The list of measurements is known once the main and execution designs have been completed. This list will be included in tendering package. (14.)

3.1.1 Ground study

The purpose of the ground study is to obtain as sufficient information as possible to carry out the design of the foundations for technically appropriate and safe construction. Ground study is also the base for all construction works. Ground study report will show the carrying capacity of the land and the appropriate foundation method. The strong and variable dynamic loads of wind turbine require that ground study must be carried out carefully, as defects made in building foundations can be difficult and expensive to correct. In worst case the defects are impossible to correct and there is no choice but to demolish the building. (16, p. 25; 17, p. 7)

Development and permitting phase's preliminary ground study uses existing maps and data of the wind farm area. This information has been used to make preliminary locations for the windmills, but those may change after further ground study. In the permitting phase, this issue has been considered and permits have been obtained for each windmill justifying relocation within a certain area.
Ground study examines the topography of the wind farm area, the height of the groundwater surface, soil layers and types and geotechnical properties. (14; 16, p. 25 - 26.)

3.1.1.1 Topography research

Topography research can be done with e.g., laser scanner, tachymeter, and mapping device. Laser scanner is a measuring device that can be used to measure points without touching the object. The laser scanner measures a three-dimensional point cloud from the desired measuring object. The measuring device has a zero point from which a laser beam is output, which can be used to measure the distance of the object from the measuring device. (18, p. 1)

The measurement of the laser scanner is based on the travel time of the light to the measurement object and back. Utilizing laser scanning is profitable because it quickly provides comprehensive measurement material and speeds up progress to the wind farm design phase. Laser scanning can also be used to inspect the finished construction work. (18, p. 1; 19, p. 7; 20.)

For a large area such as a wind farm, an airborne laser scanner can be used, which is used, for example, from an airplane, helicopter, or drone. The measurement accuracy of these laser scanners is >10 cm (18, p.1). Figure 2 shows the Digital Elevation Model (DEM) and the Digital Surface Model (DSM) composed of laser scanning material (20, p. 19).

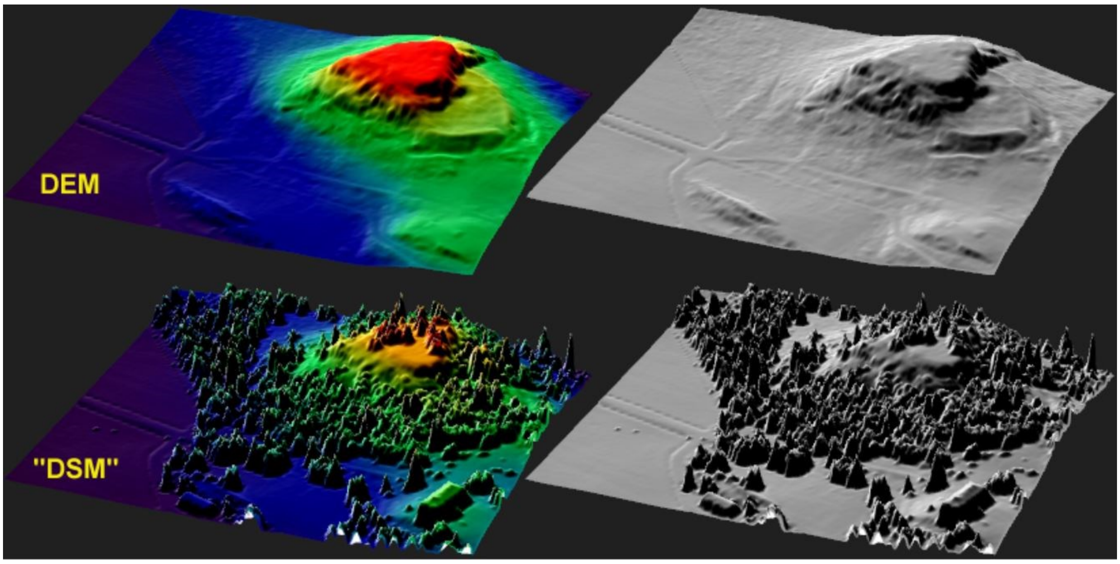

FIGURE 2. Laser scanning photos (20, p. 19)

More accurate measurement can be performed with ground laser scanners with a measurement accuracy of less than 2 cm. Topography research can be done with traditional tachymeter and mapping can be done also with drone equipped with measurement device. (18, p. 1.)

3.1.1.2 Soil layers, species, and groundwater

Drilling and laser measurement are used to study soil layers and species. Drilling is usually done with a multi-purpose wagon drill that can perform several different types of drilling (16, p. 27; 21, p. 19). Drilling determines the thickness and quality of the soil, as well as the groundwater and bed-rock level (21, p. 20 - 27). In the figure 3 Geomachine Ltd.'s multifunctional Wagon Drill, which can be used for all drill works of soil research (22).

FIGURE 3. Geomachine's GM 65 GTC Wagon Drill (22)

Groundwater level can affect ground bearing capacity and subsidence properties. The best research result on the groundwater level is obtained if research work is carried out over a period of one year to find out the changes in the groundwater level caused by different seasons. (16, p. 28; 21, p. 29 - 30.)

One of the most important research of the ground study is to find out the locations and properties of the soft soil and rocks in the construction area. At its worst, soft soil areas require large mass exchanges, piling, or ground reinforcement work. Rock areas may require large excavation or drilling work. The study of rock areas should also determine whether the quality of the material excavated from the rock is sufficient for earthworks. Complete ground study also includes geotechnical design, which includes load-bearing and stability calculations. (16, p. 25 - 26.)

3.1.1.3 Geotechnical design

Geotechnical design is done for the foundations of roads, hardstands, and windmills. The ground study report is used as a basis for planning. The goal is to design foundations that will last throughout the life of the wind farm. The foundations are designed so that the wind turbine cannot tilt, overturn, or sink to the ground. An important part of geotechnical design is to design a solution for drainage of foundations and, if necessary, frost protection. (21, p. 19)

In Finland, geotechnical design is carried out in accordance with the standard “SFS-EN 1997-1, Eurocode 7: Geotechnical design” published by the Finnish Standards Association. The standard contains formal design guidelines for geotechnical design. (16, p. 28.)

3.1.1.4 Preliminary ground study

Preliminary ground study is lighter and rougher, which is done in a wind project visually and by palpation with a pinch point crowbar. This kind of a preliminary ground study is enough in tendering process A’s tendering package because complete ground study will be carried out as part of the BoP works. A complete ground study must be done prior to the main and execution designs. (14.)

3.1.2 Owner’s Engineering

Owner's engineering is, as the name implies, engineering professional assistance, and these services can be used to carry out the project, e.g., tendering, design, management, monitoring, supervision, and measurement work. (23.)

3.1.3 Tendering plans

Tendering plans plays an important role in tendering process and should be done carefully. Tendering plans includes

- procurement objectives
- market analysis
- tendering schedule
- tender evaluation
- tender material. (14; 24.)

Clarifying the procurement objectives is key to knowing clearly what is being sought from the tender market. When procurement objectives are clear, then it is possible to find a contractor from whom you can get as much value for money as possible. Market analysis gives a realistic picture of what the market has to offer and at what price. For example, a light market analysis is to research a potential contractor's websites, send e-mails and make phone calls. Market analysis also includes waking up the market and interest among potential contractors. (24.)

The tendering schedule must be clearly created so that the tendering process can be carried out within a reasonable time. The schedule explains to the contractors how long it can take, for example:

- processing the offer material
- time to respond to the request for quotation
- tender and evaluation period. (24.)

Tendering evaluation should be planned well, so that the choice can be made smoothly and rationally. Selection criteria should be created that it can be viewed at the time of selection.
Tender material is a documentation that contains information about the project, such as e.g., the content of the project and its phases, the preschedule and the scope of the work. (24.)

3.1.4 Tendering process

The tendering process is the most time-consuming part of the tendering phase, and to carry it out as professionally as possible, the preceding parts must be completed carefully. Tendering process consists of six stages:

1. a requirement specification
2. define the selection criteria
3. identify potential contractors
4. RFI (Request for Information)
5. RFQ (Request for Quotation)
6. comparison of contractors. (25; 26; 27; 28.)

The tendering process begins with the creation of a requirement specification, which maps, analyses, and verifies what is desired in the tender market. Once this definition is made, appropriate selection criteria can be created that are desired from contractors. The selection criteria can be used to prioritize, for example, price, quality, and schedule. The next step is to identify potential contractors in the market and narrow the search scale. (25; 28.)

If potential contractors are unknown, a Request for Information (RFI) can be sent to them. RFI provides the contractors with the necessary additional information on how it is able or willing to perform the selected construction contract. Following five sections of a basic RFI should include:

- contract’s goals and objectives
- organization’s background
- skills and qualifications
- evaluation criteria
- request response time. (25; 26.)

After the RFI phase, the Request for Quotation (RFQ) can be sent to the remaining potential contractors. Following sections should be included in RFQ:

- project information
- description and scope of the works
- technical and commercial requirements
- project schedule

In the final phase, before the contract negotiations, a final comparison is made between the contractors if there is more than one contractor left. If a selection decision cannot be made, the two most potential contractors may be invited to contract negotiations. (25; 26; 27; 28.)

3.2 Agreements

The goal of the tendering phase is to find contractors for the construction work. Agreements are made with the contractors in contract negotiations. In Finland, the General conditions for building contracts, i.e. YSE 1998, is used as the basis for building contracts. YSE 1998 is especially helpful in conflict situations where reconciliation is desired. (14; 29.)

The building contract includes a variety of documents, each with its own weight in the contract. The contract documents are commercial, technical and design documents, of which the design documents are already reviewed in the tender phase. Commercial documents are documents concerning the economic and legal content of a contract. Technical documents are documents that describe the content, quality, and performance of a building contract. The design documents include documents on content, quality, scope, and performance, such as technical documents, lists of quantities and measurements, and a contract boundary annex. (29.)

In wind projects, the three building contracts for the construction phase are

- Civil Balance of Plant agreement (C-BoP Agreement)
- Electrical Balance of Plant agreement (E-BoP Agreement)
- Turbine Supply Agreement (TSA). (14; 30)

The C-BoP agreement and the E-BoP agreement are usually counted as one agreement, ie the BoP agreement. The BoP Agreement includes all wind farm construction work, but not the wind turbine works. The TSA includes wind turbine generators (WTGs) and WTG transportations, assemblies, and commissioning. The TSA provides detailed information on the actual dimensions of the wind turbines, which will be used later in the design phase. (30; 31.)

In wind project’s building contracts, it must be considered that the contract can be terminated if the project owner decides. Termination of the contract occurs, for example, if the contractor's actions are questionable or the quality of the work is poor. In this case, the contractor's work ends, and it has no choice but to leave the construction site. (30; 31.)

3.2.1 Contract Negotiations

The most potential contractor or, if none stands out overwhelmingly, the most potential contractors will be determined from the tendering phase. Minutes must be created of the contract negotiations, the validity of which is one of the most significant in the building contract. Therefore, the minutes of the negotiations are inspected by a lawyer. The lawyer checks the legality of the minutes. Once the legality is in order and both parties are satisfied, the signing of the agreement can proceed. (32; 33.)

3.2.2 Kick-off meeting

After the contracts are signed and before the execution phase, a kick-off meeting is held with each contractor. A kick-off meeting is an important meeting because there can be set expectations for the project and foster a strong co-operation relationship with the contractor. The kick-off meeting is an opportunity to go through the goals, purpose, management, procedures, and timeline of the project. Things to go through in kick-off meetings:

- Background and the purpose of the project
- Scope of the project
- Timeline and milestones
- Project organization
- Contract review and contractor’s main responsibilities
- Commercial Schedule
- Reporting procedure
- Subcontracting
- Agree on how to work together. (34; 35; 36.)

Main contractor

Main contractor oversees and manages the construction. The main contractor is selected at the contract signing stage and in a wind project usually the TSA contractor is chosen into this role. The main contractor is responsible for the Site Management duties, which are:

- site administration
- general management
- appointment of a foreman
- site Construction schedule
- health, safe and environment (HSE)
- arrangement and co-ordination of work on the site
- site insurance. (14; 29; 37.)

3.3 Design

Design phase is before the commencement of construction. In the design phase, building drawings, layouts, designs and plans for carrying out construction work are planned and made. Finished and updated building designs are delivered to Municipal building control.

3.3.1 Preliminary plans and layouts

Preliminary plans and Layouts are part of the tendering process A's tendering package. Based on the preliminary plans and layouts, the contractor participating in the tendering process will be able to evaluate its own offer and start its own design work if it is selected for the task. Preliminary plans and layouts are

- OHL (Overhead lines) and external cable route
- CapEx (Capital expenditures)
- TSA (Turbine Supply Agreement) requirements for BoP (Balance of Plant)
- substation
- hardstands
- access roads. (14.)

OHL and External Cable Route Layouts shows the wind farm power lines and assists the contractor in planning and estimating material quantities and work tasks required. These layouts are usually made in the form of Single Line Diagram drawings. (14; 38.)

Capital expenditure (CapEx) plans should be designed to estimate investment costs over the life cycle of the wind farm. By designing CapEx, the profitability of the investment can be fixed as well as possible. (14; 39.)

TSA requirements for BoP are the requirements required by a Turbine Supplier for BoP works. The requirements can be, for example, certain work tasks that must be completed before starting TSA works. The most important data for hardstand preliminary plans are obtained from the ground study report. Based on ground study report, pre-calculations and analysis can be done for the crane hardstand areas. Access road preliminary plans include plans for the roads required by the wind farm. (14; 16, p. 36.)

3.3.2 Main and execution designs

Main and execution plans must be made before construction of the wind farm can begin. Based on these plans, construction work can be done correctly. Based on the completed main and execution designs, information is obtained for creating a list of measurements. (14; 29.)

3.3.2.1 Tree cutting

Tree cutting plans are e.g., various tree cutting maps that are used to know where trees are being felled so that construction work and transportation of wind turbine parts can be carried out without hindrance. Tree cuttings also include risk and hazard management plans. There may be danger areas in the felling area, such as a public road or power lines, which should be considered when planning the felling area. (14.)

The design follows the landowner’s wishes and regulations to know how the tree cuttings are made. Information is also obtained on how to deal with felled trees. For example, does the landowner want the trees to be sold and the money delivered to the landowner, or do they want the trees to be stacked on the side of the road. Information is also needed on the treatment of felled wood, what dimensions the wood is sawn and how accurately the trimming work is performed. (14.)

3.3.2.2 Access roads

Wind farm area's access roads needs planning. A road must be planned for each WTG to enable construction and future maintenance work to be carried out in the area. The most important thing in road design is to design the roads in such a way that transportation of wind turbine parts is possible. The sizes and load-bearing capacities of the existing roads are determined, and plans are made for the modifications. The construction of new roads requires complete geotechnical designs that can be made based on a ground study report. (14; 40.)

3.3.2.3 Transportation

Transportation planning is one of the most important tasks in wind project. For example, transporting long wind turbine blades to a wind farm area is a real special transport. The entire transport route should be researched and analysed to ensure complete transport. Information is needed e.g., roads, bridges, and signboards. The structures and load-bearing capacity of the road and bridges determine the choice of the transport route. It is also good to know if there are any obstacles on the route in addition to bridges, e.g., there may be problems with some signboards and traffic lights. (41.)

Simulation planning can be done with transport simulation software e.g., CodeSquare company provides HeavyGoods.net application for such purpose. The application can be used to simulate the selected transportation route and select the size class of the load to be transported (figure 4).

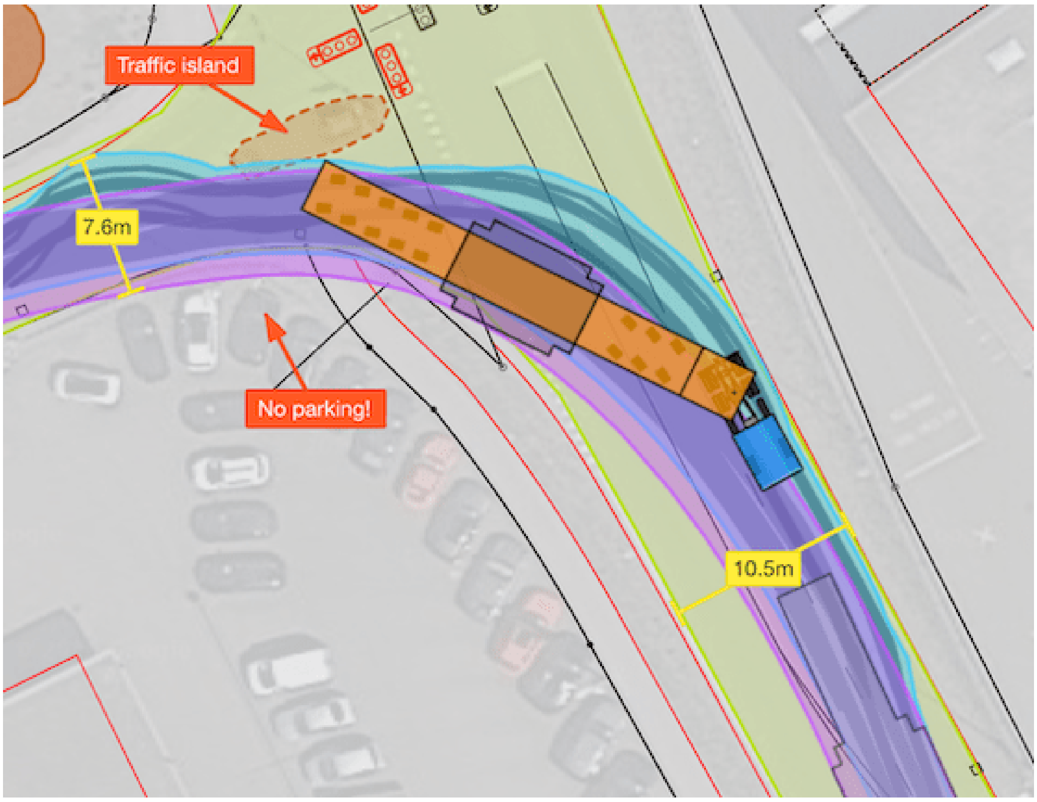

FIGURE 4. HeavyGoods.net transport simulation software (42)

Transport simulation software displays very accurate road measurements and shows route difficulties, such as buildings and trees in curves and intersections. The simulation plan helps to plan the cutting of trees as accurately as possible before the construction phase's dummy run. (43.)

3.3.2.4 Electrical works and cabling

The wind farm electrical system must be designed so that it meets local electrical safety requirements, and it is possible to operate the wind farm safely. The design also aims to optimize material costs. Plans should also ensure that the wind farm system meets the requirements of the grid owner. (31; 44.)

The cable route should be planned to know how the power lines run from the wind turbines to the substation and how the connection to the grid takes place. Power lines are usually designed to run along planned roads so that electrical construction works are as easy to do as possible and maintenance work can be performed in the future. Figure 5 shows a typical electrical layout showing the wind farm cabling. (31; 44.)

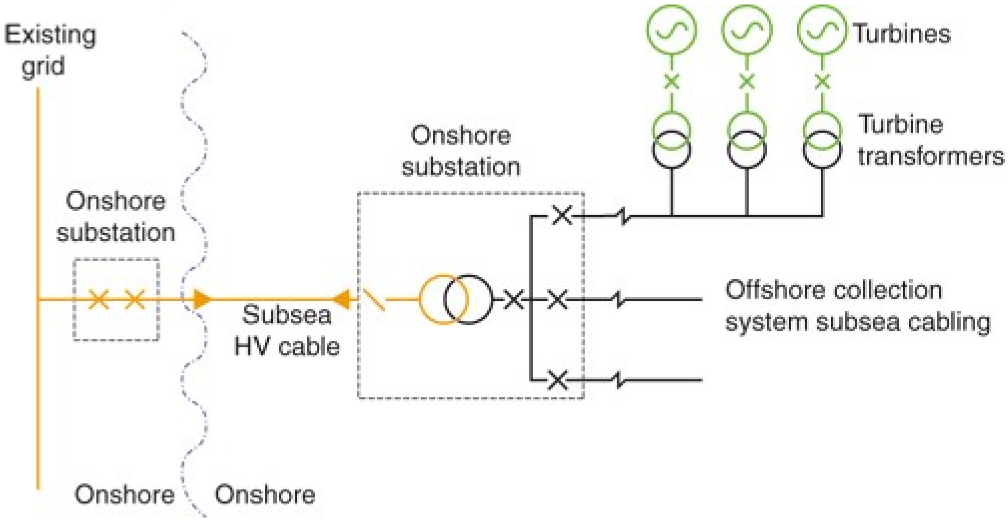

FIGURE 5. Electrical layout (44)

Earthing and protection plans must be designed to be able to operate safely in the event of a wind turbine or grid failure. The wind turbine is protected from breakage and it is also protected that the main grid is not damaged by wind turbine disturbances. Wind farm's earthing can be designed as one large entity. Each wind turbine is designed with its own earthing system, which is connected to the reinforcement of the foundations. All wind turbines are then connected to the substation with bare copper conductors. This creates an equipotential space, and its earthing resistance is a very low <0.5 Ω. Figure 6 shows the earthing system of a single wind turbine and illustrates the concept of equipotential space. (45.)

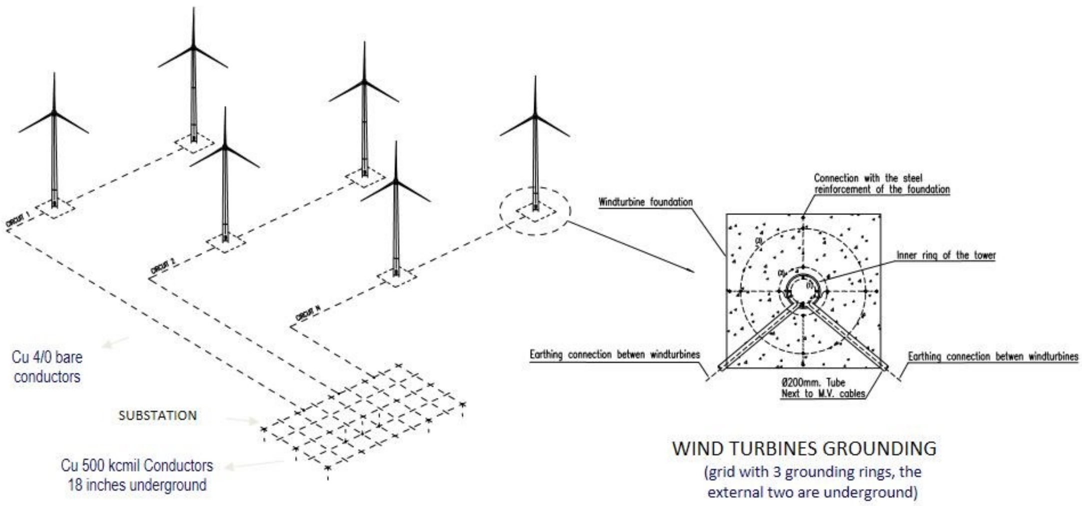

FIGURE 6. Windfarm's earthing system (45, p. 36)

For wind farm's earthing and protection, there is its own European standard SFS EN-50438, which is followed in Finland. The standard defines different requirements for earthing and protection. (44; 46, p. 65)

Cross-bonding plans are planned for the wind farm as a long-distance cabling system is made. Cross-bonding is done to improve the ability of power lines to carry more power and to reduce power losses in the system. (47; 48.)

3.3.2.5 Hardstands

Hardstand means a reinforced area that is made for a crane. Hardstand plans are made for the area where the crane operates and the area where the boom is assembled. Figure 7 shows the hardstand area for the crane and the boom assembly area, which also shows the placement of the auxiliary cranes. (14; 49, p. 30)

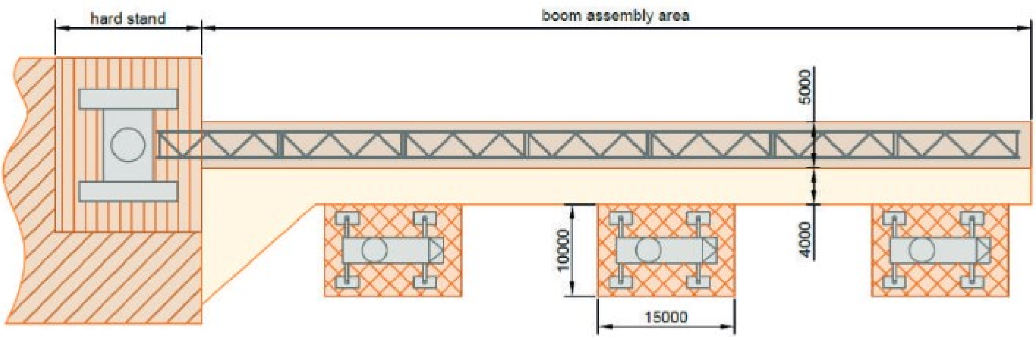

FIGURE 7, Example for a hardstand and boom assembly area (49, p. 30)

The design of hardstands must consider the loads to be lifted, the crane type, weather and wind conditions, and accurate load-bearing and stability calculations made on the basis of ground study report. Hardstands must be durable in order for the assembly of the WTG to succeed on top of it and also decades of maintenance work can be performed safely. It is important to know the choice of crane type, as a crane with all the necessary equipment and counterweights weighs several hundred tons. Different crane types also need a different hardstand area in terms of size and requirements. (49.)

3.3.2.6 Foundations

Geotechnical design can be used to select the best possible foundation for wind turbines. The drawings and plans are made for the selected foundations, these are

- anchor cage design
- anchor plans
- foundation designs.

The Anchor cage design can be used to optimize the amount of concrete and steel required by the wind turbine foundations. With a high-quality anchor cage design, a considerable amount of money can be saved at the expense of materials. Anchor cage is designed using the finite element method (FEM), which can simulate the weight and dynamic loads of a wind turbine. FEM is good for providing analysis that can be used to modify drawings. Anchor cage drawings can be used to create a 3-D model (figure 8). (50.)

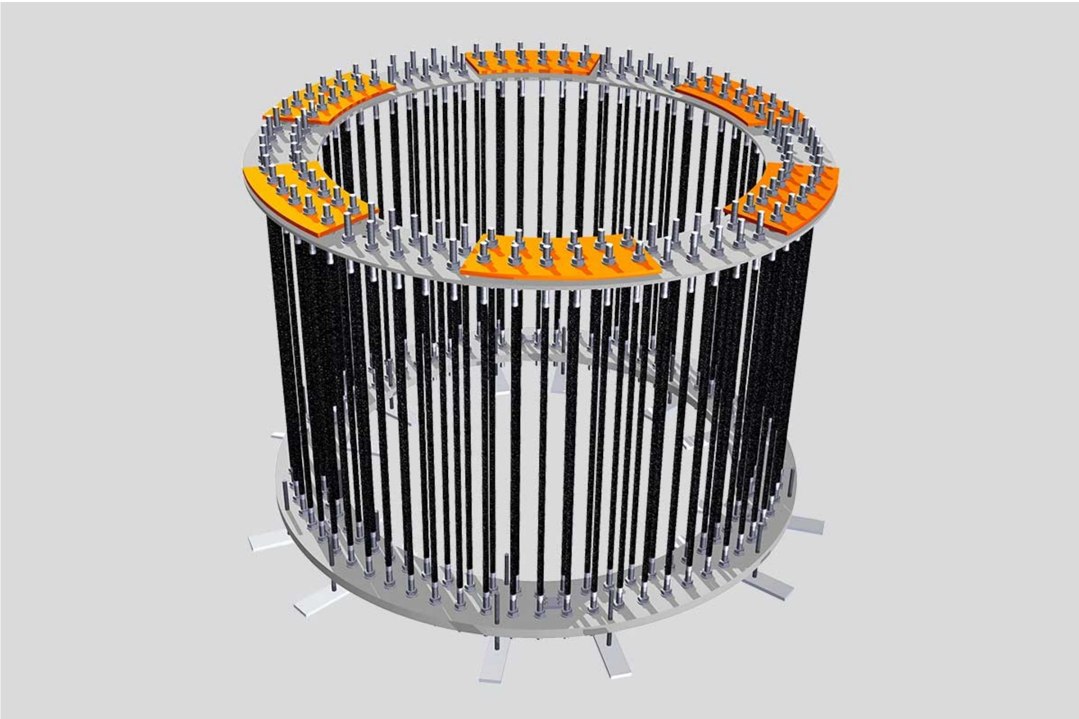

FIGURE 8. Anchor cage 3-D model (51)

Anchor plans are plans for how to anchor a wind turbine. The size of the wind farm, soil characteristics, soil types, and bedrock depth affect which anchoring system is the best possible choice. A good anchor plan makes savings in quantity of the concrete and steel. (52; 53.)

Foundation plans should include the following

- shear and moment capacities
- crack control
- anchor bolt anchorage
- anchor bolt prestress splitting
- fatigue. (54, p. 3.)

Foundation design examines the various load factors that affect selected foundations. The plans show how, soil support is optimally used. Drawings of the selected foundation will also be made during the design phase. Figure 9 shows a typical cross-section view model of a shallow foundation. (54.)

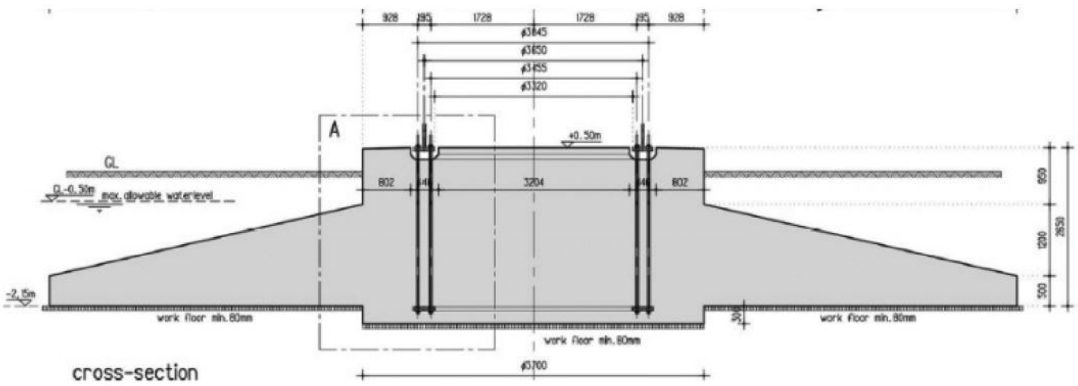

FIGURE 9. Cross-section view of foundation 3-D-model (54, p. 6)

3.3.2.7 Substation and grid connection

A step-up substation will be built in the wind farm, where the energy produced by wind turbines will be collected using medium voltage cables. Substation converts medium voltage into high voltage, which can be fed along a 110 kV power line to the grid. The substation needs the right kind of area for which construction makes the most sense. The location of the substation must be carefully planned so that wind farm cabling can be performed as easily as possible. The area must have the right properties so that drainage and erosion protection can be done. Substation needs foundation and structural designs. Figure 10 shows an example of structural design. (56; 57; 58; 59; 60.)

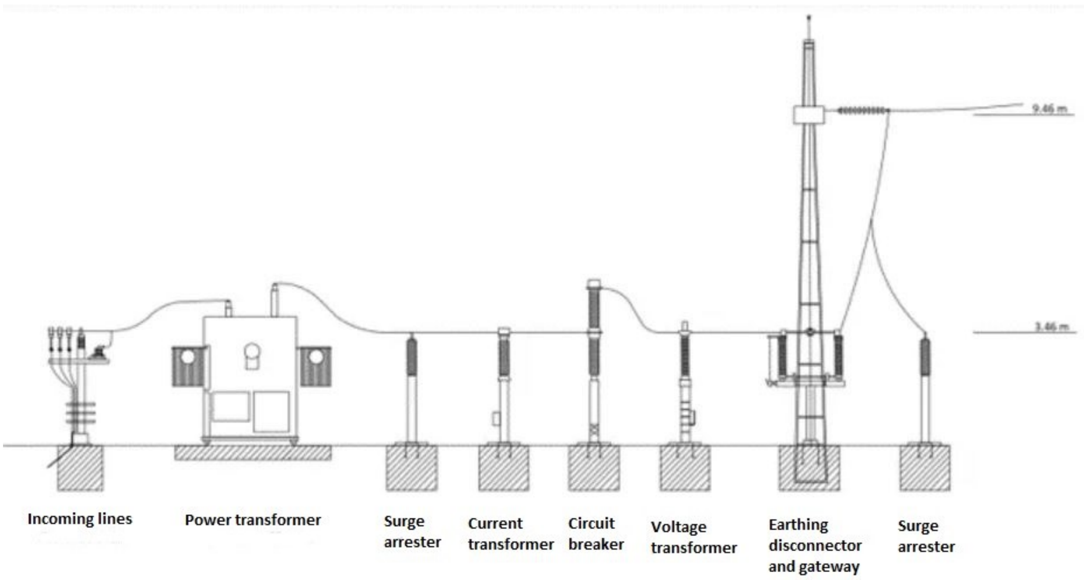

FIGURE 10. Substation's structural design (55)

Substation design includes all the substation equipment such as surge arresters, current transformers, circuit breakers, AC/DC station power, high voltage and low voltage switches, insulated cables and raceways and control system supplies. Substation lightning protection and earthing plans must be design. (56; 57; 58; 59; 60.)

3.4 Construction

Construction will begin with a meeting with the Municipality building Inspector. Construction then proceeds, first doing BoP works, which are the basis for the TSA works. The construction phase consists of three different sections, which are supervision, reporting and construction. The three sections are interconnected and work together. The construction phase ends with the taking over process, after which the wind farm is ready for production. The construction of a wind farm usually takes about 1-2 years depending on the size class of the wind farm area and the number of turbines. (14; 16, p. 22 - 23.)

3.4.1 Supervision

The first task of a construction phase is the appointment of representatives and supervisors. Project owner selects qualified supervisors to supervise the construction site's work. General supervision work includes site supervision. Site supervision includes, for example, checking the site diary. Supervisors also have the right to make inspection calls to places where building materials and components are made. (29.)

General supervision includes checking the contractor's measurement results and quality assurance. Based on these, the supervisor is able to detect whether defects have occurred in the contract work. If defects have occurred, these must be reported to the contractor who is responsible for that work. (14; 29.)

The notify may be made orally if there is a minor defect, but in the case of a major defect, the notify must be made in writing. The contractor is obliged to correct the detected defect without delay or if the defect is unreasonable in the contractor's opinion, the dispute may be resolved in the courtroom. If the situation escalates all the way to the courtroom, then written documents are concrete evidence. (14; 29.)

In many cases, however, disputes can be settled, for example as a price reduction. Another settlement is that the project owner acquires a new contractor to do the work correctly and the monetary value of the work done is deducted from the contract price. The YSE 1998 is a good tool for resolving conflict. If the result of the repair work is rejected, the contractor will be reported again, and the above process is performed again. If no defects are detected in the contract work or when the defect has been corrected and accepted as done correctly, the work can be continued. (14; 29.)

Supervision work is done in a monthly cycle and the cycle ends with a monthly meeting, from which the cycle starts again. The meeting will be attended by site contractors and supervisors. The monthly meeting reviews the site workflow, the work done, and whether the project is on schedule. From this meeting, the supervisor compiles a construction report for the project owner to read. (14.)

Site Diary

Information and events concerning the work are recorded daily in the site diary. Site diary is ensured by the contractor who is responsible for the site management. A notification concerning the site presented by the project owner, an authority, a contractor, a specialist, or a supplier must be marked, upon request, in the site diary. (29.)

3.4.2 Reporting

Reporting of construction work can be agreed in the contract between the owner and the contractor. For example, it may be agreed that each contractor will provide the owner with a monthly report. The contractor, who is responsible for the site management, will also provide the previous week's construction site diary to the owner. Based on these reports, the project owner receives information from the contractor on how the contract work has progressed, what has been done and whether it is on schedule. (14.)

3.4.3 BoP Works

Construction phase will begin with BoP contract works. The works include civil and electrical works. The purpose of the BoP work is to complete the wind farm infrastructure so that the installation of wind turbines can be done. (14; 16, p. 22 - 23.)

3.4.3.1 Tree cuttings

Construction work will begin with tree cutting works and the first task will be to contact the landowners. Contact with landowners is needed because trees are being felled from their land areas due to the construction site. Transporting long wind turbine blades is demanding, which is why the necessary trees are felled from the roadsides. Simulation of the transport route provides information on tree cutting needs. The last information about the need for tree cuttings is obtained after the dummy run. The tree cuttings and access roads work partly at the same time. (14.)

3.4.3.2 Access roads

Access roads are in key role in the construction phase. Existing roads will be used in the construction of the wind farm. The use of the existing roads will be discussed with the landowners. The ground study report provides information for planning existing road improvement and reinforcement works. The road will be modified as planned so that e.g., construction materials and parts of the wind turbine can be transported to the construction site. New roads need to be built as it is unlikely that existing roads will run ready for each wind turbine. The load-bearing requirements of the roads are at least 110 MPa, as it must carry the truck and the heaviest part of the wind turbine, ie the nacelle, which it transports. The nacelle, which is transported by truck in figure 11, weighs about 70-140 tons alone. (14; 16, p. 37 - 40.)

FIGURE 11. Nordex wind turbine's nacelle (61)

The main goal of road works is to make the transport route work for transportation. Transportation plans are made relying on simulation plans, but with a view to completeness, a final road inspection is performed. The name of this final road inspection is dummy run. (14.)

Dummy run is done when the access roads are completed. The dummy run is performed with a life-size replica of a wind turbine blade. A real-size replica is placed on the truck used for the actual transportation. The entire planned transport route is then driven and tested to determine if the route is suitable for transport. After the dummy run, final tree cutting works and road modifications will be made if necessary. (14.)

3.4.3.3 Cabling

Cabling works can be done simultaneously with access road works. The cabling works at this stage concerns medium voltage (MV) cables. The MV cables used in the wind farm are in the range of 10 to 35 kV. The International Electrotechnical Commission (IEC) has determined that the MV cable's range is between 1 kV to 100 kV. (44; 62.)

The size of the cable is expressed in mm^2, which means the cross-sectional area of the conductor under the sheath of the cable. The current resistance of the cable depends on the cross-sectional area, eg a 1,5 mm^2 cable copper conductor withstands a current of approx. 10 amperes. Conductor material used in wind farm's cables are copper or aluminium. MV cables can also be built by air, but in this thesis only buried cables are introduced. The cables are usually excavated near the road so that maintenance and construction work can be carried out easily. (14; 63.)

Wind turbine generators produce energy at voltages below 1000 V. This voltage can be converted higher with a transformer inside the nacelle. The Transformer can also be located separately in its own box in the vicinity of the WTG. Cable routing will begin from this transformer once excavation work on the cable route has been completed. MV cables run from wind turbine transformers along cable routes to the substation. The cables are brought to the construction site in wooden drums (figure 12). (44; 64)

FIGURE 12. Wooden cable drums (65)

3.4.3.4 Hardstands

Earthworks for the construction of hardstands vary depending on the foundation chosen. Earthworks may include e.g. blasting, piling, concrete casting, and earthmoving. Drainage must also be considered when constructing hardstands, as the area must be dry and must remain dry. (14; 16, p. 31 - 32; 49.)

Options for different hardstand foundations are

- Shallow foundations
    - Shallow foundation (49, p. 70 - 71)
    - Combined with soil improvement (49, p. 71)
    - Reinforced with geosynthetics (49, p. 71 - 72)
    - Mixed-in-place (MIP)/mass stabilization (49, p. 73)
- Foundation on a piled embankment (49, p. 73 - 74)
- Concrete-footed pile foundation (49, p. 74)
- Engineered Crane Mat-system (ECM).

In the shallow foundation method, the foundation layer is built on the supporting layer, the ground. The foundation layer can be put on the ground or it can be excavated a little in the ground. Crane Mats can be used to support the foundation layer. The advantages of this type of foundation are its inexpensive construction method, and no permanent concreting is required. However, there is a high risk that the bearing capacity due to the characteristics of the soil below. Shallow foundations can be improved by adding stronger soil types such as sand or gravel. Reinforcement can also be done using geogrids (figure 13). (49, p. 70 - 73.)

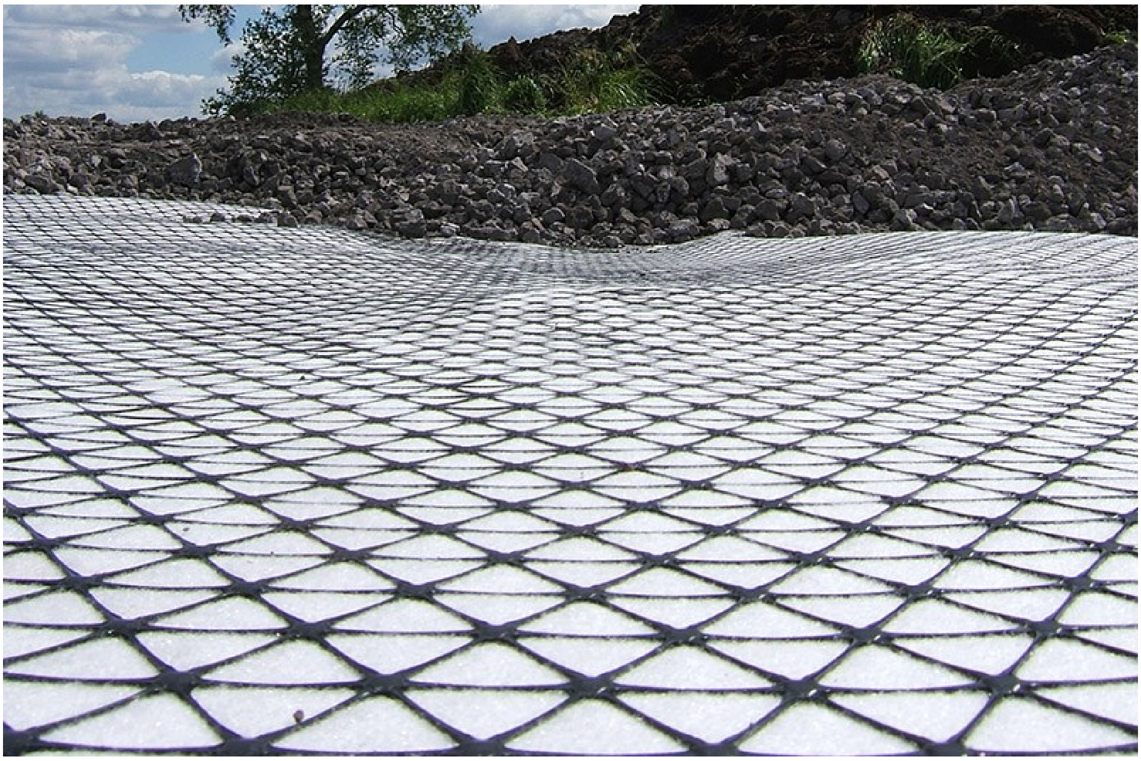

FIGURE 13, Geogrid (66.)

Shallow Foundations can be combined with a binding agent such as cement and lime. However, this method of reinforcement requires laboratory tests to determine the mixing ratio of the type of soil used and the binding agent used. (49, p. 73.)

Foundation on a piled embankment usually needs piling of the foundation area and a geogrid on top of it. However, piling can be replaced by, for example, Tensar company's Cellular Foundation Mattress System. Once the piling or cellular foundation mattress system is done, the embankment can be built on the foundation. (Figure 14; 49, p. 73; 67.)

FIGURE 14. Tensar's Cellular Foundation Mattress System (67)

One option for building hardstands comes from the United States. US Mat Systems company has a solution that can make the possible logistics and earthwork of the hardstand more efficient. The solution is called Engineered Crane Mat system (ECM). ECM's material is Douglas fir tongue-and-grooved laminated glulam beam. The ECM is reinforced with a steel channel frame and I-beam supports longitudinally. (Figure 15; 68; 69.)

FIGURE 15, Engineered crane mat (ECM). (68.)

ECM platforms are built on helical piles that allow for more environmentally friendly work. Once the crane work is done and the ECM platform is no longer needed, it can be removed by unscrewing the helical piles from the ground by damaging just a little of the soil below. For this reason, the ECM can be used, for example, in a tundra area where permafrost soil is very sensitive. Figure 16 shows the ECM hardstand built for the crawler crane and the general appearance of the wind turbine area. (69; 70.)

FIGURE 16. ECM hardstand for crawler crane (70)

3.4.3.5 Foundations

Up to hundreds of cubic meters of concrete and tens of tons of steel are needed to build the foundations of a wind farm. The amount of material required will be determined by the foundation chosen. The foundation is affected by the properties of the soil and how close the bedrock is to the ground. The foundations of an onshore wind farm can be divided into two different types, which are

- spread foundations
- piled foundations. (16, p. 29 - 31; 71, p. 1 - 3.)

A spread foundation spreads the loads caused by the weight and dynamic loads of the wind turbine on the surrounding soil. The shape of the spread foundation is usually cylindrical or a square prism. The foundation size class is precisely determined by calculation at the design stage to make it suitable for a turbine as a stable base. Reinforced concrete is used as construction material of the spread footing. Spread foundation is usually chosen when ground study report shows that the bearing capacity of the soil is strong. It is not used in soils that contain clay, silty clays or it is too organic, so the modulus of elasticity is low. Different types of a spread foundations:

- Shallow foundation
- Gravity foundation (71, p. 1 - 2.)

Shallow foundation is set up on ground or just beneath it. The base area of the shallow foundation is designed and built to such a size that it is not possible for a wind turbine to tip over. Shallow foundation benefits from its ease of construction and earthworks does not have to do much. The foundation is designed so that all loads and forces affected on the foundations must be focused on the ring interface (figure 17). (71, p. 1 - 2.)

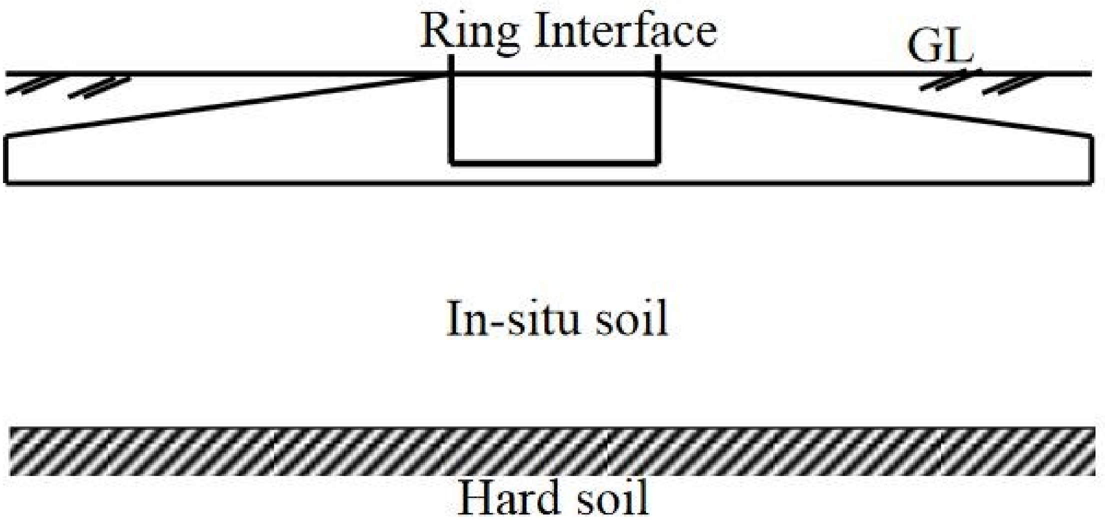

FIGURE 17. Shallow foundation (71, p. 2)

The Gravity foundation is built to a depth of a few meters below ground level. Excavation works are carefully done for this purpose. The shape of a gravity foundation resembles a shallow foundation, but it is not as large in size. Gravity foundation is constructed on strong soil layer. All loads and forces affected on the foundations must be focused on the ring interface. Pile foundations are recommended for places where soil is weak and/or soft. Soft soil needs a lot of land changes to make it strong enough for a spread foundation. (Figure 18; 71, p. 2.)

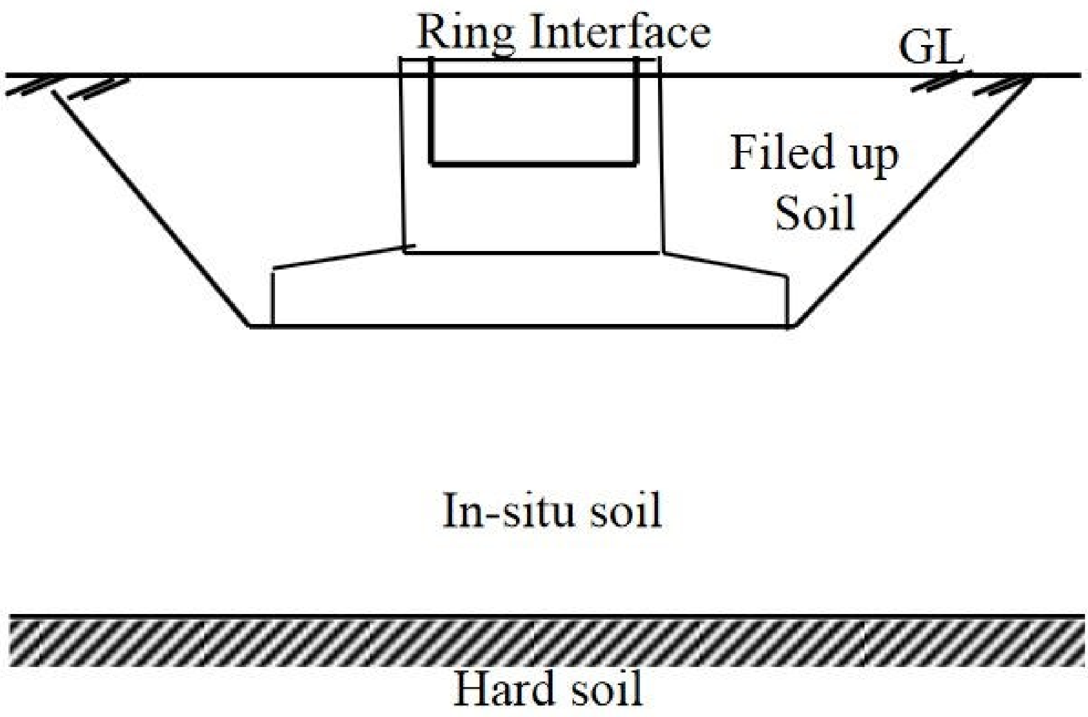

FIGURE 18. Gravity foundation (71, p. 2)

Pile foundations consists of a plate and a group of piles. The plate is usually either a steel plate or a concrete plate. There are two types of a connection between the plate and the group of piles:

- hinged connection
- clamped connection. (71, p. 2 - 3.)

The difference between these two connections is the bending moment that affects the piles. Hinged connection does not cause bending moment at all and in clamped connection the effect is large. (71, p. 2 - 3.)

Different types of a pile foundations:

- placement of piles on bedrock
- piled raft foundation. (71, p. 2 - 3.)

Ground study report provide information if bedrock is located at a reasonable shallow depth. In this case, strong bedrock is utilized, and piles are placed on top of it. In some foundation situations, it is found necessary to drill and anchor piles to the bedrock. Piles anchored in the bedrock ensure that tension loads are under control. However, rock anchoring is a moderately difficult task for designers because of the enormous amount of know-how and testing required to design it. (71, p. 3.)

Piled raft foundation is a combination of spread foundation and group of piles. This type of foundation takes advantage of both foundations. The foundations provide stability as well as soil and piles conduct loads from the wind turbine to the depths of the soil. Piled Raft Foundation does not benefit from being used in supportive soils because piles do not get enough support from it. (71, p. 3.)

3.4.3.6 Substation

Substation works are performed according to the following work steps:

1. prepare the substation site
2. excavation works and foundation
3. earthing grid
4. command building
5. backfill the foundations and substation yard
6. assembly of the steel structures
7. electrical equipment. (32; 60.)

Tree cuttings are done for the Substation site earlier and earthworks can be started. All the site's topsoil and deleterious material is cleared. Ground is levelled and analysed to begin excavation and foundation works. Excavation works include e.g., construction of drainage. Foundation needs formwork, after which concrete can be casted (figure 19). (32; 60.)

FIGURE 19. Foundations of substation equipment (72)

After the foundations, an earthing grid can be installed. A command building is then built in which all the control and protection equipment such as the SCADA system is placed. Once the foundations are completed, the site will be refilled with granular material such as gravel and sand. All supporting steel structures can then be installed to begin installation of the electrical equipment. Each installed electrical equipment is connected to the control room. Finally, the substation site is surrounded by a security fence to prevent animals or outsiders from entering the area. (32; 60.)

3.4.3.7 After works

After works are jobs that are done when BoP works, or TSA works are completed. After works are

- cable connection to WTGs
- restoration of roads and hardstands
- restoring entrance area. (14.)

After the installation of the WTGs, cable connections are made to connect the WTGs in the wind farm's cabling system. Once all construction work is completed, the roads will be restored to normal widths and unnecessary hardstands can be dismantled. (14.)

3.4.4 TSA Works

TSA works can be started when the turbine supplier requirements are met. The requirements include that the BoP works has been done and everything in the wind farm area is ready for the installation of wind turbines. (14.)

3.4.4.1 Transportation

TSA works begins with the transport of wind turbines and crane parts. Usually, large parts of the wind turbines are transported by ship to the port closest to the wind farm. Transportation planning is important because, for example, the transportation of long wind turbine blades deviates from normal traffic rules (figure 20). (14; 16, p. 23 - 24.)

FIGURE 20. Transport of the 88,4 meters long wind turbine blade (73)

Wind turbine parts are delivered before crane work begins. The parts have their own storage area in the wind turbine assembly area. The crane and the auxiliary cranes and equipment it needs are also transported. The individual part of the crawler crane weighs less than 45 tons, so it is easy to transport by truck. (16, p. 23 - 24; 74.)

3.4.4.2 Crane works

Crane works will begin once all the necessary equipment has been transported to the area. The crane is assembled in the area reserved for it with the help of auxiliary cranes. Usually in a wind project, the crane service is handled by TSA contractor's subcontractor. Crane works proceed systematically, first assembling the tower, then lifting the nacelle and the rest of the parts. (14; 49.)

This thesis reviews three types of cranes used in wind power:

- mobile crane
- tower crane
- climbing crane.

Two different types of mobile cranes are reviewed

- telescopic crane
- lattice boom crane.

Two different types of mobile crane's undercarriages are reviewed

- undercarriage on wheels
- undercarriage on crawler tracks. (49, p. 16 - 25.)

Liebherr LTM 1750-9.1 mobile crane is moving on wheels and it is telescopic boom crane. The wheel model is easy to move, as the main crane can move on its own at speeds of up to 85 km/h and this means fewer separate transports are required. It can lift to a height of 80 meters and a lifting load of 92,1 tons. As outriggers it has four hydraulic swing-out beams with hydraulic support jacks. When lifting work is prepared outriggers are supported on crane pads. With outriggers and counterweight, the crane can be balanced to stabilize and lifting work can begin. (Figure 21; 49, p. 16 - 25; 76.)

PICTURE 21. Liebherr LTM 1750-9.1 (75)

Liebherr LR 11350 is crawler and lattice boom crane. The crawler crane is transported to the area in parts by separate trucks. The great thing about the crawler crane is that it can be moved during lifting if necessary. However, movement is avoided, especially during extremely heavy lifts such as the nacelle. The LR 11350 succeeds in lifting wind turbines of all heights. Stability for the crane is done with a counterweight that is placed at the rear of the main crane. For heavier lifts, the counterweight is placed on a separate cart or swing. Separate outriggers can also be attached to the Crawler crane model to stabilize lifting. (Figure 22; 49, p. 16 - 28; 77.)

FIGURE 22. Liebherr LR 11350 crawler crane (74)

Liebherr 1000 EC-B 125 Litronic Flat-Top is tower crane. Lifting work is possible up to 195 meters and up to 125 tons. The tower crane must be built with a stable hardstand to which it is attached. The attachment is also made to the wind turbine tower. The advantage of tower crane is that it can operate in wind conditions of up to 65 km/h. (Figure 23; 49, p. 16 - 28; 79.)

FIGURE 23. Liebherr 1000 EC-B 125 Litronic Flat-Top tower crane (78.)

Lagerwey LCC140 is a climbing crane. The climbing crane allows the construction of a virtually infinitely high wind farm. It moves conveniently as mounted along the wind turbine tower as it progresses. Lagerwey LCC140 maximum hoisting weight is 140 tons. The advantages of the climbing crane are its compact size and no heavy-duty hardstand required. All that is needed is a moderately small installation site to attach the climbing crane to the first installed part of the wind turbine tower. The higher the wind turbine, the cheaper the climbing crane becomes. However, the use of climbing crane is less common because it requires special features for the wind turbine tower. (Figure 24; 80.)

FIGURE 24. Lagerwey LCC140 Climbing crane (80)

3.4.4.3 Electrical works

Before electrical work of the WTGs can begin, it must be ensured that a grid connection exists. Electrical works starts right after assembly of the WTG. WTG is energized immediately after installation. The next step is to install the windfarm controller and SCADA connection (Supervisory Control and Data Acquisition). The SCADA system monitors and controls the use of wind turbines. The SCADA system allows the collection of real-time data, which can be used to accurately maintain the efficiency of wind turbines. (14; 81.)

The main task of the windfarm controller is to adjust the voltage and frequency of the wind farm's electrical system. Controller has also the tasks of maximizing energy production and minimizing structural damage. (14; 82.)

3.4.4.4 Commissioning and testing

Installation work is complete, and WTGs are energized. The last phase of TSA works is commissioning and testing of the windfarm. During the commissioning phase of the wind turbine, it is inspected and checked that the turbine is ready for energy production and everything is installed correctly. The WTG and WTG's equipment are commissioned mechanically and electrically. Inspections of turbines must be free of material, electrical, mechanical, or other defects that could affect the operation of the turbine. (14.)

Test on Completion means the test period during which the turbine is tested for functionality. In the test, the turbine is operated for 120 consecutive uninterrupted hours. The turbine is tested at 4–20 m/s wind conditions and its nominal power is tested. Test inspects that SCADA-systems works for every single WTG and no limitation of power occurs during the test of completion.
When test on completion is completed, TSA works continues with Punch List works and taking over phase is ahead. (14; 83.)

3.4.5 Taking over

Each contract ends with a taking over process. The taking over process ensures that the work results in end result and quality agreed in the contract. The project owner is responsible for taking over inspection. Taking over inspection is performed in accordance with §71 of the YSE 1998.
It is possible for the contractor to request a taking over inspection when the construction work has been completed or when the work has progressed to the stage where it is time to carry it out before the inspection. (14; 29.)

Taking over request must be done in writing and then the inspection must begin within 14 days. The contractor's responsibility is to ensure, before the inspection, that the work is complete and that the quality is as agreed. The first task of the contractor is the delivery of commissioning documentation, which is inspected. If it is noticed that the documents are missing, then the process is started from the beginning. Once all the documents are found, in process can be proceed to the next step. In next step as built documentation is required from the contractor. If defects are found in these documents, correction is required. If the above steps are in order, a taking over inspection can be performed. (14; 29.)

Taking over inspection shall not occur if:

- taking over criteria are not met.
- the quality of the defects found during the inspection is such that they affect the further construction, commissioning or operation of the project.
- the defects found during the inspection are big and their monetary value exceeds the value of the defect agreed in the contract. (14; 29.)

Taking over inspection is accepted when the above three points are not met. If any of the above three points are met, correction is required and the whole process will be started from the beginning. An inspection record is kept of the taking over inspection, in which the results of the inspection are recorded. The inspection record is made in accordance with § 71 p. 5 of the YSE 1998. (14; 29.)

The inspection record includes

- whether the job is accepted for taking over
- reasons if the job is not accepted for taking over.
- defect correction schedule
- the start and end dates of the guarantee periods.

Before an entry is made in the inspection record, the contractor has the opportunity to make a statement on the defect, which is added to the record. (29.)

3.4.5.1 Taking over meeting

Taking over meeting goes through the inspection record and sets a schedule for repairing defects. A memo of the meeting is made, which serves as written evidence. When both parties to the contract reach an agreement, a Final Inspection Agreement will be signed. (14; 29.)

3.4.5.2 Final settlement meeting

The final settlement meeting is one of the most important of the contract, as it is where the final settlement of accounts is made. The final settlement of accounts shall be made in accordance with § 73 of the YSE 1998. The contractor must submit an individualized final settlement within two weeks of receiving the inspection record. The project owner will make a response to this final settlement, which will be reviewed at this meeting. The meeting agrees on the amount of money to be withheld, which will be released only after all work defects have been corrected. (14; 29.)

3.4.5.3 Taking over agreement

A final site inspection is performed to verify that the contractor has completed the required repairs. When all repairs have been made and the result is satisfied, a Taking over agreement can be signed. Upon signature, the final payment, usually 10% of the contract price, is made to the contractor. After this, the Taking over is completed, and warranty work can begin. The wind farm is ready for the operation phase. (14; 29.)

4 FLOWCHART

The task of the thesis was to create a flowchart for the commissioner that the company could use to guide the work phases of the construction phase of the wind farm. There is a need for a flowchart, as it serves as a guide, especially for new employees in the company. The goal was to make the flowchart as good as possible so that even more experienced employees would take it as a tool.

4.1 Flowchart

A flowchart is a diagram that shows a work process or workflow. In Flowchart, the steps of a process or workflows are described by blocks of different shapes. Flowchart shows how a process proceeds step by step and how different decisions affect the course of the process. (84.)

The direction of Flowchart should be considered so that its understanding is as clear as possible. In general, the top-down process is easy to follow. The flowchart can be clarified by adding different colour codes, shapes, and comment sections to different stages of the process. Various commonly used forms include e.g., rectangle, diamond, triangle, circle and oval. Generally, for example, a diamond-shaped block is used for decisions and one process is described by a rectangle. Flowchart's directions are described by arrows. (84.)

4.2 Flowchart of the construction phase of a wind farm

The final product created in the thesis, ie the flowchart guiding the work of the construction phase, was the most time-consuming part of the thesis. The flowchart was based on the construction of VSB's Juurakko wind farm. Part 3 of the thesis, which went through the construction stages, follows the hierarchy of building a real wind farm. The flowchart is created in the same hierarchical order.

The collaboration with the commissioner was smooth and the weekly Teams meetings facilitated the work of creating the flowchart. During the weekly meetings, the progress of the flowchart was reviewed, and feedback was provided by the VSB supervisor. Based on the feedback, the flowchart was modified in the right direction. When the flowchart was almost complete, at a mid-term seminar at the VSB office, it was analysed together with the VSB team. With the final comments received from the mid-term seminar, the flowchart took its final form.

4.2.1 Raw version of the flowchart

The Raw version of the flowchart was first created in Microsoft Excel. The tasks of the different phases were placed in Excel in chronological order and the overall picture was outlined. There were dozens of different tasks, plans, designs, and layouts, and combining them into a few blocks in a flowchart had to be carefully considered.

To create the flowchart, the commissioner provided material about the Juurakko wind farm, which revealed the construction hierarchy, different tasks, responsibilities, contract boundaries, schedules and milestones. In addition to the material provided by the commissioner, research and collection work was carried out to obtain comprehensive information on various wind and construction projects, European standards, contract terms, legal matters, work and design guidelines, and general literature. The broad knowledge base had to be delimited sensibly and summarized in the flowchart in a clear and understandable way. The flowchart created in Excel began to fill menacingly and it became difficult to follow. At this point, it made sense to move to using the diagram creation software that the commissioner required to be used.

4.2.2 Final version of the flowchart

The final version of the flowchart was made with a network diagram software created by Diagrams.net. Using the program was simple and easy. Only the placement of the progress arrows caused problems, but in the end a solution to that problem was found. With Diagrams.net's software, the work of the flowchart became clear, and it was possible to control the whole (figure 25).

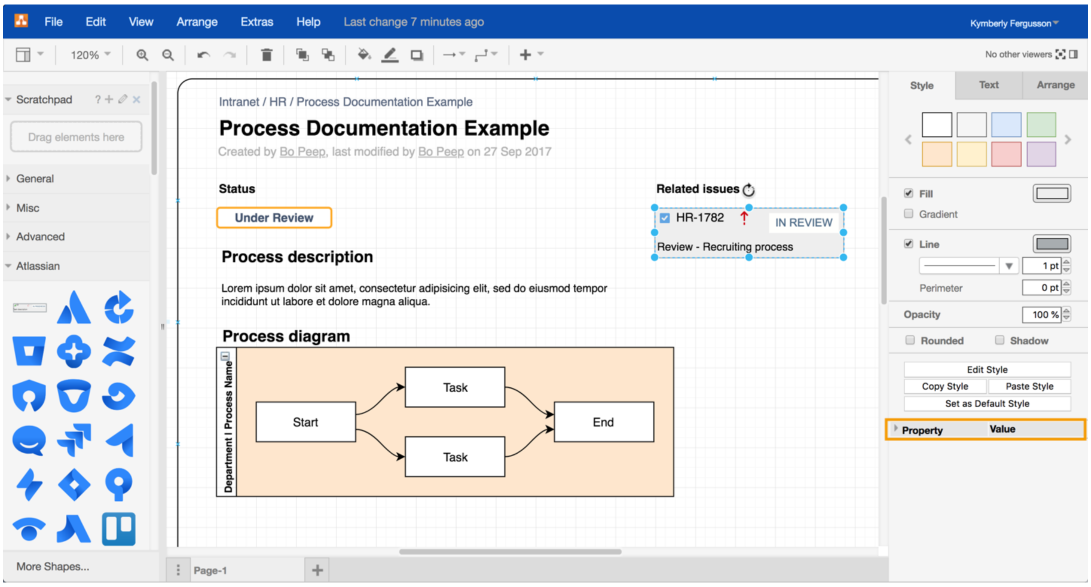

FIGURE 25. Network diagram software created by Diagrams.net (85)

The various stages of the flowchart exploded into pieces several times during the creative work and many ideas flew into the rubbish bin. However, the final version was completed on schedule and the commissioner was pleased with the result.

Flowchart of the construction phase of a wind farm is presented in appendices 1-4. Flowchart is strictly divided into three different sections and each appendix contains one of these steps. Appendix 1 presents the tendering phase's workflow, appendix 2 presents the workflows of agreements and design, and appendix 3 presents the construction phase's workflow. Appendix 4 contains the full version of the flowchart.

5 SUMMARY

The aim of the thesis was to study and obtain a broad knowledge base on the construction of a wind farm. At the same time, I wanted to learn more about wind power and gather a lot of know-how, as my interest in future employment in the wind power industry was high. I was interested in the cleanliness of the wind power and its environmentally friendly construction. I also wanted to know what the PPAs contained and why they have revolutionized the wind power business in recent years.

During the thesis work phase, I had to gather a good knowledge base and an understanding that I was able to create a flowchart to guide the construction phase of the wind farm. The Commissioner was helpful and clearly explained the importance of each work step and contract in the wind project. The Commissioner provided material related to the construction of the Juurakko wind farm. The information it contained was interesting to read. By researching and gathering additional material from the endless bank of the internet, I got a good idea of the overall picture of the wind project. As a result of the thesis, I was able to create a working flowchart that was what the company wanted.

The thesis taught me a lot and I gained more knowledge than I could hope for. I wanted to do the job of a genuine wind power expert and the work done met my desire. During the work of the thesis, it was great to realize and come up with solutions to get the work done. The work developed me a lot and my understanding of wind power expanded significantly.

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