Hyundai Engineering Co. Ltd.

Anma-do Offshore Wind Farm Project [Phase 2] Technical Advisory Service

Design Criteria and Design Scenarios for Phase 2 (Part 2)

Reference: AWF-ARUP-V-2.0-001

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This report takes into account the particular instructions and requirements of our client. It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 281874

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1. Introduction

1.1 Background

Korea Wind Energy Co., Ltd. ("KWC"), Hyundai Engineering Co ("HEC"), Korea Hydro & Nuclear Power Co. Ltd., ("KHNP") and Jeonnam Development Corp.("JNDC") in the Republic of Korea (Korea) entered into the Memorandum of Understanding on May 2019 which sets forth that the parties agreed to develop the Anma-do 220MW offshore wind power plant (the "Project") on 'build-own-operate (BOO)' basis in Korea. After that, Equis Wind (Korea) Holdings Pte.Ltd ("EQUIS") has joined in the Project since 2021. Therefore, the Consortium of KWC, EQUIS, HEC, KHNP and JNDC intend to develop the Project which involves the design, construction, operation, maintenance, finance and ownership of the Plant including all ancillary facilities, with around 528MW of gross capacity. HEC intended to form a consortium with an international consultant to participate in the Project and provide the Engineering service. Arup, with the support of ODE, has been commissioned by HEC to be the technical advisor for the concept design of the project.

1.2 Purpose of this Report

This is the Design Criteria (Basis) Report – Part 2: Electrical System and Grid Connection. The purpose of this document is to provide the background, basis and assumptions for the concept design of the electrical system for the phase 2 as well as the integration of phase 1 and phase 2 of Anma-Do Offshore Wind Farm Project with a total capacity circa 528MW. It details the methodology for conducting the required preliminary study on the connection to grid options (see **Table 1.1**) and the concept design of the major electrical elements such as cables and substations.

Design data available in this document are based on available documents regarding the site from the project specific document. If no suitable project data become available assumptions have been made based on the previous experience.

Two WTGs options will be investigated in this concept design phase as follows:

Table 1.1: WTGs Options

Phase 1	Phase 2	Total
8MW x 28, total of 224MW	8MW x 38, total of 304MW	8MW x 66, total of 528MW
10MW x 23, total of 230MW	10MW x 30, total of 300MW	10MW x 53, total of 530MW

Phase 1 is intended to be rolled out on day 1 with the additional capacity from phase 2 intended to be rolled out in a year time. Once phase 2 is commissioned, the wind farm is intended to be operated as one with a total capacity circa 528MW.

Connection to grid will be achieved through an onshore substation located on Jukdo island (subsequently will be referred to as Jukdo substation), close to the WTGs clusters, with export voltage of either 154kV or 230kV to a landing point on the mainland and mainland switching station or substation, depending on the export voltage, before onward connection to utility substation at West Yeongwang. Redundancy will not be investigated as per HEC's advise.

1.3 References and Nomenclature

1.3.1 Normative References

Reference	Title
DNVGL-OS-A101	Safety principles and arrangements
DNVGL-OS-D201	Electrical Installations

DNVGL-OS-D202	Automation, Safety and Telecommunication Systems
DNVGL-OS-D301	Fire protection
DNVGL-ST-0145	Offshore Substations

1.3.2 Applicable Codes and Standards

Reference	Title
KEPCO grid code	KEPCO transmission/distribution electric facility usage code, 20-10-2021
CIGRE, Technical Brochure 483	Guidelines for the Design and Construction of an AC Offshore Substations for Wind Power Plants
CIGRE 124	Guide on EMC in Power Plant and Substations
EN 54	Fire detection and fire alarm systems
EN 858	Separator systems for light liquids (e. g. oil and petrol)
EN 55014-1	Electromagnetic compatibility. Requirements for household appliances, electric tools and similar apparatus. Emission
IEC 61892-7	Mobile and fixed offshore units - Electrical installations - Part 7: Hazardous areas
IEC 60529	Degrees of Protection Provided by Enclosures (IP Code)
IEC 60812	Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA)
IEC 61000 (all applicable parts)	Electromagnetic compatibility (EMC)
IEC 61025	Fault tree analysis (FTA)
IEC 61882	Hazard and operability studies (HAZOP studies)
ISO 2394	General Principles on Reliability for Structures
ISO 31000	Risk management – Guidelines
ISO 9001	Quality management systems - Requirements
ISO 14224	Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment
ISO 15138	Petroleum and natural gas industries — Offshore production installations — Heating, ventilation and air-conditioning
ISO 14001	Environmental Management

1.3.3 Applicable Codes and Standards for Equipment

Reference	Title
IEC 62271 (all applicable parts)	HV Switchgear and Control Gear

IEC 60071 (all applicable parts)	Insulation Coordination
IEC 60076 (all applicable parts)	Power transformers
IEC 60079-10	Electrical apparatus for explosive gas atmospheres– Part 10: Classification of hazardous areas
IEC 60099 (all applicable parts)	Surge arresters
IEC 60300-3-11	Dependability management: application guide, reliability centred maintenance
IEC 60364 (all applicable parts)	Low-voltage electrical installations
IEC 60598 (all applicable parts)	Luminaires
IEC 61099	Insulating liquids - Specifications for unused synthetic organic esters for electrical purposes
IEC 63012	Insulating liquids - Unused modified or blended esters for electrotechnical applications
IEC 61643	Low-voltage surge protective devices
IEC 61936-1	Power installation exceeding 1 kVa.c. – Part 1: common rules
IEC 62305 (all applicable parts)	Protection against lightning
IEC 62485	Safety requirements for secondary batteries and battery installations
IEC 61869 (all applicable parts)	Instrument transformers
IEC 60044 (all applicable parts)	Instrument transformers
IEC 61439 (all applicable parts)	Low-voltage switchgear and controlgearassemblies
IEC 60947 (all applicable parts)	Low Voltage Switchgear and Controlgear
IEC 60214 (all applicable parts)	Tap Changers
IEC 60137	Insulated bushings for alternating voltages above 1000 V
IEC 60255 (all applicable parts)	Measuring Relays and Protection Equipment
IEC 60502 (all applicable parts)	Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV)
IEC 60840 (all applicable parts)	Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV)
IEC 62067 (all applicable parts)	Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV)
IEC 60287	Electric cables. Calculation of the current rating.
IEC 60794 (all applicable parts)	Optical fibre cables

BS 6622	Armoured cables with thermosetting insulation for rated voltages from 3.8/6.6 kV to 19/33 kV. Requirements and test methods
EN 61009	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs).
EN 60898	Electrical accessories. Circuit-breakers for overcurrent protection for household and similar installations.
EN 50288-7	Multi-element metallic cables used in analogue and digital communication and control. Sectional specification for instrumentation and control cables
BS 7846	Electric cables. Thermosetting insulated, armoured, fire-resistant cables of rated voltage 600/1 000 V for fixed installations, having low emission of smoke and corrosive gases when affected by fire. Specification
BS 7671	Requirements for Electrical Installations. IET Wiring Regulations.
EN 12599	Ventilation for buildings. Test procedures and measurement methods to hand over air conditioning and ventilation systems
EN 50052	High-voltage switchgear and controlgear. Gas-filled cast aluminium alloy enclosures
EN IEC 60376	Specification of technical grade sulfur hexafluoride (SF6) and complementary gases to be used in its mixtures for use in electrical equipment
EN 60865-1	Short-circuit currents. Calculation of effects. Definitions and calculation methods
EN 61936-1:2010+A1:2014	Power installations exceeding 1 kV a.c. Common rules
EN 60715:2017	Dimensions of low-voltage switchgear and controlgear. Standardized mounting on rails for mechanical support of switchgear, controlgear and accessories

2. Major OWF Components & Considerations

2.1 General Design Concept

Anma-Do wind farm design concept has a total installed capacity of 528MW in two phases. Ultimately, the wind farm is intended to be operated as one.

Figure 2.1: Typical wind farm concept

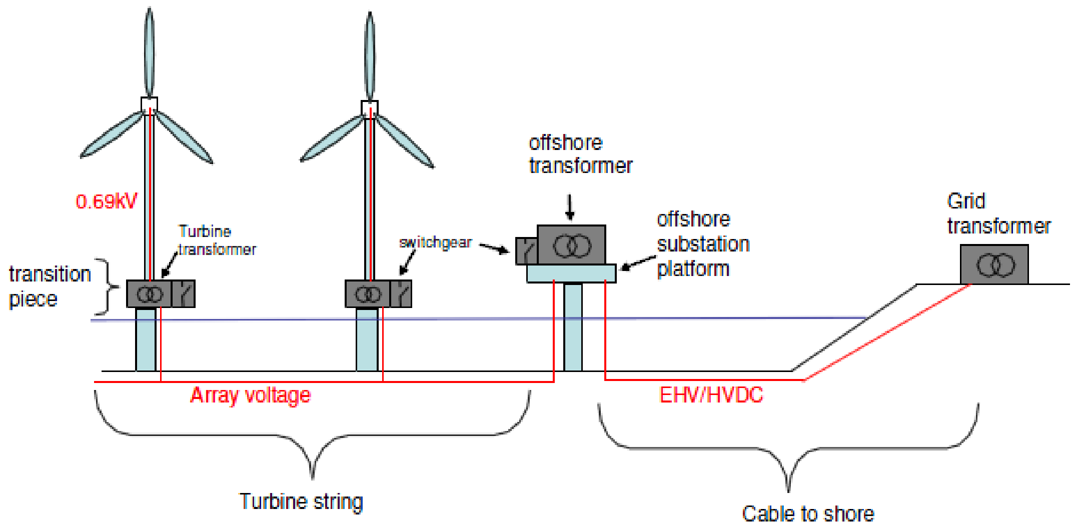


Figure 2.1 shows the typical wind farm concept, which an offshore substation will be provided for stepping up the voltage for transmission to the mainland. In the case for Anma- do wind farm, this offshore substation is substituted with a substation that is located on an island located nearby the WTG arrays. Electrically the wind farm will comprise:

- The wind turbine generators (WTGs) and associated wind turbine transformers to step the voltage from circa 1000V up to 66kV for onward transmission.
- WTG switchgear to provide a local isolation point between for the WTG and facilitate the interconnection to upstream/downstream turbines.
- 66kV EPR insulated subsea array cables developed for offshore wind utilise a lightweight, lead free, cable design to facilitate installation; minimise installation time and maximise vessel load out, which can be procured in the UK and European market, or alternatively, if EPR insulation cable is not available, XLPE insulation that is commonly available for subsea cable can be utilised
- Transmission cables (154kV or 230kV)
  - 3 core designs will be adopted for offshore cables for ease of installation both subsea and overhead on Songi island
  - Onshore cables will be conventional single core cable designs installed in trefoil or flat formation. The single core designs are a necessity for practical reasons to allow reasonable lengths to be transported by road.

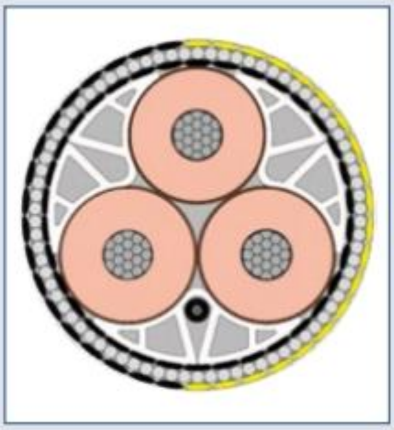
2.2 Array Cables

66kV subsea array cables developed for offshore wind utilise a lightweight, lead free, cable design to facilitate installation; minimise installation time and maximise vessel load out. **Figure 2.2** shows the details of 66kV array cables, which utilises EPR insulation. Table 2.1 shows the typical 66kV subsea cable technical data that has been adopted in this analysis.

Array cables are 3 core and can be supplied with either aluminium or copper conductors. The minimum cable size is usually limited to circa 240mm^2 for practical/mechanical reasons and the maximum 800mm^2 for Copper and 1000mm^2 for aluminium, though larger values are possible. Based on previous study for phase 1 and availability of supply in Korea, 300mm^2 and 800mm^2 copper cable will be utilised for the Anma-do offshore wind farm.

Array cables are expected buried in trenches at circa 1-2m depth to protect against damage and at spacings of circa 50m, depending on water depth, to allow for repairs where more than one is utilised.

Figure 2.2: EPR insulated 66kV Array Cables



Conductor	Copper or aluminum conductors longitudinally water blocked
Conductor screen	Extruded semi conductive compound
Insulation	EPR
Insulation screen	Extruded semi conductive compound
Screen	Individual Cu-tape screen on each phase
Fibre optic unit	Up to 3 FO units with metal tube
Lay up	Three power cores laid up with extruded fillers
Armour Bedding	Polypropylene yarns
Armouring	One layer of galvanized steel wires, flushed with bitumen
Outer protection	Polypropylene yarns in customisable colours

Table 2.1: Typical 66kV array copper cable technical data

Cable element	Dimension	3 x 300 mm²	3 x 800 mm²
Conductor Diameter	mm	20.4	33.7
Insulation Thickness	mm	9	9
Diameter over insulation	mm	40.8	54.5
Lead sheath thickness	mm	1.6	2.1
Outer diameter of cable	mm	143.0	167.0
Cable weight in water (copper)	kg/m	34.3	60.1
Capacitance	µF/km	0.24	0.35
Inductance	mH/km	0.37	0.32

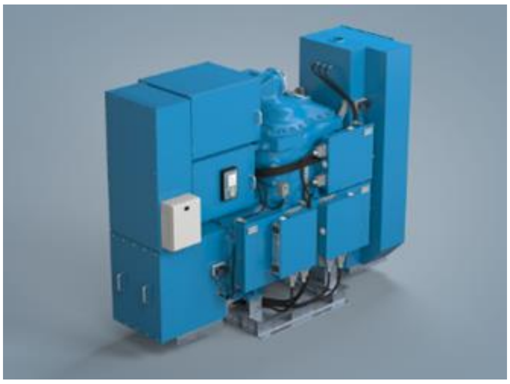
A tapered radial string configuration will be used as the basis of the analysis in this concept design stage with optimisation part of the FEED stage of the project.

2.3 WTG Switchgear

WTG switchgear will be installed to provide a local isolation point for the WTG and facilitate the interconnection to other WTGs on the array string. The WTG switchgear must be appropriately rated for the voltage level and current rating of the arrays to which they will be connected.

WTG switchgear will be designed to be compact to fit into the turbine tower or transition piece. However, increases in the rating of the switchgear, generally, requires increases in the dimensions of the switchgear. Current WTG switchgear designs will be based around 66kV rated equipment and is part of the WTG package.

Figure 2.3: Examples of 66kV WTG switchgear



Siemens 8VM1 66kV WTG switchgear

Hitachi ABB PASS M00 66kV WTG switghear

2.4 WTG Transformers

WTG transformers are OEM specific equipment and will be part of the WTG package.

Figure 2.4: Examples of 66kV WTG transformers

ABB WindSTAR 66kV WTG transformer

Siemens 66kV WTG transformer

2.5 Jukdo substation

Jukdo substation is mainly identical to an onshore substation albeit located on an island offshore the mainland and comprises the main transformer, reactor and both the array and export switchgear to facilitate the step up from the 66kV array voltage to the transmission voltage (154kV or 230kV).

It is presumed a standard minimalistic approach will be taken with respect to equipment housing, with the transformer and reactors (if any) mounted in free air. Rooms housing protection cabinets and SCADA equipment would be expected to be designed together with rooms for the switchgear inside the substation building, which could span across multiple storeys. Additionally, space is generally allowed for auxiliary systems and personnel accommodation.

2.5.1 Electrical Equipment

An overview of the main electrical equipment installed on the different platform is as below.

- Main transformer (2 x 360MVA)
- Array switchgear (66kV)
- Export switchgear (154kV or 230kV)

- Station control, monitoring and automation system
- Auxiliary / Earthing Transformers

2.5.2 Export Switchgear

Both 154kV and 230kV switchgear will be considered for the transmission system depending on the export voltage. Gas Insulated Substation (GIS) will be utilised to optimise spatial requirement.

2.5.3 Array Switchgear

Current designs with 66kV array circuits are utilising GIS switchgear with higher voltage ratings to cater for the high current requirements of designs over 350MVA.

2.5.4 Power Transformer

Power transformers used in the layouts are naturally cooled ester oil filled units. The use of ester oils, natural or forced cooling, remote radiators, and the potential for removing fire suppression equipment varies with the requirements of developers. A single style of design will be used for consistency.

Firewalls have been provided between transformers regardless of the use of ester oil filled units in accordance with DNV requirements.

A single 360MVA transformer will be utilised at day 1 to cater for phase 1 of the Anma-do wind farm with additional 360MVA transformer added as part of phase 2. Civil works for both transformers will be prepared at day 1 although the second transformer will not be installed at day 1 to maximise warranty period.

2.5.5 Station control, monitoring and automation

In addition to housing the primary equipment, the Jukdo substation will also house control, monitoring and automation equipment including but not limited to protection panels, metering panels and SCADA cabinets.

2.5.6 Auxiliary Systems

Jukdo substation will also house the systems including LV systems (substantially lighting and small power), telecoms equipment, HVAC, safety systems and personnel facilities. DC auxiliary system including batteries and DC distribution board will also be included if required.

Auxiliary “stand-by” generation is not provided as standard but could be included if required.

LV auxiliary supplies are derived from auxiliary transformers fed from the Main transformers.

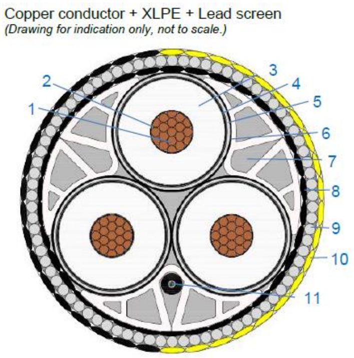
2.6 Export Cable

Export cables refers the cables that transmits the power to the connection point at the onshore mainland substation or switching station. It includes both the single core onshore cables as well as the three core offshore cables. For the offshore export cables, the scenarios considered assume that the transmission system used to transmit power back to the mainland would be either 154kV or 230kV from Jukdo substation. This export cable will be a combination of subsea cable and land cable.

The selected design is independent of array design and is, thus, consistent for each option considered.

The size and number of export cables required to connect the Jukdo substation is dependent upon the rating and design of the offshore windfarm, including requirements for redundancy.

Figure 2.5: Cross-section of a typical subsea export cable



1	Conductor	Stranded round compacted copper conductors class 2, longitudinally water blocked
2	Conductor screen	Extruded semi conductive compound
3	Insulation	XLPE
4	Insulation screen	Extruded semi conductive compound
5	Metallic screen	Extruded Lead sheath
6	Anticorrosion sheath	Extruded PE sheath
7	Fillers	Extruded PE shaped fillers
8	Armour Bedding	Polypropylene Yarns
9	Armouring	One layer of non-magnetic wires
10	Outer protection	Polypropylene Yarns
11	Optical unit	Up to 48 fibres for each unit

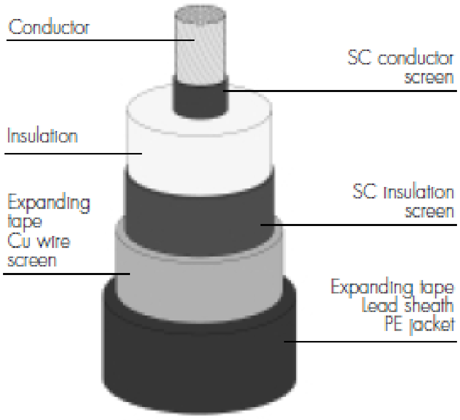
Table 2.4: Dimensions of a typical three core 154kV subsea export cable

Crosssection of conductor (mm^2)	Diameter of conductor (mm)	Insulation thickness (mm)	Diameter over insulation (mm)	Lead sheath thickness (mm)	Outer diameter of cable (mm)
500	26.2	18	65.0	2.5	190
630	29.8	17	66.6	2.5	194
800	33.7	17	70.5	2.7	204
1000	37.9	17	75.3	2.8	215
1200	43.7	17	76.0	2.2	206
1600	46.3	16	78.5	2.2	210
1800	49.1	16	82.4	2.2	225
2000	51.9	16	86.2	2.2	237

Table 2.5: Dimensions of a typical three core 230kV subsea export cable

Crosssection of conductor (mm^2)	Diameter of conductor (mm)	Insulation thickness (mm)	Diameter over insulation (mm)	Lead sheath thickness (mm)	Outer diameter of cable (mm)
500	26.2	24	77.6	2.9	219
630	29.8	23	79.2	3.0	224
800	33.7	23	83.1	3.1	234
1000	37.9	23	87.3	3.1	241
1200	41.2	23	90.6	3.1	248
1400	44.4	23	93.8	3.1	255
1600	47.4	23	96.8	3.1	261

Figure 2.6: Typical Onshore Single Core Cable



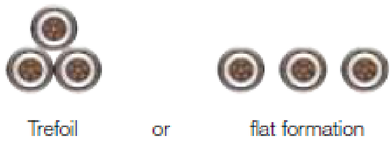


Table 2.6: Typical 154kV single core Copper Cables Dimensions and weights

Crosssection of conductor (mm^2)	Diameter of conductor (mm)	Insulation thickness (mm)	Diameter over insulation (mm)	Crosssection of screen (mm^2)	Outer diameter of cable (mm)	Cable weight (Cu-conductor) (kg/m)
400	23.2	19	63.6	95	77.7	8
500	26.2	18	65	95	79.1	8.9
630	29.8	17	66.6	95	80.9	10.2
800	33.7	17	70.5	95	85.4	12
1000	37.9	17	75.3	95	91	14.3
1200	42.8	17	81.8	95	97.9	16.7
1400	46.4	17	85.4	95	101.9	18.8
1600	49.8	17	88.8	95	105.5	20.9
2000	54.4	17	93.4	95	110.3	24.9

2.7 Onshore mainland substation/switching station

The onshore substation (mainland) or switching station (where no main transformer is required) provides the interface with the wider transmission system and includes the necessary EHV switchgear, transformers (if the export voltage does not match grid voltage), reactors, auxiliary systems, and control systems. Typically, the switchgear will be compact indoor, gas insulated (GIS) design to minimise footprint and visual impact. Outdoor air insulated switchgear may be possible where sufficient space is available and planning requirements allow. As with the power transformers, the reactors used are assumed to be naturally cooled ester oil filled units. Firewalls are provided between circuits.

Other plants required at the onshore mainland substation/switching station will include:

- Transformer noise enclosures, depending on the noise study
- Auxiliary transformers
- LV Systems
- Reactors, STATCOMs, or other reactive compensation

- Control and protection systems
- Telecommunications equipment
- Miscellaneous equipment.

Aside from the electrical equipment, building works, and miscellaneous civil works will be considered.

The control building will house the control room and telecoms room, LVAC and LVDC supply equipment, protection equipment, metering equipment and operator facilities including mess room, etc.

2.8 Grounding/ Earthing & Lightning

Grounding/ earthing of wind turbines generators, submarine cables, land cables, Jukdo substation and mainland substation or switching station will be provided to ensure safe operation of the complete system.

In addition, Lightning protection systems will be considered to protect the wind farm from lightning strikes.

3. Design Assumptions

At this stage of the project full data is not available and thus assumptions will have to be made. The intent at the concept stage would be to be cautious, without being overly conservative, to ensure that equipment proposed falls within standard ranges. Full optimization of the wind farm electrical system design would be possible at later stages of the project.

Costs would be derived from inhouse databases and both availability and losses, which ultimately form part of any cost assessment, would be determined on an annualised basis, based on a combination wind distribution for the site and turbine power curves, allowing for wake effects. Results will depend on the accuracy of the input data but for comparative analyses (between options) generic wind profiles and turbine power curves would be sufficient if site specific data is not available.

The technical information defined is summarized as follows:

- Installed WTG capacity — 528MW (224MW for Phase 1 and 304MW for Phase 2) to be operated as one once phase 2 is online
- Offshore array voltage — 66kV
- Submarine HV cable voltage — 154kV or 230kV
- Number of WTGs — 53 to 66
- WTG Capacity — 8MW to 10MW
- Turbine rating — 8MW, 10MW
- Subsea export cable — 41km (between Jukdo substation and Songi island and Songi island and mainland)
- Onshore export cable — 1.4km OHL on Songi island
- Underground cable — 7.6km from switching station to KEPCO West Yeongwang substation

3.1 Option 1

For this option, the array cables at 66kV are connected to an Jukdo substation and then stepped up before transmitting the power through HV cables to the shore. The transmission of power to the shore at a voltage level of 154kV to match grid voltage for direct connection to the grid. A switching station consisting of reactor and circuit breaker will be required on mainland before onward transmission to the utility substation through underground cable. This option will consider turbine sizes 8MW and 10MW. In total 2 scenarios will be analysed in this option.

3.2 Option 2

For this option, the array cables at 66kV are connected to an Jukdo substation and then stepped up before transmitting the power through HV cables to the shore. The transmission of power to the shore at a voltage level of 230kV will be considered. As this voltage does not match the grid voltage of 154kV, the voltage will have to be stepped down at the mainland substation via a 230/154kV transformer. This option will consider 8MW and 10MW turbine sizes. In total 2 scenarios will be analysed in this option.

This gives a total of 4 options for the analyses carried out in this study. **Table 3.1** presents a summary of the different options.

Table 3.1: Summary of options for study

Options	Connection voltage to the grid	Connection to grid options	WTGs options	Redundancy
OP1A	154kV	Array cables to Jukdo substation and HV cables to the mainland	8MW x 66	none
OP1B	154kV		10MW x 53	
OP2A	230kV		8MW x 66	
OP2B	230kV		10MW x 53	

3.3 Requirement and Methodology

The following relevant information for the Anma-do wind farm has been extracted from KEPCO grid code as a main basis of design to be adhered to in the design and assessment:

- In principle, generators will be connected to the grid through the utilisation of a collector bus to smooth out output fluctuations
- Generator must have a fault ride through capability and reactive power supply capability in times of fault
- Generator must be capable of continuous operation within 10% of 154kV
- Maximum total harmonic distortion of less than 1.5%
- The active power exported to the grid cannot exceed the previously agreed amount
- The load power factor should be kept above 0.9, generator should maintain the ability to supply reactive power within 0.9 lagging pf to 0.95 leading pf at rated voltage
- The generator must have capability to maintain continuous operation within 5% of rated terminal voltage and frequency between 58.5Hz to 61.5Hz

The methodology proposed for the assessment considers the following:

- The number and size of the subsea cables back to shore and onshore cables back to the onshore mainland substation have been chosen allowing for real and reactive (charging current) power flow based on the reactive power compensation undertaken onshore.
- The wind turbine transformers have been sized for the capacity of the wind farm allowing for minimum voltage of 0.9pu and 0.9 pf leading to lagging, operating as this is the expected operating range of the turbine generators and the minimum requirement for grid code compliance.
- For operating conditions reactive compliance/voltage control assumes the use of a STATCOM which shall be included as part of the onshore mainland substation.
- Cable lengths are based on the horizontal distance between turbines and platforms. It should be noted that the actual lengths shall also consider the up & down length. Nonetheless, the slightly simplified calculation is sufficient for the concept design purpose.
- The array cables will be sized for the maximum current flow that is expected to flow in them, which occurs when the turbines are exporting real and reactive power and operating a power factor of 0.9 and voltage of 0.9pu.
- The base case array layout will consider tapered strings with two cable sizes: 800mm^2 and 300mm^2 copper cable proposed. 800m^2 is considered the maximum practical, widely available, size for array cables.

- The assessment uses, where possible, typical in-house component and installation costs to provide weighting between options and a consistent comparative assessment of alternative configurations using the Capex and lifecycle cost of each option. Cost information has been gathered from various sources and cross referenced where possible to ensure that they are reasonable.
- Electrical losses in the electrical system between the turbine LV output and the point of connection with the TSO are calculated by evaluating the losses at each wind speed. Using the wind distribution for the site and the turbine power curve the net power output, for each wind speed and after losses (e.g. due to the wake effect), for the turbines can be established. For each case the losses in the system are calculated using a simplified MS Excel model, assuming unity power factor operation, and then combined with the associated number of hours per year to derive annual losses. The results are presented as a percentage of annual output. Losses have been calculated as follows:
- Transformers and cable losses are related to the current flowing through them and so as the wind fluctuates the losses in the equipment will also change. Careful design of the transformers and selection of cable can reduce losses, but this will have an impact on capital costs.
- The following transformer and reactor losses no load losses are assumed in the calculations:
    - Transformer: 0.05%
    - Reactor: 0.25%
- Due to the agreement with KEPCO and the location of the metering, the burden of loss on the 154kV transmission line falls on KEPCO whereas the burden of loss on the 230kV transmission line, should this option be chosen, will be borne by Anma-do.
- The wind distribution shall allow for wake effects and to provide a suitable range of wind farm outputs against probabilities.
- Availability calculations based on typical Mean Time to Repair (MTTR) and Mean Time to Fail (MTTF) scenarios have been developed to test the design options. This approach helps circumvent the issues of limited and low-quality reliability data for array cables and other offshore components. As with losses availability calculations are based on a “full-year” approach taking into account the wind duration curves and turbine power curves. This assesses any part-load benefits and partial/full cable redundancy.

4. Electrical System Concept Designs

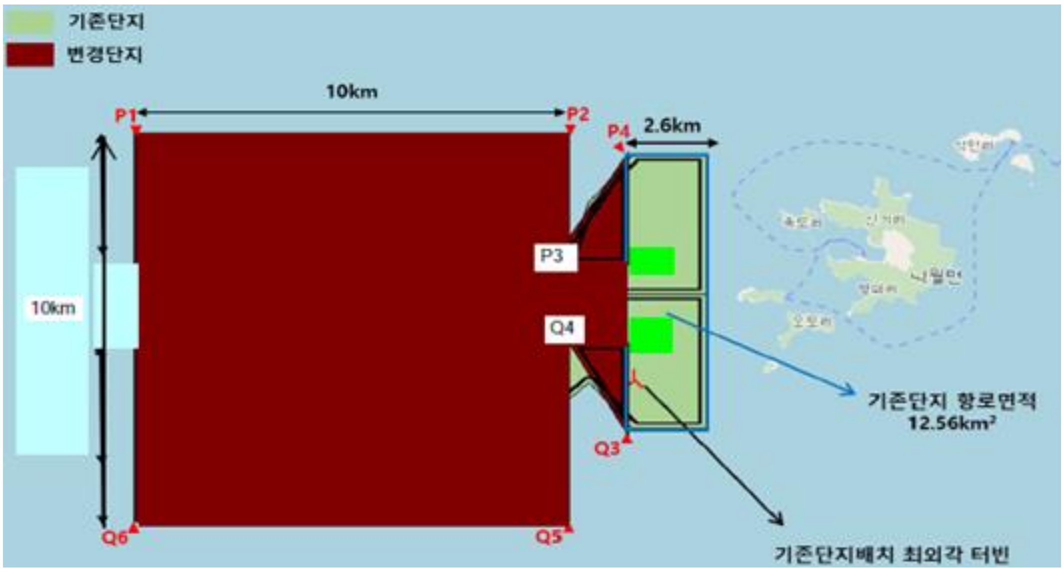
4.1 General

The options being considered offer a range of equipment and transmission options. The remit is to develop each concept sufficiently so that the merits and disadvantages of each can be assessed and compared.

4.2 Cable Array

The wind turbine array cable layouts are to be selected based on the provided geographic information system (GIS) data on the location of the wind turbines to provide the best cabling solution. WTG sizes of 8MW and 10MW are to be considered.

Figure 4.1: Footprint of WTG arrays



Though there are a variety of ways to connect wind turbines, this study assumes a radial connection of the WTGs and a limited tapered string approach using two (copper) cable sizes 800mm^2 and 300mm^2. Smaller cables are placed at the far end of each array and larger cables nearer to Jukdo substation.

The maximum number WTGs per string for each option, WTG rating, and voltage level can then be determined, as shown below.

Appropriate cable selection is done based upon current rating and WTG MW rating, allowing for minimum voltage operation (0.9pu) and power factor (±0.9). Based on manufacturers typical data a 3-core 66kV Cu cable with cross sectional area (CSA) of 800mm^2 at a burial depth of 1m (ambient temp of 20^{o}C, and thermal resistivity of 1km/W) is rated at 775A while the equivalent for 300mm^2 is 530A. For practical reasons, the number of array cable options is usually limited to 2 cable sizes. For this concept design, cable sizes have been limited to 800mm^2 and 300mm^2 only. Each string will have 8x8MW WTGs or 7x10MW WTGs.

Cable selection for the 3 WTG sizes is shown in **Table 4.1**.

Table 4.1: 66kV Array cable selection based on array cable rating and WTG size

8MW			10MW		
No of WTGs	Current (A)	CSA	No of WTGs	Current (A)	CSA
1	86.4	300mm2	1	108.0	300mm2
2	172.8	300mm2	2	216.0	300mm2
3	259.2	300mm2	3	324.0	300mm2
4	345.6	300mm2	4	432.0	300mm2
5	432.0	300mm2	5	540.0	800mm2
6	518.4	300mm2	6	648.0	800mm^2
7	604.8	800mm2	7	756.0	800mm^2
8	691.2	800mm2			

4.3 Transmission Cables

The transmission system has been based on 154kV and 230kV. The selected design is independent of array voltage and is thus consistent for each option considered. The selection is based on a 41km distance subsea cable from Jukdo substation to Songi island and Songi island to switching station/mainland substation on the landfall, 1.4km OHL on Songi island and 7.6km underground cable onshore between the landfall to KEPCO substation at West Yeongwang. The charging current is calculated using 60 Hz which is the operating frequency for of the grid where the windfarm is to be connected. The reactive compensation is sized considering the total charging current of the offshore transmission cables between Jukdo substation and landfall. Tentative cable route is shown in **Figure 4.2**.

Figure 4.2: Tentative export cable route

For the basis of these studies cable ratings are based on one thermally isolated cable circuits with a sea bed/ground temperature of 20ºC, depth of laying of 1m an thermal soil resistivity of 1km/W.

4.4 Jukdo substation

The Jukdo substation includes the array switchgear and 2 x 360MVA step up transformers (one at day 1 and an additional one as part of phase 2 implementation) to convert the array voltage to the transmission level voltages of 154kV or 230kV. Transformer ratings are selected to match the load, allowing for a reasonable voltage tolerance (10%) and 0.9 power factor operation.

4.5 Onshore mainland substation

The grid voltage of the network where the windfarm is connected is 154kV. This implies that there will be onshore transformers installed for OP2A and OP2B that involve transmission at 230kV to step the voltage down to 154kV to match grid voltage. The need for onshore transformers is eliminated for OP1A and OP1B where power is transmitted at 154kV. However, a disadvantage of this would be the loss of voltage control thereby subjecting the export system to the whole range of TSO voltages.