System Service Provision
An independent view on the likely costs incurred by potential System Service Providers in delivering additional and enhanced System Services.

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1 EXECUTIVE SUMMARY

To meet Government targets for Ireland and Northern Ireland, of 40 % renewable energy penetration by 2020, fundamental changes to the power system of Ireland and Northern Ireland are needed. Through the DS3 system services review, which was put in place by EirGrid and the System Operator for Northern Ireland (SONI), the challenges of ensuring sufficient system services have been identified.

TSOs have asked DNV KEMA to indentify what additional capital investments needed to meet these new system service requirements from a range of different technologies. EirGrid developed two principle areas of asset upgrades:

1. A Generation Solution, including Wind, CCGT, OCGT and Coal fired power plants
2. A Network Solution, including Flywheel, STATCOM, Synchronous condensers and Batteries.

The costs calculated in this report represent the general technical enhancement for each technology which enables/ allows compliance with the proposed new system service provisions.

Summary			
Generation Technologies	Units Size	Base Case	Enhanced
[Name]	[MW]	[Normalised Cost, EUR/kW]	
Wind	2	2,125	139
CCGT_new	450	800	30
CCGT_existing	450	800	122
OCGT_new	50	650	74
OCGT_existing	50	650	143
Thermal (Coal)	650	1,300	83[1]
Network Technologies	Units Size	Total Cost	
[Name]	[MW or MVA or MVAR]	[EUR]	[EUR/kW, EUR/kVA, EUR/kVAR]
Flywheel (5 MWh)	20	15,328,000	766
STATCOM	50	5,428,000	109
Synchronous Condenser	75	4,726,500[1]	63[1]
Batteries (10 MWh)	40	33,170,000	829

DNV KEMA is confident that, within the short timeframe provided for the research, the figures in this report are representative of what the likely impact of the proposed system service provisions on the capital investments necessary to facilitate the high renewable energy penetration moving towards 2020. DNV KEMA has used its experience and expertise to present the capital costs that are highly likely to be incurred, see the 'Enhanced' column in the summary given above[1] for generator Technology Solutions and the 'Total Cost' columns for Network Technology Solutions.

[1] The numbers of coal and synchronous condenser conversions are only an indication, because of the bespoke nature of these installations, further explained in this report.

2 INTRODUCTION

The Government targets for Ireland and Northern Ireland (NI) are to have 40% renewable energy penetration by 2020. This will require fundamental changes to the power system. Through the DS3 system services review, which was put in place by EirGrid and SONI, the challenges to ensure sufficient and appropriate system services have been identified. EirGrid and SONI have put in place a multi-year, multi-stakeholder programme of work, “Delivering a Secure Sustainable System” (DS3), to enable efficient, reliable and secure power system operation. In earlier detailed studies and technical analysis the TSOs established the need for additional system services, and also proposed new products which address the emerging challenges associated with achieving the governments’ renewable energy policy objectives.

To achieve the government renewable energy policy objectives will, however, require a transformational change in plant portfolio and operational policies. The studies, carried out by the TSOs, indicated that greater capabilities than are defined in the current Grid Codes are required in order for the renewable targets to be achieved.

One of the critical success factors in managing these challenges is to ensure that the entire system portfolio of generation and demand side have the necessary capabilities and are utilised in an appropriate manner.

These changes include:

- New Grid Code standards on Rate of Change of Frequency capability for the power generation assets
- New Grid Code standards for wind farms:
    - Reactive Power Range
    - Dynamic Active and Reactive Power during and after faults
    - Improved frequency response provision
- Revised ancillary/system service payment structures that incentivise the provision of particular technical characteristics/services based on the needs of the power system when operating with very high levels of non-synchronous plant

3 REPORT STRUCTURE

This report highlights the technical and financial necessities for each technology regarding the ancillary services proposed by the TSOs, namely:

- For the Generation Solution:
    - Enhanced fault ride through
    - Enhanced voltage control
    - Reduction of the technical minimum load
    - Inertia enhancement
    - Enhanced frequency response
    - Reduction in ramp-up time of the technology
- For the Network Solution:
    - Ancillary services through Synchronous compensators
    - Ancillary services through STATCOMs
    - Ancillary services through Synchronous condensers
    - Ancillary services through Batteries.

DNV KEMA was asked to provide a cost indication for the following technologies:

- Wind
- new CCGT
- existing CCGT
- new OCGT
- existing OCGT
- Thermal power plant (Coal fired power plants)
- Flywheel
- STATCOM
- Synchronous condenser
- Batteries

This report considers the technical and financial requirements for each technology regarding the ancillary services proposed by EirGird and SONI.

In section 5 the technical requirements, from now on referred to as enhancements, and the total proposed capital investments are summarised for each technology. For both the Generation and Network Technologies a short technical explanation is given. For the Generation Technology it is explained why the enhanced costs need to be incurred if the technology must be capable of delivering the ancillary services proposed. Note that for the Network Technology installations, the sole purpose is to provide ancillary services, hence enhanced costs alone do not apply so the total installation costs are provided.

It is important to note that the costs of technologies provided in the table cannot be directly compared to each without considering the context of the types and volumes of services provided. For example, the capabilities for the Wind Technology are different to the other CCGT Technology which in turn are different to the OCGT Technology.

4 PROJECT APPROACH AND METHODOLOGY

DNV KEMA used their extensive knowledge and expertise to give a summary for each technology enhancement and their implications. First the technical implications were identified for each enhancement in each technology and then the cost implications were calculated using reference projects within our company.

The cost figures shown in this document are not an exact estimate but a guideline of the main financial implications for the provision of additional ancillary system services. DNV KEMA was asked for a generic picture for each technology considering the portfolio in Ireland and Northern Ireland. Without detailed investigations on each specific asset in Ireland and Northern Ireland it is not possible to cover all local issues with regards to specific modifications and the accompanied costs.

For most technologies a reliable accuracy level with regards to the figures has been achieved. However thermal (Coal fired) power plants and synchronous condenser conversions (for instance) are highly bespoke installations and therefore an accurate calculation in general cannot be developed. Therefore for Coal fired power plants and conversion of existing generators to synchronous condensers only rough estimates could be provided. The generic nature and approach to this review capital investment figures are not appropriate to apply to any single operating or designed asset. However, this paper presents the important constraints and enhancement costs and provides guidance on the changes needed to accommodate high penetration of renewable energy sources.

5 TECHNOLOGIES

5.1 Generation Technology: WIND

5.1.1 Costs

The table below gives an overview of the costs proposed to make the wind turbines capable of delivering the enhanced ancillary services.

Wind							
			Capex				
Capacity	2	[MW]					
Normalised built cost			Total	4,249,500	[EUR]	2,125	[EUR/kW]
Enhanced cost			Total	325,600	[EUR]	139	[EUR/kW]

5.1.2 Short technical explanation

On average 37 % by 2020 has to come from wind. At times this might represent up to 75 % of real time system energy. To make sure that the grid in Ireland and Northern Ireland can facilitate this, the following fault ride through enhancements is proposed by the TSOs as a result:

		A Current Grid Code	B Proposed GC modifications	C Enhanced Standard (proposed products)
Fault Ride Through	Voltage Dip	15% retained voltage for 625ms at connection point	15% retained voltage for 625ms at HV terminals of Grid Transformer	*Not relevant*
Fault Ride Through	Active Power (post fault)	90% of available active power within 1 second of voltage recovering to normal range	90% of available active power within 500 ms of voltage recovering to 90% of nominal where fault is cleared within 140 ms and within 1 second for longer duration faults.	90% of available active power within 250 ms of voltage recovering to 90% of nominal where fault is cleared within 140 ms
Fault Ride Through	Reactive Response	Maximise reactive current until the voltage recovers or for at least 600 ms. *Response time not defined.*	The reactive current response shall attempt to control the Voltage back towards the nominal Voltage. The reactive current response shall be supplied within the rating of the Controllable WFPS, with a Rise Time no greater than 100ms and a Settling Time no greater than 300ms.	The reactive current response shall be supplied within the rating of the Controllable WFPS, with a Rise Time no greater than 40ms and a Settling Time no greater than 300ms.
Voltage Control	Voltage Regulation	Three control modes: Voltage Regulation, constant PF, constant Q	*no change proposed*	*Not relevant*
Voltage Control	Reactive Power Range	Q = ±33% of registered capacity (0.95 pf at reg cap) for active power outputs from 100% down to 50% of reg cap, decreasing linearly from 50% to zero.	Q = ±33% of registered capacity (0.95 pf at reg cap) for active power outputs from 100% down to 12% of reg cap. Below 12% of reg. cap the reactive power is to be supplied as technically as much as possible down to cut-in speed of the turbines.	Q provided over as wide a range as possible (including at zero MW output)

DNV KEMA looked at the additional investment needed to make a wind turbine capable to comply with the enhanced standard requirement, provided in column C. The enhanced costs involve the upgrade from the new Grid Code requirements, column B, to the enhanced standard, column C

One of the enhanced capabilities proposed in the Grid Code modifications is the delivery of 90 % of available active power within 500 ms of voltage recovering to 90 % of the nominal voltage where a fault is cleared within 140 ms. For most modern wind turbines these enhancements are most likely not a big challenge and therefore no additional equipment is needed as a result. For the capital investment however, it is most likely wind turbine manufacturers expect any clients to share in the research and development costs requiring this capability. The Software upgrade costs, therefore, will heavily depend on the manufacturer and the number of total wind turbines in the farm.

A similar fault ride through is proposed under the enhanced standards (proposed products), column C. This is the delivery of 90 % of available active power within 250 ms of voltage recovering to 90 % of nominal where a fault is cleared within 140 ms. Of all enhancements proposed for the wind turbine technology, this is probably the most technically challenging.

To provide reactive current response with a rise time smaller than 40 ms together with a settling time within 300 ms, a STATCOM is needed. It is important to notice that when the wind turbine is made capable of the active power service described above, additional equipment is already installed. If not, as a rule of thumb, a STATCOM of 75 % to 80 % of the nominal power rating of the wind turbine needs to be installed. (For the active power service this is 80 % to 95 %.)

For stationary operation conditions, the required reactive power range can be provided using shunt reactors and/ or capacitors. The Shunt reactors will keep the wind turbine within its operating voltage limits. Together with the controls of the wind turbine, the machine will stay within its control and operating limits. If the wind turbine is equipped with a STATCOM to provide the earlier mentioned capabilities, the shunt reactors are superfluous.

5.2 Generation Technology: New build CCGT

5.2.1 Costs

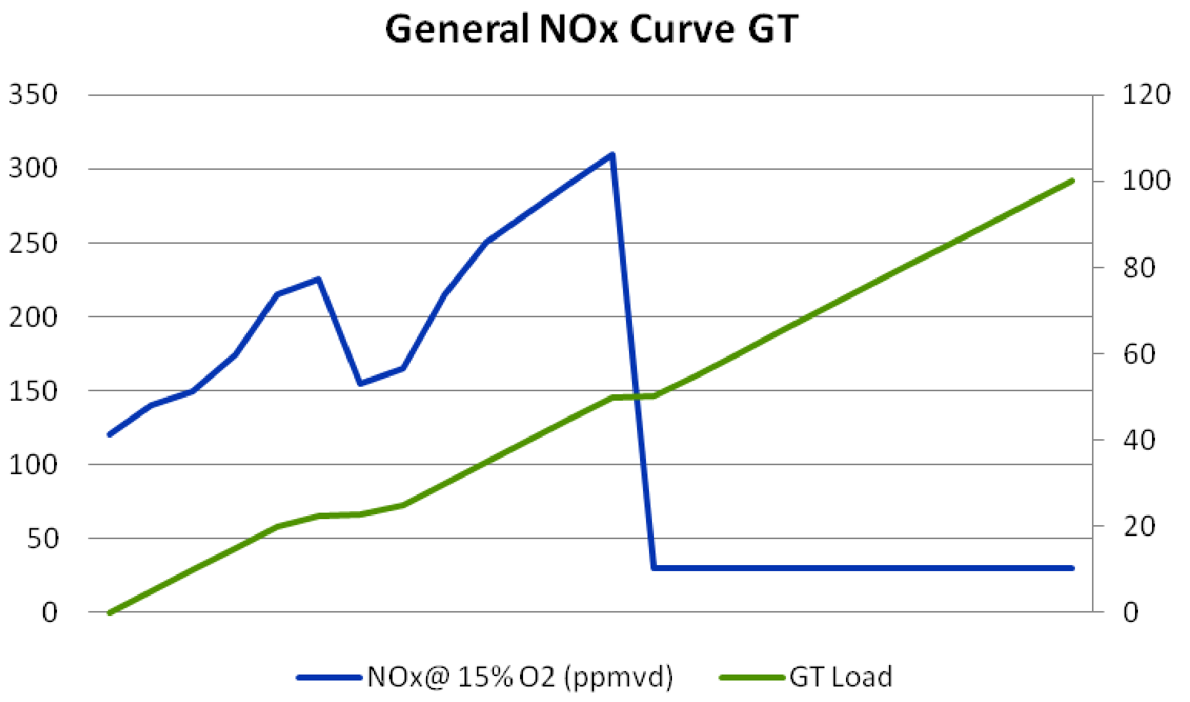
CCGT new						
			Capex			
Capacity	450 [MW]					
Normalised built cost		Total	360,000,000	[EUR]	800	[EUR/kW]
Enhanced cost		Total	13,446,172	[EUR]	30	[EUR/kW]

5.2.2 Short technical explanation

Reducing the minimal load for long periods of time will have an impact on the efficiency and the NOx emissions. To mitigate those drawbacks as far as technically feasible, certain additional equipment will be needed compared to a new CCGT installation that is not designed to provide additional system services. Gas turbines equipped with state-of-the-art Dry Low NOx (DLN) burners are capable to stay within a NOx emission value range of 30 – 50 mg/ m_0^3. However the low emissions capability does only apply for loads of 40% and more.

At part loads of 20–30 % the emissions for most machines will at least double. To make the installation capable of operating at such low loads, additional equipment is needed. Significant investments would require to be made in a Selective Catalytic Reduction (SCR) system and state-of-the-art burners.

The indicative graph on the next page shows the emission curve of a 400+ MW CCGT installation



NOx (blue line, in ppmvd @15% O_2 dry) and load (green line, in MW) indication graph, left vertical axis represent the NOx, the right vertical axis represent the load in %.

The main active parts of the installation responsible for contributing to frequency response service are the governor and the excitation. Modern CCGT installations have fast acting control systems and therefore it is unlikely that additional equipment is required in order to comply with the enhanced ancillary services. Machines equipped with variable air inlet fans will be quick enough to react. When operating in full load the air inlet fans will be fully open.

Some machines can operate for some hours on 110 % load. In that situation the air inlet fans will stay fully opened and the fuel supply will be increased. This will have an effect on the burning efficiency and therefore on emissions. In addition operating a gas turbine at 110 % load will have an increasing effect on the Equivalent Operating Hours (EOH) of the machine. Though, it will provide capability to give frequency response even at times when the machine is running at full load. What will be necessary is the adjustment in the control parameters.

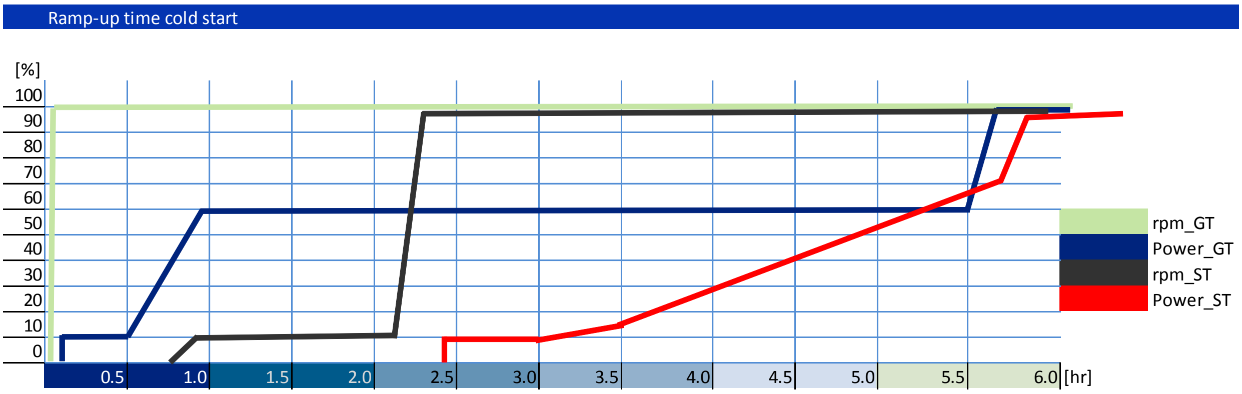
To improve the ramp-up time of a CCGT installation, however, the equipment needs to be kept warm at all times. In general, new CCGT installations are capable of producing full load power within 3 hours, but only considering a hot start.

To keep the installation warm, the additional equipment listed is proposed. Main items are the:

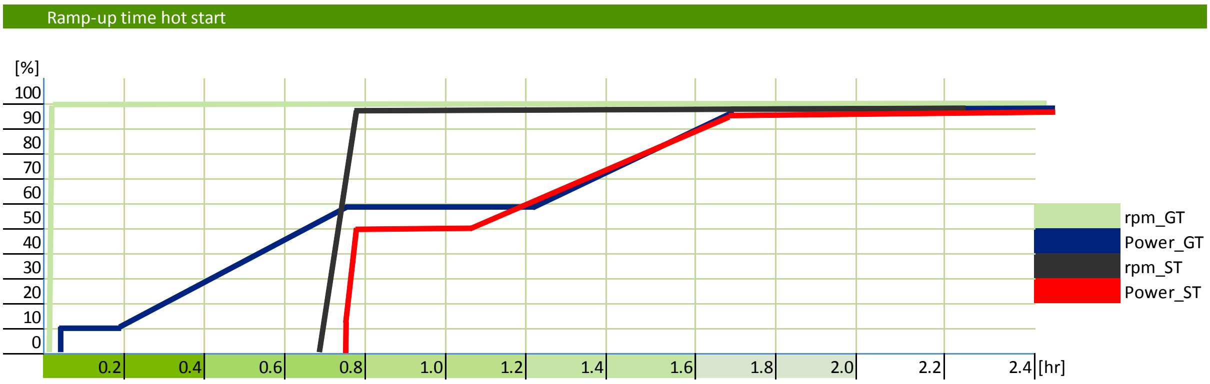
- Auxiliary boiler, installed to keep the systems warm. This will drive the capital cost up together with the operational cost due to the fuel and demineralised water usage.

- Flue-gas valve, preventing a large part of the heat leaving the installation.
- Chest warming, to keep all mechanical parts of the steam turbine/ generator set warm.
- DCS improvement, automations of drains for remote operation.
- Insulation improvement, to keep the heat emission in check

Typical ramp up time from cold start:



Typical ramp up time from hot start:



DNV KEMA looked at the improvement of inertia. One of the few possibilities is to extend the axis of the rotor. Complex technical challenges accompanying this approach are for example the system resonant frequencies of the machine. Such adjustments can not be done without close cooperation of manufacturers. Providing the short time window for this study, no proven concept has been found at present. Together with the need of manufacturer input and the bespoke nature of such solution, no cost indication is included in this document for the improvement of inertia.

5.3 Generation Technology: Existing CCGT plants

5.3.1 Costs

CCGT information								
				Capex				
Capacity	450	[MW]						
Normalised built cost			Total	360,000,000	[EUR]	800	[EUR/kW]
Enhanced cost			Total	54,690,497	[EUR]	122	[EUR/kW]

5.3.2 Short technical explanation

Reducing the minimal load for existing CCGTs will have the same implications mentioned for the new CCGTs. However, the enhancement costs are significantly different due to the changes that have to be made in an existing installation. Most significant cost increases can be found in the burner replacement, the period the installation is out of operation and the inspections on the generator sets to make sure that the new operation mode will not introduce severe risks. In addition converted plants may need to purchase new equipment, therefore scrapping existing equipment, as it may not be possible to upgrade already installed equipment.

Depending on the age of the installation, frequency response enhancements can come with additional control and instrumentation equipment, ensuring that the new ancillary services will be provided reliably. Therefore new governor controls are proposed together with the necessary additional instrumentation equipment. The Distributed Control System (DCS) will need additional functionality and the parameters of both the new governor controller and the excitation are likely to need adjustment and testing. Because the installation cannot run during the upgrade of the instrumentation, a loss in power generation revenue will be a result.

To improve the start up time of an existing CCGT, the same equipment applies as for the new CCGT mentioned. The difference between the costs of keeping the installation warm for an existing as opposed to a new installation is the changes that have to be made in an already built installation. The additional auxiliary boiler, the installation itself, balance of plants, DCS upgrade, etc., will be more expensive as opposed to a new built CCGT.

5.4 Generation Technology: New built OCGT

5.4.1 Costs

OCGT information		NEW					
				Capex			
Capacity	50	[MW]					
Normalised built cost			Total	32,500,000	[EUR]	650	[EUR/kW]
Enhanced cost			Total	3,699,440	[EUR]	74	[EUR/kW]

5.4.2 Short technical explanation

To reduce the technical minimal load of an OCGT, the same NOx emission challenges apply as for the CCGT. The main difference is the power rating of the machines and therefore the SCR to be installed will be considerably smaller. Other cost reductions are due to the more simplified installation compared to the CCGT. Unlike an OCGT, 450 MW CCGT (non-single shaft) needs to control 3 power generating units, of which one is a steam turbine with a heat recovery steam generator.

One of the reasons why OCGT machines are used for this application is because they can be available from a cold start position in a short timescale (a few minutes rather than tens of minutes). Therefore the improvement of start-up time is not applicable for this technology.

5.5 Generation Technology: Existing OCGT plants

5.5.1 Costs

OCGT information			EXISTING					
				Capex				
Capacity	50	[MW]						
Normalised built cost			Total	32,500,000	[EUR]		650	[EUR/kW]
Enhanced cost			Total	7,163,575	[EUR]		143	[EUR/kW]

5.5.2 Short technical explanation

For an existing OCGT the same adjustments apply as per a new OCGT, though at almost double the cost. There are two main drivers responsible:

- Full purchase price of the items that need to be upgraded as opposed to buying higher quality equipment in the initial purchase phase.
- Need of inspections making sure that the installation is able to operate under the new regime.

5.6 Generation Technology: Thermal power plants

5.6.1 Costs

Thermal (Coal)			EXISTING					
				Capex				
Capacity	650	[MW]						
Normalised built cost			Total	845,000,000	[EUR]		1,300	[EUR/kW]
Enhanced cost			Total	53,663,920	[EUR]		83	[EUR/kW]

GENERAL

Thermal power plants are, as opposed to most OCGTs and CCGTs, bespoke installations and not off-the-shelf products. A generic cost overview for the different ancillary service enhancements is therefore not applicable in all situations. The explanations of the costs below, together with the specific items in the costs documented can only be used as an example and indication of what the challenges are.

5.6.2 Short technical explanation

Reduction of the technical minimal load of a Coal fired power plant is associated with severe negative impacts on the operating performance and safety. Main issue is the boiler flame stability. To be able to lower the technical minimum load and keep the flame stability, new burners designed for this purpose is necessary. Reason for the flame instability is the minimum airflow necessary to transport the coal to the burners.

It is only since the beginning of 2000 that the first research developments took place to design burners for Coal fired power plants with the aim to reduce the technical minimum load keeping the flame stability and with that an efficient burning process, reducing emissions. As a result, the number of Coal fired power stations equipped with these burners, although some projects are known, is at present low. The Coal fired power plants of Ireland and Northern Ireland, when built, were not equipped with this kind of burners.

Replacement of burners is not a simple task and will involve a large number of changes to be made in existing installations. A view of the improvements to reduce the technical minimum load are indicated below:

- Retrofit DCS:
    - Power control improvement

    - Air-flow control
    - Improved feed water control
    - Boiler/ Turbine control
- Improved Burner Management System (BMS)
- Turbine/ generator protection enhancement
- Etc.

In the financial cost estimation it is assumed that for the retrofit of the DCS only part of the instrumentation will need replacement and that measuring reference points do not have to be altered. In practise this could prove difficult since the boiler will be operated in different modes which might come with necessary changes or additional measurement reference points which at present are not considered. Reference measuring point changes are expensive and the costing of such, providing a general overview, is arbitrary, and therefore left out of the equation.

It is likely that the control layer will be completely renewed since the old controls cannot cope efficiently with the different operation modes. The new control layer of the DCS will provide advanced plant control which is needed for stability and safety of the installation. A new BMS system is needed to support the new burners and will make sure the number of trips stays within accepted limits for the extended load range and does not jeopardise safety.

With the instalment of a new DCS control layer, the start-up time can be improved. Special Software will utilise the system boundaries of the installation, using a highly controlled start-up, keeping all safety boundaries in check.

The turbine/ generator protection needs to be able to allow for different operating loads, with focus on the steam turbine.

5.7 Network Technology: Combined Flywheel with Synchronous Generator/Motor

5.7.1 Costs

Flywheel							
			Capex				
Capacity	20	[MW]					
Normalised built cost			Total	14,000,000	[EUR]		
Auxiliary equipment			Total	1,328,000	[EUR]	66	[EUR/kW]

5.7.2 Short technical explanation

A flywheel is capable of giving Fast Frequency Response (FFR) in areas where the energy consumption or energy generation is highly impulsive. The Flywheel is capable to deliver its rated power within a certain time frame. Depending on the purpose and therefore, specification this can differ. The high speed flywheel power electronics are in theory capable to deliver inertia to the grid. Though, manufacturers are of the general opinion that it is possible, proven commercial projects have not been identified.

Using a flywheel mechanically attached to a synchronous machine connected to the electricity grid, will deliver a limited inertia response. Due to the limited frequency bandwidth the machine can use only a small part of its stored energy, hence synchronised with the electricity grid, the machine can only deliver its energy within the allowable frequency limits of the electricity grid as specified in the grid code.

Until the power electronics have been proven for this application (and in a commercial market) by providing efficient response times, it is possible to provide the instantaneous inertia using the smaller synchronous machine. The proposed Network Technology can deliver efficient inertia without the need of the larger synchronous machine with a flywheel mechanically attached.

The Flywheel principle is based on kinetic energy. The rotation speed contributes to Flywheels can spin within a range of 8,000 to 60,000 revolutions a minute. High speed Flywheels are relatively small and posses a large energy capacity storage and because of the power electronics used the speed of the flywheel does not affect the electric frequency output of the installation. This result, in addition to the high energy capacity, also in a larger bandwidth the installation can deliver its energy.

Combining a high speed Flywheel using power electronics to connect the kinetic energy to the grid in combination with a synchronous machine connected in the same area can deliver the inertia response sought for with a much smaller machine and maintenance costs. The power electronics will be given adequate time to respond and delivering the additional inertia needed.

Although at the moment there are many developments, the general specifications regarding 20 MW flywheels proposed here are in the following range:

- Power: 20 MW
- Energy: 3 – 6 MW/h
- Charge/ discharge time: 15 min – 1 hours

The auxiliary equipment costs represent the likely needed capital investment to connect the facility to an existing 110 kV substation. The costs include, for example, switchgear, protection, controls and step-up transformers. In addition a synchronous machine is proposed. In the near future it could prove that the quick response of the power electronics are capable to provide such emulated inertia response that the instantaneous inertia, provided by the synchronous machine, becomes unnecessary. The latter is highly dependent on the electricity network and detail assessments must be carried out to identify if this response will be sufficient for Ireland and Northern Ireland.

5.8 Network Technology: STATCOM

5.8.1 Costs

STATCOM							
				Capex			
Capacity	50	[MVAR]					
Normalised built cost			Total	4,500,000	[EUR]		
Auxiliary equipment			Total	928,000	[EUR]	19	[EUR/kVAR]

5.8.2 Short technical explanation

For the Network Technology, STATCOMs can be used to regulate voltage, give support to critical loads, and help improve transient stability providing power oscillation damping. STATCOMs are placed in grid areas where interruptible loads or generation are a problem for the system.

The STATCOM is a power electronics (IGBT inverter bridge) device based on the voltage source converter principle. In general the technology is a digitally controlled shunt for reactive power. The installation is connected to the grid through a filter and possibly a coupling transformer. Depending on voltage level and total power rating, the technology makes use of a two- or three-level voltage source converter but it gets its energy from the grid.

The main advantage of the STATCOM as opposed to a thyristor based SVC is that the compensating current does not depend on the voltage level of the connecting point. This allow for a compensating current independent of the voltage. The result is a higher control bandwidth and the additional capability of providing higher currents at low voltage levels. In addition it has the capability to increase the transient stability margin by injecting a controllable reactive current independently of the grid voltage. Therefore locally the STATCOM can supply reactive power variably depending on network demand and actual voltage level. This is important for Ireland and Northern Ireland if it is to meet the 40 % of renewable generation target.

Similar to the previous technology, the auxiliary equipment costs in here represent the likely needed capital investment to connect the facility to an existing 110 kV substation. The costs include, for example, switchgear, protection, controls and step-up transformer.

5.9 Network Technology: Synchronous Condenser

5.9.1 Costs

Synchronous Condenser								
				Capex				
Capacity	75	[MVA]						
Normalised built cost			Total	2,000,000	[EUR]			
Auxiliary equipment			Total	2,726,500	[EUR]		36	[EUR/kVA]

5.9.2 Short technical explanation

The main service Synchronous condensers can provide is the reactive power consumption and generation in and towards the system. This will result in voltage control, short circuit power capacity and inertia response. Synchronous condensers of the size mentioned though have a small effect for improving inertia. Only if large generators, e.g. 1200 MVA and above are converted, an appropriate effective level of inertia energy can be used.

Synchronous condensers are synchronous electrical machines attached to the electricity grid. The machine will be brought up to speed with an electrical motor attached or via a frequency convertor. When the machine is synchronised with the electricity grid it will act as a motor, turned by the energy taken from the grid. Because of the nature of the synchronous machine, reactive power can be consumed and generated by controlling the excitation of the rotor.

The conversion of non- profitable or deactivated power station is currently seen as the most cost effective option applying synchronous condensers. Making an accurate cost calculation in general is not possible however, because depending on the existing installation the project will differ from unit to unit. Investments are relative low when most of the existing infrastructure can be utilised (e.g. Step-up transformer, network infrastructures, buildings, auxiliary equipment and machinery, substations, etc). In addition the excitation and control and excitation itself may be changed, depending on the specific machine. The costs shown are therefore only a very rough indication.

General specifications:

- Energy consumption: 1 % – 4 % of the nominal power rating
- Inertia: approximately 1 sec.
- Response time: immediate
- Start-up time (if switched off): < 15 min

5.10 Network Technology: Batteries

5.10.1 Costs

Batteries								
				Capex				
Capacity	40	[MW]						
Normalised built cost NaS			Total	90,000,000	[EUR]			
Normalised built cost Li-ion			Total	30,000,000	[EUR]			
Auxiliary equipment			Total	3,170,500	[EUR]		79	[EUR/kW]

Batteries can be used for frequency response, peak shaving and energy storage. There are several types of batteries today that can be used for electrochemical energy storage and can provide ancillary services to the grid, a summary of which is given below:

- Lead-Acid
- Nickel Cadmium and Nickel-Metal hybride
- Lithium-ion
- Sodium-Sulphur
- Zinc-Bromine
- All Vanadium Redox
- Vanadium/air Redox
- Polysulfide/bromide

At current, out of the above list, the most feasible technologies are Sodium Sulphur (NaS) and Lithium-ion (Li-ion). The latter has a far smaller power to energy ratio and therefore can be used for frequency response. Li-ion is thus a cheaper alternative as opposed to NaS regarding frequency response services. For peak shaving however, and ultimately energy storage, NaS batteries are the better technology at the moment, having a power to energy ratio of approximately 1 : 8.

The proposed batteries have the following general characteristics:

- Energy efficiency: 95 % (Li-ion); 90 % (NaS)
- Ramp-up time: < 1 electrical frequency cycle period
- Load time: 2 min – 3 hours (Li-ion); 1 hour – 8 hours (NaS)
- Life cycle: > 4,500 load cycles

The energy efficiency and subsequent energy loss has to do with the chemical reaction needed to transfer the energy. The NaS batteries lose some of its efficiency in addition due to its operating temperature. NaS batteries need to be kept warm around 300 degrees Celsius to be able to operate. This means that the installation must be kept warm at all times. Although thermal insulation is applied, a small energy loss due to thermal emission can not be prevented.

A large part of the auxiliary equipment costs are for the power electronics to control the energy from and to the grid. Other costs represent the likely needed capital investment to connect the facility to an existing 110 kV substation. The costs include, for example, switchgear, protection, controls and step-up transformer.

6 CONCLUSION

DNV KEMA is confident that, given the short timeframe provided for the research, the figures in this report are representative of what the likely impact of the proposed system service provisions on the capital investments necessary to facilitate the high renewable energy penetration. DNV KEMA has used its experience and expertise to present the capital costs that are likely to be incurred, a summary of which is given below[2].

Summary			
Generation Technologies	Units Size	Base Case	Enhanced
[Name]	[MW]	[Normalised Cost, EUR/kW]	
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Thermal (Coal)	650	1,300	83[2]
Network Technologies	Units Size	Total Cost	
[Name]	[MW or MVA or MVAR]	[EUR]	[EUR/kW, EUR/kVA, EUR/kVAR]
Flywheel (5 MWh)	20	15,328,000	766
STATCOM	50	5,428,000	109
Synchronous Condenser	75	4,726,500[2]	63[2]
Batteries (10 MWh)	40	33,170,000	829

It is not appropriate to make a like for like comparison between the costs represented in the table. At the same time, this paper presents the important constraints and enhancement costs and provides guidance on the changes needed to accommodate high penetration of renewable energy sources.

[2] The numbers of coal and synchronous condenser conversions are only an indication, because of the bespoke nature of these installations, further explained in this report.