| Issue | Revision |
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# The Statement of the Constraint Cost Target Modelling Methodology

# Effective from 1 April 2013

**nationalgrid**

## About this Document

This document contains one of three methodologies that National Grid Electricity Transmission plc (NGET) employs to calculate the Modelled Target Costs, against which its actual balancing costs will be compared, on a month-by-month basis, under the Balancing Services Incentive Scheme (the 'Scheme').

The remaining methodologies are as follows:

- The Statement of the Energy Balancing Cost Target Modelling Methodology
- The Statement of the Ex-Ante or Ex-Post Treatment of Modelling Inputs Methodology

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# Chapter 1: Modelled Target Costs

1.1     The Modelled Target Cost (in £ million) are defined in Special Condition 4C as "…the target cost to the licensee of procuring and using balancing services (being the external costs of the Balancing Services Activity)..." derived in accordance with the methodologies referred to Part K of Special Condition 4C …"

1.2     This document sets out the constraints methodology referred to in paragraph 4C.35 of Special Condition 4C. It should be read in conjunction with the other methodologies:

- The Statement of the Energy Balancing Cost Target Modelling Methodology; and
- The Statement of the Ex-Ante or Ex-Post Treatment of Modelling Inputs Methodology.

1.3     The target constraint cost is made up of the costs associated with actions taken in the balancing mechanism to manage constraints and additionally, the costs associated with the replacement of constrained headroom.

$$\text{CONSTRAINT\_COST\_TARGET}_t =$$
$$\text{DF x TARGET\_BM\_costs}_t$$
$$+ \text{TARGET\_HEADROOM\_REPLACEMENT\_COST}_t$$

Where:

DF

A discount factor of 0.62 (to promote efficient cost management)

$\text{TARGET\_BM\_costs}_t$
Defined in Paragraph 2.4

$\text{TARGET\_HEADROOM\_REPLACEMENT\_COST}_t$
Defined in Paragraph 6.2

1.4     The incentive on constraint management encourages NGET to develop innovative configurations for operating its substations, explore contractual or service solutions to reduce constraint costs and agree mechanisms for Users to provide post-fault actions to manage the impact of faults.

## Principles

1.5     The principles applied when modelling constraints costs are as shown in Figure 1 below:
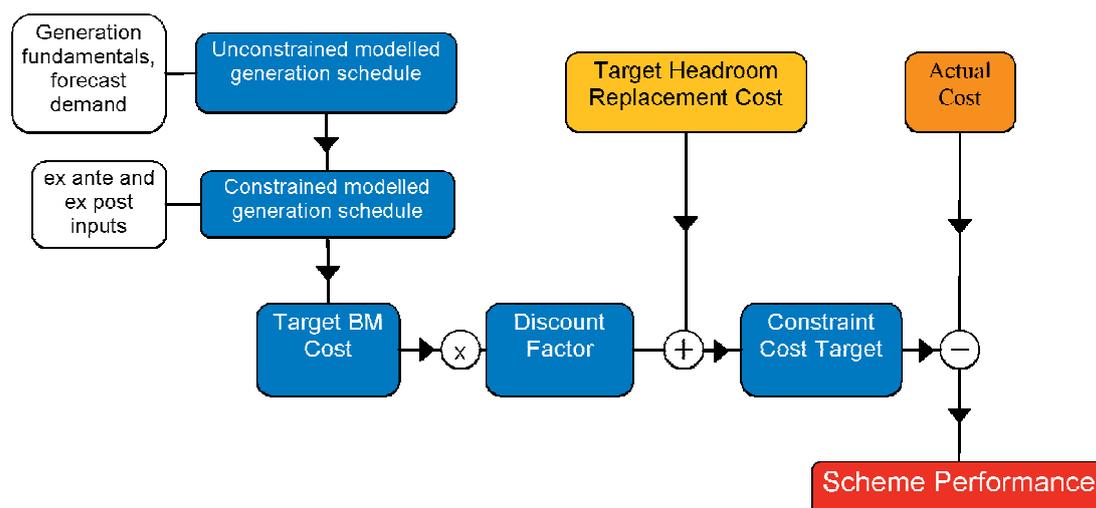
**Figure 1: Overview of constraint modelling process**

1.6    Plexos is power market modelling and simulation software from Energy Exemplar. This tool is used by NGET to model constraint costs.

1.7    The 'generation fundamentals' capabilities of Plexos are used to generate a schedule of plant to meet demand. The output of this schedule is 'unconstrained' – i.e. it assumes infinite transmission capacity. The model is then re-run introducing GB transmission network layout and associated boundary limits. The boundary limits are derived to represent flow limits across groups of transmission lines on an intact system as well as taking account of outages anticipated up to year ahead timescales. i.e. cut off for financial year 2013-14 would be 31 March 2013. Where a boundary limit is exceeded, the resulting constraint is resolved by Plexos through the re-scheduling of plant dispatch. This new plant dispatch solution is achieved through providing PLEXOS with a representation of offer and bid prices[1] submitted by participants into the balancing mechanism. This provides an overall 'constrained' schedule of plant dispatch that satisfies transmission system constraints and also meets demand.

1.8    The cost arising from moving the system from the unconstrained run to the constrained one gives a modelled target direct cost, which is then reduced by a discount factor. This is designed to recognise that resolution of constraints through the balancing mechanism is not the only or most efficient means to manage costs. It is therefore also intended to provide an incentive to derive efficiencies through the application of both existing and new balancing services and tools. The sum of this discounted modelled direct cost and the Headroom Replacement Cost[2] gives the incentive target against which NGET's out-turn will be compared to determine its performance under the SO incentive.

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[1] The derivation of the bid and offer price representations are described in more detail in sections 4.9 through 4.21
[2] See Chapter 6 for explanation of headroom replacement costs

# Chapter 2: Plexos Model

## Model overview

2.1     The software application used to model constraint costs on the network is Plexos (from Energy Exemplar), as per BSIS 2011-13. NGET has constructed a new model in Plexos for BSIS 2013-15. The use of the Plexos software model for constraints modelling is based on the application of optimisation techniques aimed at minimising total BM costs.

2.2     The key output of the model is the anticipated total cost of constraints incurred by NGET in adjusting the self-dispatch position of generators in order to maintain a security standard on the network.

2.3     The first run of the model derives a simulation of market behaviour and applies the principal of an efficient market, self-dispatching to satisfy a forecast demand. The optimisation uses individual BMU heat rates or efficiency factors to derive a plant dispatch that minimises the short run marginal cost. The solution takes account of a number of additional plant dynamics including maximum export limit, stable export limit minimum zero and non zero times, run up and run down rates, etc.

2.4     The Modelled Target Cost for constraints results from the second run of the model. This looks to obtain a minimum cost to delivering a feasible plant dispatch solution for a given set of transmission boundary limits. The resultant plant dispatch solution away from the initial plant dispatch condition (as derived from the first run) is achieved through bid and offer acceptances in the balancing mechanism.

$$\text{TARGET\_BM\_costs}_t = Min \sum_{mt} Balancing\ Mechanism\ Costs_m$$

Subject to:
   (i)     Power flows being within limits of constrained boundary model
   (ii)    Supply equals demand
   (iii)   Generator dynamic ratings are not exceeded

   Where:      t is the Relevant Year within the scheme period (of 2 years)
               m is a particular month in the period under consideration.

## Modelled network

2.5     The modelled network has been developed in line with the network used in operating timescales and the boundary capabilities have been calculated to represent the transmission outage plan for each year within the scheme period.

2.6     The BSIS constraints model has been designed to be able to accommodate almost all potential transmission constraints which can occur on the GB system, in order to make the constraint cost forecast more accurate. These constraints can be thermal, voltage, or stability. The network model is defined at GB substation level, down to 275kV in England and Wales, and 132kV in Scotland: in other words, assets under the control of the System Operator, (SO) are explicitly modelled in the network topography. This represents the assets comprising the main interconnected system (MIS).

2.7     The modelled network is made up of nodes, lines and interfaces. Each individual substation which is part of the main interconnected system (MIS) is represented by a single node. There are a few nodes which purely represent

points where lines join together for example a T- point. The properties of a node are its load participation factor (LPF), the generation connected at that node and the lines to which it connects. The sum of the load participation factors of all the nodes must be equal to 1.

2.8     The nature of network system operation means that substation configurations are frequently re-switched by the SO. Because practically it is only possible to manage one static network topology in the Plexos model, a snapshot of the GB system is used, showing all substations, in a 'solid' electrical configuration (i.e. all points within the substation that are at the same nominal voltage are connected together) and all substations are connected with one to one representations of the real transmission circuits.

2.9     A line is used to join nodes and although named with the actual asset code it represents a virtual connection between them (not the physical network). Therefore, the min and max flows are ±99999 MW as Plexos is not used to perform electrical load calculations, the physical characteristics of the transmission lines are not relevant (e.g. resistance and impedance values) as we are modelling transmission constraints using a boundary methodology.

## Interfaces and Boundaries

2.10    An interface is a collection of lines and serves as the Plexos representation of a boundary in NGET terminology, but to all intents and purposes they are the same thing. The interface is used to limit the flow across the boundary. The limit can be in a single direction across the interface or in both directions and can be time-varying.  Each line that crosses an interface is a member of that interface. It is important to note that a line may be a member of more than one interface.

2.11    All substations and lines are present in the model.  Any boundary which cuts any lines can be incorporated into the model. Any limitation of flow which cannot be represented by a group of lines, for example, a boundary which cuts through a split substation, can be accommodated by defining a rule from which Plexos creates a 'Constraint Object.' These can be applied to the model in the same way as interfaces.

2.12    The final property to be defined for an interface is the flow coefficient.  This is a 'secondary property' as it is a property of a specific line and interface.  If the reference line flow is defined in the same direction as the interface, the flow coefficient is 1. If the reference line flow is opposite to the interface, the flow coefficient is -1.

2.13    The location and number of boundaries and rules have been selected by NGET based on year ahead outages and the resultant bottlenecks in the transmission system. This is derived from historic data alongside operational experience of its power system engineers. Offline power systems studies are carried out where historic data is not available due to new outage combinations or changes to transmission system topology.

2.14    Some boundary limits will vary as a result of the underlying generation mix. Where a boundary limit does vary as a function of a generation type that uses an ex-post input to the model, for example, interconnectors, the most appropriate boundary limit will be applied. It is important to note that the different potential boundary limits will still be identified on an ex-ante basis.

## Demand and generation

2.15   Nodal demand has been derived based on the historical percentage of each node's demand in relation to the total GB system demand, derived from 2012 data.

2.16   Demand is based on historic demand take-off from Grid Supply Points (GSPs) and care has been taken to ensure it reflects underlying demand.

2.17   Transmission connected generation is connected to the GSP in the model to reflect its actual connection in reality. Embedded generation is connected to the most appropriate node which has been defined by the physical location of plant on the system.

2.18   The diagram below represents how Plexos 'sees' the GB electricity network with nodes being connected by lines across interfaces



**Figure 2 showing extract of E+W electricity network**
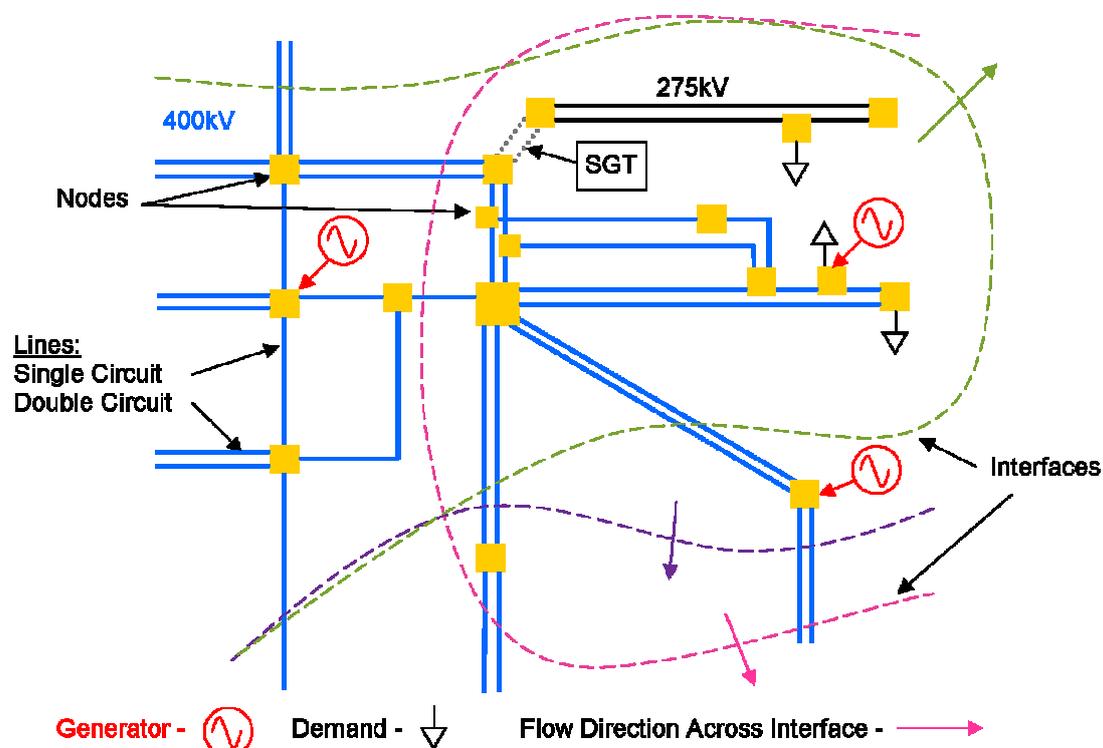
2.19   Transformers on the GB system are represented by a line connecting two nodes (shown by grey dotted line - SGT). These two nodes are at the same location on the GB system but split in the model to separate different voltages on the network.

2.20 In order for Plexos to distinguish between lines, NGET nomenclature codes are used (unique code given to each transmission asset on the GB system) preceded by one of the following:

| Letter | Meaning |
|--------|---------|
| A | 400kV line |
| B | 275kV line |
| C | 132kV line |
| F / S / T | Transformer |

**Table 1 showing Plexos line references**

## Boundary limits during outage conditions

2.21 For each boundary, a subset of the outages planned to take place throughout the outage year are selected. The selection process is based on historic data and the operational experience of power system engineers, and represents the most significant outages in relation to their impact on boundary transfer capabilities.

2.22 The offline power system studies are used to calculate an appropriate power flow that can be accommodated across a particular boundary, namely the 20 minute short term rating. For each boundary, multiple contingencies (circuit trips) are run to establish the most onerous fault conditions. For the most onerous fault conditions, the maximum appropriate power flow that can be achieved across the boundary is calculated according to NETSQSS requirements.

2.23 In the case of a thermal constraint, the boundary limits have been calculated using the 20 minute short term rating of the worst overloaded circuits. This means that the maximum power flow across a boundary will be calculated to ensure that the power flows on these overloaded circuits can be reduced to their post fault continuous rating within 20 minutes. It's important to realise that this limit is achieved by selecting the most effective generation available in reducing those overloaded circuits. The post fault generator effectiveness is considered in a similar way for other types of constraint that can occur.

2.24 In addition, NGET will apply logical rules to generators to model constraints which are not able to be modelled via boundaries. For example, if a specific number of generators are required for voltage support, then the model will ensure that they are running. If there is an outage at a substation that is local to a generator, then this can be modelled by a logical rule which restricts the output of the generator accordingly. These voltage rules will be reviewed prior to the second year of the scheme for implementation in the model from 1st April 2014.

2.25 Limits are also a function of generation and demand backgrounds and can for example change between night and day or weekday and weekend.

2.26 The boundary limits are applied to the interfaces between the interconnected nodes.

2.27    Constraint boundary limits will be recalculated based on the latest view of the year ahead outage plan prior to the second year of the scheme for implementation in the model from 1st April 2014.

## Model Settings and Erroneous data management

2.28    The optimising software is a commercially available optimiser. There are multiple settings within the software and there may be occasions where these need to be changed.

2.29    If NGET detects data that it believes is erroneous (i.e. bad data), NGET will verify with the generator in question that the BM data was submitted in error.

2.30    In accordance with licence paragraph 4C.38 of Special Condition 4C, where NGET finds an error(s) in the model, or an error in a model input submitted by a third party, which prevents the model from appropriately reflecting this methodology statement, NGET shall notify the Authority of the error(s) and its materiality and promptly seek to correct this error(s). In this context, an error may include but not be limited to:

- Model settings - internal parameters which define the solution space and affect the running time in which the optimisation is performed;
- Data submissions by generators into Balancing Mechanism Systems - such as price which is clearly incorrect and subsequently corrected by the third party for future settlement periods but that remains erroneous for the periods whereby gate closure has passed, i.e. resubmission is impossible;
- Direction of constraint boundary limit flow

## Out of scope

2.31    Transmission system losses and net imbalance volume (NIV) are ignored in order to ensure that total demand equals total supply.

# Chapter 3: Unconstrained model

## Overview
3.1     The objective function of the unconstrained model is to minimise the sum of the short run marginal cost of generation dispatch when no boundary limits are present.
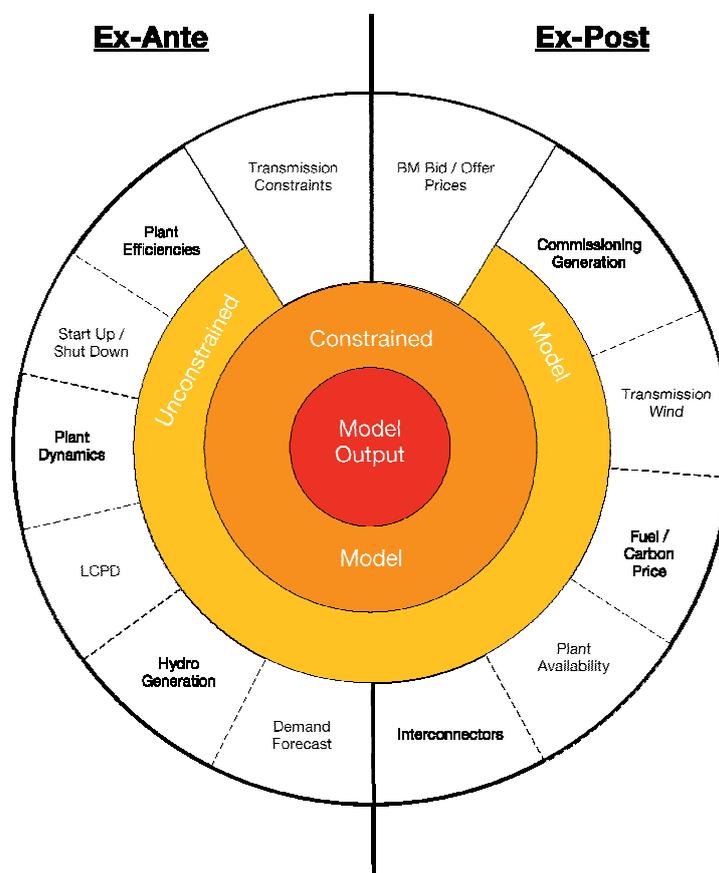


**Figure 3: Output Model**

3.2     The diagram above illustrates the full run of the model; starting with the inputs around the outer circle, going through the unconstrained model, where the output is joined by Transmission Constraints and BM bid / offer prices before the constrained model is run giving the final output at the circle centre. The diagram shows which inputs are ex-ante and which are ex-post, this is explained in further detail below.

## Generation dispatch
3.3     Using demand forecast, fuel and carbon prices, plant efficiencies, start up costs, generator availability, wind and hydro generation data and interconnector flows, a generator running schedule is derived that minimises the short run marginal cost of generation. This is done without regard to the transmission system as the market dispatch under BETTA disregards location.

## Inputs for deriving target cost
3.4     The first crucial data required is the demand forecast which is to be met by generation in the model. Demand forecast, an ex-ante input, is obtained through the well established processes within NGET. Demand is forecast at a GB level and apportioned to grid supply points based on observed and understood relationships. The demand forecast is based on average weather

(over a 30 year period) and uses underlying historical data from the previous three years. Based on the recent trend in demand profile for weather corrected and seasonal adjusted demand, the future trend has been forecast.

3.5 The demand forecast used for the model is based on historic demand take-off from GSPs and care has been taken to ensure it reflects underlying demand.

3.6 To achieve the initial run from a supply or generation perspective (the unconstrained dispatch), a number of inputs are provided for each generation unit, for example:

- Fuel price
- Carbon prices
- Plant efficiencies
- Start up / Shut down costs
- Plant dynamic parameters
- Availability
- Commissioning generation output (if applicable)

3.7 In addition to these inputs and demand as previously detailed, interconnector flows and wind generation output files are also fed in to the unconstrained run of the model to enable a dispatch of unconstrained generation to be produced.

## Fuel and carbon prices

3.8    In order to input large amounts of time varying data, input data files are used. The fuel prices are measured in £/GJ, and the carbon price is measured in £/kg. Emissions costs are included in dispatch decisions. For the unconstrained model, they are as follows:

| Data file name | Description | Source |
|---|---|---|
| Gas Price | Daily gas price in £/GJ | Bloomberg[3]- Day Ahead Spot price at NBP |
| Coal price | Weekly[4] coal price in £/GJ | Bloomberg – Generic CIF ARA Coal forward price |
| Carbon price | Annual carbon price in £/kg | Bloomberg – European Futures Contract for Carbon |
| Oil | Monthly price in £/GJ | Bloomberg – Crude Oil, Brent Futures Price |

**Table 2 describing the input data files**

## Plant dynamic parameters, efficiencies and start up costs

3.9    Plant dynamic parameters are detailed below.

3.10    Data sources used by generation plants are given in the table below:

| Input | Source |
|---|---|
| BMU Heat rates | Ex-ante, based on historic generation. |
| VO&M cost | Ex-ante, based on market intelligence. |
| Start Up & Shut Down cost | Ex-ante, based on market intelligence/ analysis. |
| Technical plant parameters | Ex-ante, based on market intelligence. |

**Table 3 describing data sources for generation plants**

3.11    BMU heat rates are the energy input required for 1MWh of output.

Heat rate = Potential Energy [GJ]/Electrical Energy output [MWh]

Efficiency = Electrical Energy Output [GJ]/Potential Energy Input [GJ]

Since, 1MWh = 3.6 GJ,

BMU heat rates= 3.6/Efficiency

3.12    VO&M (Variable Operation and Maintenance) charge is a component of the incremental cost of generation per megawatt hour. It is used to recover maintenance costs which are a direct function of generation such as wear and tear and other servicing costs. It is factored into units' short-run marginal costs.

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[3] The Bloomberg indices used as source data are NBPGDAHD, MSCMUSDT, ICEDEUA and EUCRBRDT. The Bloomberg exchange rates used to convert the prices into GBP are GBPUSDGN and GBPEURGN with the addition of an appropriate unit conversion formula.
[4] Prices are submitted weekly based on a rolling 3 month ahead assessment period. Refer to MSCMUSDT for full details.

3.13   Start up / shut down costs for existing units are estimated in a similar way as that of efficiencies, i.e. through simulating historic market conditions and adjusting the costs until a reasonable match is reached. A full recalibration of the unconstrained dispatch against historic running patterns was undertaken. As it is not possible to verify individual start up / shut down costs we use these parameters to improve the calibration only.

3.14   The inputs BMU heat rates, VO&M and Start up/Shut down costs will be all reviewed prior to the second year of the scheme for implementation in the model from 1st April 2014.

3.15   Selected CHP generators will be treated as "must run". These generators supply process steam to industrial plants with electricity as a by-product. As such they will always run when available to do so.

3.16   Some other generators will be treated as a "must run at SEL, (stable export limit) or above" with the model free to dispatch the economically optimal level at or above SEL for each of these units.

3.17   Generation availability is treated as an ex-post input to the unconstrained run of the model where outturn MEL / SEL data is employed as the source data. This will be taken for each BM unit for each settlement period and input to the model on a monthly basis in line with other ex-post inputs. The source of this data will be the National Grid Economic Data warehouse (NED), a system that stores and aggregates operational and half-hourly settlement data. On the rare occasions that a generator does not submit a MEL / SEL but is available, one of the following alternatives will be used (in order of preference)

> (i)     The last submitted value by that unit; or
> (ii)    An average of submitted values from other units of the same type at the same power station.

3.18   Commissioning generation is treated as an ex-post input to the model for the first 6 months of operation. Its output will be modelled in the same way as all other generation thereafter. Generation which undergoes conversion to a new fuel type will be treated as a newly commissioning generator.

3.19   Interconnector flows (HVDC) will be modelled at the intraday gate closure position i.e. will be input to the model on an ex-post basis. This input data will be derived using Elexon settlement final physical notification (FPN) for interconnector BMUs, excluding system/error admin accounts, minus trade volumes from NGET's Energy Trade Management System (ETMS). Any further interconnectors would be added to the model at the point of commissioning and handled in the same way as existing interconnection.

3.20   In addition to the above, further inputs are required to fully represent generation levels on the system. These are:

- Hydro generation running assumptions
- Treatment of Large Combustion Plant Directive (LCPD) opted out plant
- Interconnector assumptions

These are described in further detail in Chapter 5: Generation.

## Outputs

3.21   The unconstrained model comes up with a number of outputs which are written to a file as shown in the table below. These are then used as inputs for the constrained model.

| Data file name | Description |
| --- | --- |
| FPN | Generation, used as Base Generation profile input |
| MEL | Available capacity |
| FPN to SEL | The difference in volume between generation and generator's stable export limit. This is calculated as Min (0, SEL-FPN) |
| SRMC | Short run marginal cost |
| Pump Load | Pumping, used as Base pumping profile input |
| IsOperating | Will have a value of True if the unit is generating and False at all other times (only applies to generation side) |

**Table 4 showing unconstrained model outputs**

# Chapter 4: Constrained Model

## Overview

4.1    The forecast of constraint costs is done by running a simulation of the unconstrained system followed by a run with boundary limits included, using the result from the first run as the starting position of the generating units. Each unit is assigned a set of prices as part of the balancing mechanism explained below and the optimisation engines identifies the minimum cost to move the system from the original position to a feasible position, given the transmission constraints. The diagram below illustrates the second run of the model which will determine the generation output of the constrained system. The inputs are BM bid/offer prices and transmission constraint boundary limits (explained in paragraph 4.23).
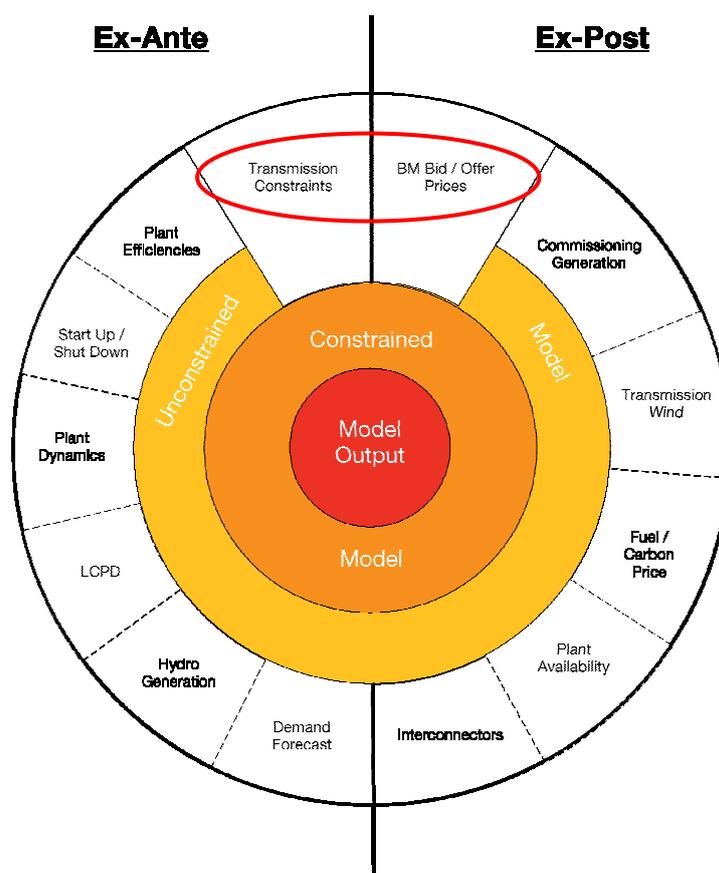


**Figure 4 Output Model**

4.2    This second run of the model factors in the limitations of the transmission network, where the difference between the two runs represents the model's assessment of the required volume and associated cost of constraint management activities. The generation output levels from the unconstrained model are therefore used as inputs to the constrained model where Plexos re-dispatches generation to meet demand on application of the boundary constraints and the submitted prices for re-scheduling plant.

4.3    Where a boundary's capability is exceeded, the resulting constraint is resolved through re-scheduling plant. This is achieved using a representation of offer/bid prices submitted into the balancing mechanism as described in 4.9 through 4.21. This provides a 'constrained' schedule of plant that satisfies transmission system constraints whilst meeting demand.

4.4     The sum of accepted bid and offer costs will give the modelled target costs against NGET's out-turn and will be used to determine its performance under the incentive.

4.5     The following section describes the way in which the model is constructed, including simulation of the balancing mechanism.

## Balancing Mechanism

4.6     The objective function used for the constrained model is to minimise total amount of money spent on the balancing mechanism subject to the boundary limits (and other constraints) set in the model above.

4.7     The balancing mechanism is exclusively used in the constrained model. It is simulated through four bid/offers price-quantity pairs, as described in 4.11, and using the unconstrained dispatch model as an initial condition.

4.8     The unconstrained dispatch shall be changed to respect interface limits, and where arbitrage opportunities exist between generators, they shall be taken.

## Generation

4.9     Offer Base is the unconstrained generation (FPN). This is the generator self-dispatch level and therefore the base level for each generator in the balancing mechanism.

4.10    Offer Prices are read in three bands and are conditional on whether the generator is operating. When generating the three bands are to move between FPN and off (De-sync Bid), FPN and SEL (Energy Bid) and FPN and Max availability (Energy Offer). When not generating, the first two bands are zero, and the third band is to take the generator up to max capacity (Sync Offer).

4.11    Four prices are used because there are broadly four categories of actions in the BM that have different price drivers; they, and their drivers, are as follows:

   • De-sync Bids - the submitted bids on a unit to reduce its output from SEL to zero. One would expect the price to reflect the value of the fuel saved, and also the cost of increased maintenance due to the extra synchronisation that will occur at a future time.
   • Energy Bids - the submitted bids on a unit to reduce its output from FPN towards SEL.  One would expect the price to reflect the value of the fuel saved.
   • Energy Offers - the offers on a synchronised unit above SEL. One would expect the price to reflect the cost of fuel used plus an opportunity element
   • Sync Offers - the submitted offers on a unit to switch the unit on and increase its output to SEL. One would expect the price to reflect the cost of fuel used, and the maintenance cost due to the synchronisation event.

4.12    To derive the prices for the four operating modes described above, the volume weighted average offer and bid prices are calculated on a half hourly basis for each BMU, using an ex-post input of actual submitted prices. These are calculated from the capped physical notification (CPN) which is defined as the minimum value of the final physical notification and the maximum export level. Using the CPN, the offer prices can be calculated for their corresponding offer quantities. From these, the weighted average per half hour per BMU for each operating mode can be found. These are the prices used in the constrained model.

4.13    The tables below give the relationship between the three Plexos bands and the corresponding offer prices and quantities.

| Offer Price | | |
|---|---|---|
| Band | When Operating | When Off |
| 1 | De-sync Bid | 0 |
| 2 | Energy Bid | 0 |
| 3 | Energy Offer | Sync Offer |

**Table 5 showing offer price bands**

| Offer Quantity | | |
|---|---|---|
| Band | When Operating | When Off |
| 1 | -99999MW | 0 |
| 2 | Min(0, SEL – FPN) | 0 |
| 3 | 99999MW | 99999MW |

**Table 6 showing offer quantity bands**

4.14    Offer and bid quantities are calculated based on an unconstrained dispatch. Negative quantities are used for bands 1 and 2 to denote bids for reducing output below FPN. Note that although bands 1 and 3 are set values, Plexos caps the value based on the generator parameters. The three offer quantity bands for an operating generator are illustrated in Figure 6.
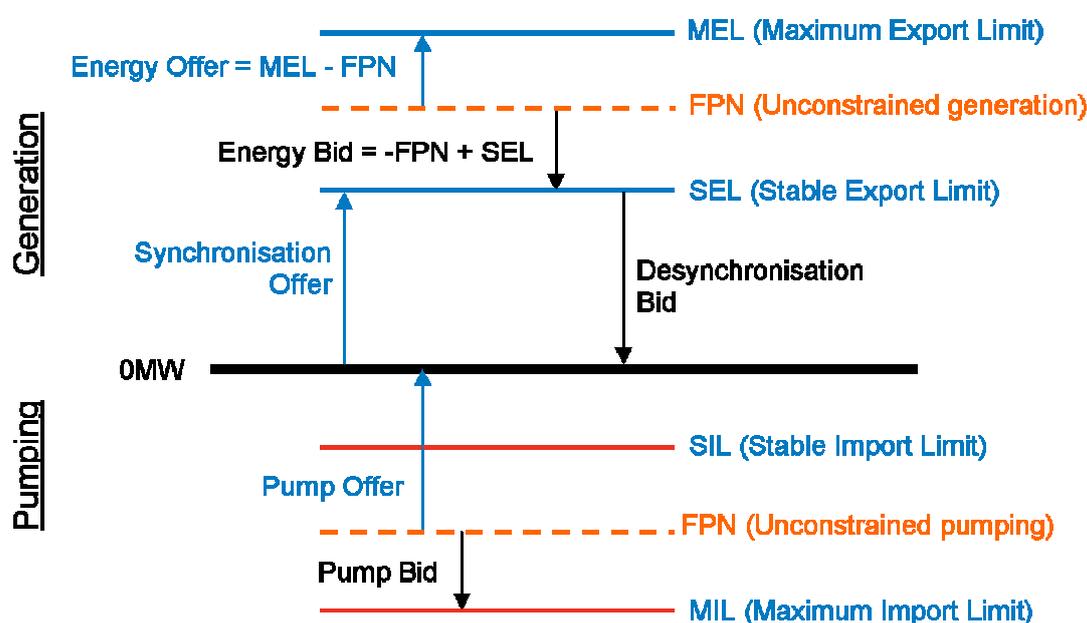


**Figure 5 showing the balancing mechanism price-quantity relationships**

## Pumping Load

4.15    For pump storage units, prices and volumes for actions affecting the amount of pumping are required.

4.16    Pumping Bid Base is the unconstrained pumping (FPN). This is the generator self-dispatch level and therefore the base level for each generator in the balancing mechanism

4.17    Pumping Bid prices are read in two bands; to move between a positive FPN and zero (Pump Offer), or max availability between zero and MIL (Pump Bid).

4.18    Two prices are used because there are two categories of actions in the BM that have different price drivers; they, and their drivers, are as follows:

- Pump Bids - the submitted bids on a unit to increase its pumping load. One would expect the price to broadly reflect the cost of energy used.
- Pump Offers - the offers on a unit to reduce its load from a negative FPN towards zero. One would expect the price to broadly reflect the value of energy saved.

4.19    To derive the prices for the two Plexos bands described above, the volume weighted average of the submitted offer price for each BMU, is calculated for each half-hour period. These are calculated from the capped physical notification (CPN) which is defined as the minimum value of the final physical notification and the maximum export level. Using the CPN, the offer prices can be calculated for their corresponding offer quantities. From these, the weighted average per half hour per BMU for each band can be found. These are the prices used in the constrained model.

4.20    The tables below give the relationship between the two Plexos bands and the corresponding offer prices and quantities.

| Pumping Bid Price | |
|---|---|
| Band | Pumping |
| 1 | Pump Offer |
| 2 | Pump Bid |

**Table 7 showing pumping bid price bands**

| Pumping Bid Quantity | |
|---|---|
| Band | Pumping |
| 1 | -99999MW |
| 2 | 99999MW |

**Table 8 showing pumping bid quantity bands**

4.21    Offer quantities are calculated based on unconstrained dispatch. Negative quantities are used for band 1 to denote offers for reducing load below FPN. Note that although bands 1 and 2 are set values, Plexos caps the value based on the pumped storage generator parameters. The two pumping bid quantity bands for an operating generator are illustrated in Figure 6.
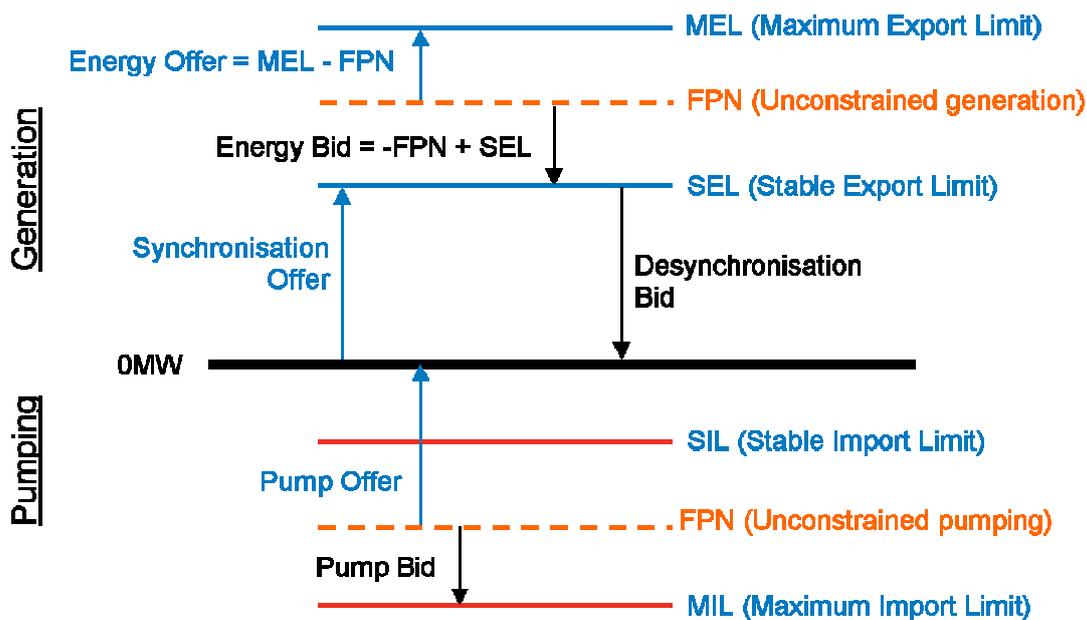
**Figure 6 showing the balancing mechanism price-quantity relationships**

4.22    The model will take any number of the above actions in whatever combination is most economic on a particular unit, given its dynamic parameters.

## Data Inputs

4.23   In addition to the inputs to the unconstrained model, the constrained model has additional data file inputs for the balancing mechanism and the boundary limits. These are as follows:

| Input name | Description | Source |
|---|---|---|
| Generation | | |
| FPN | Used as Offer Base input for generation; Half-hourly generation level of each asset. | Unconstrained model |
| MEL | Energy offer volume, also used for the Synch Offer volume | Unconstrained model |
| FPN to SEL | Energy Bid volume, only applied when unit is generating | Unconstrained model |
| IsOperating | Flag to indicate what state the generator was in when unconstrained. | Unconstrained model |
| De-sync Bid | Bid price to turn off | Volume weighted average of bid prices submitted in the BM between SEL and 0, subject to the condition FPN > 0 |
| Sync Offer | Offer price to turn on.  Only used when plant is off in the unconstrained solution | Volume weighted average of offer prices submitted in the BM between 0 and SEL, subject to the condition FPN = 0 |
| Energy Bid | Price to turn down from present level to SEL (minimum stable level) | Volume weighted average of bid prices submitted in the BM between FPN and SEL, subject to the condition FPN > SEL |
| Energy Offer | Price to turn up from present level to max capacity. | Volume weighted average of offer prices submitted in the BM between FPN and MEL, subject to the condition SEL ≤ FPN < MEL |
| Pumping | | |
| -FPN | Used as Pumping Bid Base input for pumping; Half-hourly generation level of each asset. | Unconstrained model |
| Pump Offer | Price to reduce pumping from present level towards 0 | Volume weighted average of bid prices submitted in the BM between FPN and 0, subject to the condition FPN < 0 |
| Pump Bid | Price to increase pumping from present level towards MIL | Volume weighted average of bid prices submitted in the BM between FPN and MIL, subject to the condition 0 > FPN > MIL |
| Transmission Constraints | | |
| Import Limit | Limit on flow across an interface in a south-north direction, at weekly detail | Determined by NGET (explained in chapter 2) |
| Export Limit | Limit on flow across an interface in a north-south direction, at weekly detail | Determined by NGET (explained in chapter 2) |

| Input name | Description | Source |
|---|---|---|
| Minimum Inertia | Minimum inertia (provided by generation) to ensure that RoCoF is manageable | Determined by NGET (explained in chapter 7) |

**Table 9 showing input sources for the unconstrained model**

4.24    If the relevant prices are not available, then a number of options exist. These are listed below in order of preference and subject to data availability capped (or collared) to avoid the possibility for self arbitrage[5]:

> 1. The last relevant price can be used
> 2. Else, the average of all units of the same fuel type at the node can be used
> 3. If none of the above is possible, then the average of the same fuel type at neighbouring Plexos nodes.
> 4. Alternatively, the average price of the same fuel type within the country can be used.
> 5. Finally, the average price of the same fuel type within GB can be used.

## Out of scope
4.25    Intertrips are not modelled as this model assumes that all constraints are resolved by the BM and that any efficiency gained through intertrips and other contracts will be captured through the application of the discount factor.

## Outputs
4.26    The outputs from the constrained model are the actions taken and the extent of congestion, giving the constraint volumes (cleared offer quantities) in total and per generator along with the cleared constraint costs. The sum of the all units cleared offer costs and cleared pump bid costs makes the total cost of resolving the constraints. This is to be used as the target for the incentive scheme.

4.27    When NGET become aware of significant issues in the Constraint model related to target costs, NGET will report these to Ofgem and propose amendments to the model as appropriate. No changes will be undertaken without prior written approval from Ofgem.

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[5] Self arbitrage is accepting bids and offers at the same unit to generate a net income to the SO. The BSC requires that the prices submitted to the BM do not allow for self arbitrage.

# Chapter 5: Generation

5.1     This section describes how non-conventional forms of generation are treated within the model.

## Transmission Connected Wind Generators

5.2     Wind is an intermittent generator which currently has little capability to respond to price signals or instruction from Grid (it can turn down/off, but can not turn up)

5.3     Settlement meter data will be used as an ex-post model input for wind where available. Settlement meter data is the half-hourly time series of power output for each wind generator in MW. Where this data is not available we will use the MERRA dataset in the same manner as set out for the treatment of embedded wind generation.

5.4     Wind is modelled using the percentage of available capacity and ex-post wind output data. This will be half hourly metered wind output data.

| Input | Description | Source |
|-------|-------------|--------|
| Variable wind | Ex-post half hourly wind generation | Settlement metering, adjusted for any BM actions and/or trades taken on the unit |

**Table 10 showing the wind data input to the model**

## Embedded Wind and Non Settlement Metered Wind Generators

5.5     Embedded wind is modelled on a regional basis: that is to say the network model is divided into approximately fifty regions for the purpose of forecasting wind generation. This aligns with National Grid's current wind power forecasting capabilities.

5.6     Hourly historical weather data will be extracted from the MERRA (https://gmao.gsfc.nasa.gov/merra/) dataset for each of the fifty regions, and used to generate hourly load factors. Each embedded wind generator which is included in the constraints model is assigned to one of the fifty regions and allocated the respective hourly load factor. Each of the embedded wind generators is electrically connected to the transmission network model at the relevant Grid Supply Point (GSP) / TO substation, or where that information is not available, to the closest appropriate TO substation.

## Monitoring of the commissioning of wind farms

5.7     It is important to ensure that as new wind farms are connected to the electricity network, the model is kept up to date to ensure that the metered output of the wind farms ex-post can be input and their contribution to meeting demand more accurately modelled. Hence, a list of all wind farms along with the nodes at which they are connected, their connection dates and capacity will be maintained in order to ensure that the models are updated in a timely manner. Updates to new generation connections for which Elexon data is unavailable, such as for embedded wind farms, will be made using an appropriate auditable source (such as Grid Code data submissions).

## Hydro

5.8     Hydro is modelled in two ways – pumped storage and run of river.

5.9     Run of river is modelled by assuming a monthly water inflow into a head pond. Plexos then optimises the release of this water to generate electricity. The observed monthly hydro generation is used to calculate the average value.

5.10    Pumped storage is dispatched based on price differential within a day.  If there is sufficient price differential during the day, Plexos will schedule pumping at times of low price and generation at times of high price.

5.11    Pumped storage plants are modelled as a closed system comprising a head storage and a tail storage, shared between the multiple BM units at each plant. There are no energy flows into or out of the head or tail storages other than from generating or pumping. A pump efficiency is also defined for each pumped storage generator.

5.12    Pumped storage utilisation is optimised on a daily basis. In the unconstrained model, pumped storage will arbitrage between peak and off-peak periods in order to lower system-wide generation costs in the objective function.

5.13    The treatment of pumped storage units with respect to unconstrained model outputs is as follows.

- The unconstrained period-level output of each generator, including pumped storage units, is passed to the constrained model run.
- When pumped storage units are pumping rather than generating, this is reported by Plexos as pump load rather than negative generation.
- However, across the system as a whole, the unconstrained generation output will increase in order to meet pumping load.

5.14    In the constrained model, deviations in pumped storage generation (due to transmission constraints for example) from the initial FPN position are optimised in the same manner as for other generators.

## Large Combustion Plant Directives (LCPD)

5.15    The LCPD limits the operating hours of a series of plants in the UK.  The latest BM Reports data provides LCPD plant cumulative running hours as of 30/04/2013. The table below shows the remaining hours, the current Plexos model assumptions on closure dates, and the implied maximum annual capacity factor for each plant stack.

| Generator | Average capacity factor to date since 1/1/08 | Remaining hours as of 30/04/2013 | Current model closure date | Implied remaining days | Implied annual max capacity factor |
|---|---|---|---|---|---|
| Ironbridge | 19.3% | 10977 | 01/01/2015 | 611 | 74.9% |
| Ferrybridge C Unit 1 & 2 | 35.0% | 3663 | 01/01/2015 | 611 | 25.0% |
| | | | | | |
| Didcot A | 42.8% | 0 | 31/03/2013 | 0 | |
| Tilbury LCP 1 Boilers 7 & 8 | 37.4% | 2501 | 31/03/2012 | 0 | |
| Tilbury LCP 2 Boilers 9 & 10 | 38.1% | 2183 | 31/03/2012 | 0 | |
| Cockenzie LCP 1 Units 1 & 2 | 42.8% | 0 | 31/03/2013 | 0 | |
| Cockenzie LCP 2 Units 3 & 4 | 42.8% | 0 | 31/03/2013 | 0 | |

**Table 11 showing the Plexos model assumptions for LCPD plants**

## Interconnected Markets

5.16    Interconnected markets can drive constraint levels across certain key boundaries, either as sink (export) or source (import). The GB system presently has four interconnectors (GB-France), Moyle (GB-NI), BritNed (GB-Netherlands) and the East-West (GB-Eire).

5.17    In order to accurately reflect the impact of interconnector flows on constraints within the model, Interconnectors flows (HVDC) will be modelled at the intraday gate closure position i.e. will be input to the model on an ex-post basis. This input data will be derived using Elexon settlement Final Physical Notifications (FPNs) for interconnector BMUs, excluding system/error admin accounts, minus trade volumes from NGET's Energy Trade Management System (ETMS).

# Chapter 6: Headroom Replacement Volume

6.1     Headroom represents spare capacity on operating generating units which NGET can potentially access to meet its reserve requirements. Headroom may become inaccessible due to transmission constraints in the case of generators located behind an export constraint boundary. The cost of replacing this 'sterilised headroom' can contribute materially to overall constraint costs. If an action is taken to completely replace sterilised operational margin, then the costs are assigned to constraint costs.

6.2     The headroom replacement costs for each month will be calculated as follows:

$$
\begin{aligned}
\text{CONS\_HR} = \\
-1530070 \\
+ 38574.2 * \text{VWA\_Op\_Reserve\_P} \\
+ 51.6337 * \text{CMM\_V}
\end{aligned}
$$

Where

CMM_V is Constrained Margin Management Volume
VWA_Op_Reserve_P is monthly operational reserve price.

Defined in the statement of the Energy Cost Target Modelling Methodology

# Chapter 7: Inertia Modelling

## Rate of Change of Frequency

7.1     A large generation or demand loss on the system can cause the frequency to change at a fast rate. The level of Rate of Change of Frequency, (RoCoF) is dependent on two factors

- Size of generation/demand loss
- System Inertia- A synchronous generating unit (mainly large steam or gas turbine generating plant) operating in the electrical power system will deliver its stored energy (in the rotating mass of the shaft of the turbine) to the system on falling system frequency. This inertia response will help to slow down the initial fast drop of the system frequency and hence a reduction of RoCoF and is measured in Hertz per second (Hz/s). Interconnectors and converter interfaced generating plant are unable to deliver any further inertia response.

7.2     Some generators are equipped with protection relays to prevent them generating as part of a non viable isolated system.  This Loss of Mains (LOM) protection is normally set to 0.125Hz/s.

7.3     The RoCoF of the NGET system needs to be limited to 0.125Hz/s at all times. If the frequency changes faster than this rate then potentially around 3GW of further generation susceptible to RoCoF could be tripped.

## System Inertia

7.4     System inertia will reduce as a result of increasing the penetration of asynchronous generators which have no or very little natural inertia compared

to large synchronous generators (due to the absence of a large rotating mass in the generator). The degree of reduction is dependent on how much asynchronous plant is connected, and the generation output of this plant, which in turn determines how much synchronous plant is left running at any time. At the end of 2012 the reduction in system inertia was visible.

## Modelling the Cost of System Inertia

7.5     In the Plexos Constraint Model each generator has been assigned an inertia value in MVAs. This denotes how much inertia this generator can provide to the system when synchronised. A minimum level of system inertia requirement is defined per period.

7.6     Plexos will be run with the generators positions as dispatched by constrained run of the model. Plexos will apply these inertia conditions and re-dispatch generation to satisfy them and determine costs.

## Glossary

The following definitions are intended to assist the reader's understanding of this document. In the event of conflict with definitions given elsewhere, those used in the Transmission Licence, Grid Code, Balancing and Settlement Code and Connection and Use of System Code take precedence.

| Term | Definition |
|------|-----------|
| BMU | Balancing mechanism units |
| CPN | Capped Physical Notification |
| Classes | Groups of Object types – e.g. Production class contains the Object types Generator, Storage, the Transmission class contains Lines and Nodes etc |
| Ex-ante | Ex-ante data is data reflecting events that have yet to happen by the time of the beginning of the Scheme.  By implication, such data has to be estimated or predicted. |
| Ex-post | Ex-post data is outturn data, i.e. data reflecting events that have happened by the time of the beginning of the Scheme. |
| FPN | Final Physical Notification |
| Memberships | A method to link two objects together.  For example, a generator will have a membership to a fuel and a node. |
| MEL | Maximum Export Limit |
| MIL | Maximum Import Limit |
| Objects | Physical and financial features of electricity market – for example, Generator, Line and Company.  They are defined by Properties, and their relationship to other objects is defined by memberships |
| Properties | They define an object. For example, a generator can be defined by a Max Capacity and a Heat Rate.  It is typical for more properties to be used to define an object. |
| SRMC | Short Run Marginal Cost |
| SEL | Stable Export Limit |
| SIL | Stable Import Limit |
| VO&M | Variable Operation & Maintenance |

## Revisions

| Issue | Modifications | Changes to Pages |
|-------|--------------|------------------|
| Final Draft | | |