PARSONS BRINCKERHOFF

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Technical Assessment of the Operation of Coal & Gas Fired Plants

DECC

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LIST OF ABBREVIATIONS

CCGT	Combined Cycle Gas Turbine
CEM	Continuous Emissions Monitoring
CO	Carbon Monoxide
DECC	Department of Energy & Climate Change
IED	Industrial Emissions Directive
FGD	Flue Gas Desulphurisation
FSNL	Full speed no load
HRSG	Heat Recovery Steam Generator
GW	Giga Watt
GWh	Giga Watt Hour
LCPD	Large Combustion Plant Directive
MEL	Maximum Export Limit
MSG	Minimum Stable Generation
MW	Megawatt
NGT	National Grid Transco
NOx	Oxides of Nitrogen
OCGT	Open Cycle Gas Turbine
OEM	Original Equipment Manufacturer
PSSR	Pressure Systems Safety Regulations
SEL	Stable Export Limit
SOP	Stable Operating Point
STOR	Short Term Operational Reserve
TEC	Technical Export Capability
UK	United Kingdom
VIGV	Variable Inlet Guide Vane

EXECUTIVE SUMMARY

Introduction

This report describes the capability of four types of generating technologies to provide reserve generation which can be delivered at short notice to balance any shortfalls in grid capacity:-

- Coal fired (500MW and 660MW)
- Combined cycle gas turbine (160MW – 300MW)
- Open cycle gas turbine – large scale industrial (125MW – 180MW)
- Open cycle gas turbine – aero derivative (60MW – 100MW)

The ability to provide reserve generation capacity is a function of the start times for each type of plant technology

Start Up Times

The indicative time for start-up is made up of two phases namely:-

- notice to deviate from zero and
- synchronisation to full load.

The Notice to Deviate from Zero (NDZ) time is a term used by the grid operator which covers the prior notice that a power plant requires, to be able to start up the plant to the point of synchronisation. This comprises preparation of the unit for starting by adjusting the boiler drum water level, purging the furnace of any explosive gases, lighting up the burners to commence raising pressure, pressure raising, temperature matching, blowdown of wet steam to drains and running the turbine to speed. This activity is the same for both coal and gas fired power plant

The time from synchronisation up to full load is a function of the design of the plant; for example unit size, the initial material conditions and its ability to ramp these to the final conditions as the generator is loaded. The table below show a summary of the technology indicative start up times.

Table 1 – Indicative start up times

	Technology	Notice to Synch (mins)	Synch to Full Load (mins)
Hot start	Coal	80-90	50-100
	Existing Gas CCGT	15	40-80
	Modern Gas CCGT	15	25
	Gas Large OCGT	2-5	15-30
Warm start	Coal	300	85+
	Gas CCGT	15	80+
	Gas Large OCGT	2-5	15-30
Cold start	Coal	360-420	80-250
	Gas CCGT	15	190-240
	Gas Large OCGT	2-5	15-30
All Starts	Gas (Aero) OCGT	2-5	4-8

The start-up rates shown above show a clear correlation, with the fastest start up times being achieved by the smallest units. This means in priority order the aero derivative OCGTs (~60 MW) are capable of the fastest start up times followed by the CCGTs (300 MW) and the coal fired units (500 MW). The times have been derived from our knowledge of the plant technologies and evidence seen in the UK power trading market. To that extent, the indicative duration shown reflects both the technical parameters and the commercial offer of the plant and these can differ as the plant optimises its market position from day to day. However in a competitive market it is likely that the durations will align.

Mothballing/Preservation

In the context of a power station the words mothballing or preservation applies to those techniques which could be applied to the plant in order to prevent or reduce deterioration when out of service.

There are two options for preservation, namely short term and long term preservation. The techniques used for each option differ significantly, together with the timescales required to successfully mothball and reinstate the plant back to an operational condition. These returns to service timescales can also vary considerably between technologies (Coal, CCGT or OCGT).

No allowance has been included in Long Term for re-recruitment of staff and training or for major overhaul (if required) prior to return to service. These additional durations have been included in Section 6.4 of this report and should be added (where applicable) to the plant reinstatement duration.

The table below shows a summary of the durations to mothball/reinstate for a technology type.

Table 2 – Indicative mothball / reinstatement times

		Activity	Duration (days)
Short Term	Coal	Mothball/Reinstate	4
	Gas CCGT	Mothball/Reinstate	2
	Gas OCGT	Mothball/Reinstate	1
Long term	Coal	Mothball/Reinstate	42*
	Gas CCGT	Mothball/Reinstate	30*
	Gas OCGT	Mothball/Reinstate	5

* The durations specified above include time required to mothball and reinstate the plant back into service only.

Within this report no indicative costs have been included for two shift operation or plant mothballing/reinstatement. These costs are outside the scope of work for this report but will need to be considered at a future time in order to establish the optimum technical/commercial fit when deciding on which strategy should be adopted to provide reserve generation which can be delivered at short notice to balance any shortfalls in grid capacity.

1 INTRODUCTION

Parsons Brinckerhoff has been asked by the Department of Energy and Climate Change (DECC) to undertake work in relation to gas and coal power plant technology and the associated modelling assumptions. This report considers specifically the achievable start up times which could be applied to existing coal and gas fired power plants and expected new CCGT and OCGT designs in order to provide reserve generation which can be delivered at short notice to balance any shortfalls in grid capacity.

1.1 Structure of the Report

Section 2 describes the power market arrangements and parameters applicable to generators providing reserve generation capability.

Section 3 of this report describes the physical limitations in starting up a power plant to provide a repeatable and reliable return to service without causing any long term damage and premature ageing.

Section 4 describes the start-up times and factors that affect the flexibility of a coal fired power station.

Section 5 describes the start-up times and factors that affect the flexibility of a CCGT and Open Cycle Gas Turbine (OCGT).

Section 6 describes the mothballing process and gives indicative times to place the plant into a state of preservation and to return the plant back into service.

1.2 Scope of work

The aim of this report is to describe the capability of the three types of generating technologies to provide reserve generation which can be delivered at short notice to balance any shortfalls in grid capacity.

The indicative time for start-up is made up of two phases namely:-

- notice to deviate from zero and
- synchronisation to full load.

This report does not include consideration of the costs associated with:

- Retaining the generating unit to be made available as requested (to include the range of fixed costs e.g. staffing, maintenance, insurance, use of system charges and rates).
- Holding the generating units in a state of readiness to be able to respond (to include the range of fixed costs above and fuel required to keep the plant in a state where it could move to synchronisation quickly.
- Operating the synchronised unit at low load in order that it can increase output immediately (to include the range of fixed costs above and fuel required to keep the unit generating above Minimum Stable Generation).

2 POWER MARKET ARRANGEMENTS AND PARAMETERS

2.1 Balancing Market

The UK has moved away from the pooling and central despatch arrangement that was set up on privatisation and implemented a system based on bi-lateral trading between generators, suppliers, traders and customers. The parties contract with each other for power based on a rolling half hour basis with generators then despatching their plant themselves. Any imbalance between the parties' contractual positions and the actual physical flows are determined and the volume settled at the system buy or system sell prices.

National Grid is responsible for balancing the system in real time, maintaining frequency by matching supply and demand. The Balancing Mechanism has been established by which parties can submit:

- Offers - to increase generation / decrease demand.
- Bids - to decrease generation / increase demand.

Generators are required to submit their availability and plant parameters and are rewarded for their activities in the balancing market by the prevailing system prices.

2.2 Synchronisation

The UK electricity grid system's target frequency is set at 50 Hz with small variations around that level depending on the balance of supply and demand. All machines connected to the grid are held at the system frequency and National Grid balances the system frequency by calling for generators to increase or decrease the power supplied in response to fluctuating demand.

Synchronisation is taken to be the point at which the individual generating unit is connected to the national grid system. At the time the switch is closed and connection made, the frequency of the generator has to be synchronous to that of the grid.

2.3 Ramp Rates

The ramp rates define the rate (in MW per minute) at which units can be brought up and down the load range once they are synchronised to the system. The individual generating units can have varying characteristics which require different operating techniques and therefore different plant parameters. Each generator discloses its ramp rates to assist the system operator in determining which generating units can be called to respond to an impending imbalance on the system.

In addition generators can use the plant parameters to manage their plant's exposure to the market and submit attractive or prohibitive rates accordingly. This allows them to protect plant which they would not wish to run in the short market unless it was amply rewarded for the risk.

2.3.1 Ramp Up

The Run-Up Rate Export shows the rate(s) of **increase** in active power production for a particular unit which is exporting power within a particular range. There can be up to three rates for any unit allowing the generator to give a profile of production over the run up period including two “elbow” points where the rate can be changed. This is to enable a unit that is starting up to match its technical requirements with that of the grid operator.

2.3.2 Ramp Down

The Run-Down Rate Export expresses the rate(s) of **decrease** in active power production for a particular unit which is exporting power within a particular range. There can be up to three rates for any unit allowing the generator to give a profile of production over the run down period including two “elbow” points where the rate can be changed. This is to enable a unit that is shutting down, to match its technical requirements with that of the grid operator.

2.4 Operating Regimes

2.4.1 Base load

All the 500 MW Coal plant currently operating was designed and built in the 1960s and 70s to provide base and near full load, operation 24 hours a day across the year.

Combined Cycle Gas Turbine plants constructed since the 1990s were similarly designed and built to provide a base load regime, e.g. 7,980 operating hours with a small number of annual starts, typically <15 (5 hot starts, 4 warm starts, 3 cold starts, and 2 trips).

Plant adopting this base load regime not only provides the highest generated output, but is also able to run at the higher levels of efficiency and to manage the plant damage caused by variations in temperature and pressures associated with starts and changes in loading.

2.4.2 Two Shifting

Plants which come off load overnight on a regular basis as demand falls are said to “two-shift”. They are required to come on load around 05:00hours for the morning peak, stay synchronised on the system (often at part load) during the day and are ready to respond to the higher evening peak before coming off load around 22:00hrs.

For CCGT plant two shift operation is around 3,875 operating hours with a high number of annual starts, typically, 200-250 (200 hot starts, 0 warm starts, 50 cold starts, and 4 trips.

2.4.3 Coal Fired

Until recently and since the world price of coal has fallen relative to gas, most coal plants had been operating flexibly and with some incurring circa 200 starts per annum as they came off load overnight and across the weekends in response to the demand profile.

In the past the smaller generators below 500 MW had offered themselves to the market with double two-shift capability, looking to take advantage of higher prices across the peaks, coming off load during the day. This regime has been undertaken by some 500 MW units in the past but operators generally have looked to avoid the potential plant damage associated with frequent variations in metal temperatures.

2.4.4 Gas Fired - CCGT

As gas turbine technology has developed in the last 25 years, efficiency has improved markedly from circa 49 per cent in 1990 (e.g. Killingholme A) to circa 57 per cent of more recent projects (e.g. Carrington). Consequently those plants with lower efficiencies have been less able to compete and moved away from base load, through two shifting and, in the face of recent low coal prices, had to consider running intermittently to cover peaks only. Certain plants subsequently have been positioned to work in the Short Term Operating Reserve (STOR) capacity market or have been taken into mothballing for short or longer periods until their market position improves (e.g. Keadby in 12 month storage).

2.4.5 Gas Fired - OCGT

With much lower efficiency and burning light fuel oil or natural gas these plants would not compete in the power market for long duration runs. However their responsiveness gives them an advantage over other technologies and they can be brought on and off load very quickly for short, infrequent periods in the year to address system imbalances at a national or local level (e.g. Indian Queens).

3 PHYSICAL LIMITATIONS OF START TIMES

3.1 Thermal Fatigue/Rate of Temperature Rise

Whilst the time taken to start a unit on a conventional power station is made up of multiple operational activities and plant limitations, the most time critical activity is the plant limitation caused by thermal fatigue.

In the context of a power station, thermal fatigue is defined as the gradual deterioration of a material by alternate heating and cooling. This type of thermal fatigue may also be classified as low cycle fatigue due to the low frequency of cycles, typically one or two per day. Thermal fatigue cracks can usually start to initiate in less than 200,000 cycles.

At the design stage of a power station, detailed attention is given to the selection of material properties and wall thickness of high temperature components, to optimise temperature ramp rates during start up. Typical thick walled components such as boiler/Heat Recovery Steam Generator (HRSG) drums and headers, main steam pipework and steam turbine, valves, steam chests and cylinders are limited by the material yield point. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed (which can be achieved by overheating the component using excessive rapid ramp rates), some fraction of the deformation will be permanent and non-reversible. It is therefore essential not to exceed the design rate of temperature rise, in order to prevent the premature onset of thermal fatigue cracking and to achieve the required component design life.

Modern control systems are designed to prevent critical “thick walled” components from being heated too quickly by setting limits on rates of temperature rise and maximum temperature allowed. There are also limits on the rate of loading on the electrical generators, since excessive electrical loading can generate high thermal temperatures in the copper core of the rotor and stator.

3.2 Coal Fired Plant

Designed in the 1960’s and 70’s, the materials used in large coal fired power plants can be classed as “basic” by today’s standards. The methods used to increase the power output from the earlier 120 MW units to the existing 500 MW units was to “scale up” the design. This involved increasing the thickness of some critical boiler and steam turbine components, thus increasing the start-up time.

3.3 Combined Cycle Gas Turbine (CCGT)

The majority of the first generation CCGT plants were designed in the late 1990s or early 2000’s. Based on aero derivative turbines (similar to aircraft engines) the materials used in the gas turbines of CCGTs are highly developed alloys with significantly thinner cross-sections than used in a steam turbine. The average size of a class F gas turbine is typically 300 MW; this discharges hot gas through a HRSG, producing steam for a nominal 150 MW steam turbine. The component size of the HRSG and steam turbine is therefore smaller having been based on 150 MW capacity. An improvement in materials over the last 30 years has allowed some boiler and steam turbine components to be designed with reduced wall thickness.

3.4 Open Cycle Gas Turbine (OCGT)

Traditionally OCGTs have been used to provide a black start capability (with some grid/frequency response) and were typically sized <40 MW. Based on aero derivatives the gas turbine components are highly developed alloys of thin section, being capable of rapid start up. Since there is no HRSG or steam turbine installed in an OCGT, the total start up time is dependent only upon the gas turbine.

4 GUIDE TO COAL PLANT FLEXIBILITY

4.1 Types of Coal Plant

Coal fired power plant in the UK now comprises a range of 500 MW and 660MW units designed and built predominantly in the 1960s and 1970's for a nominal 25 years design life, equivalent to 250,000 operating hours. The original specification for these large generating sets anticipated predominantly base load operation with few starts or requirements for flexible loading while in service. As the power market has developed, there has been an increasing need for coal fired generating units to operate more flexibly in response to competitive pressures from alternative fuels and renewables and in order to target periods of higher prices.

The flexible generation profile has placed more demands on the operators and stresses on the plant itself. The original operating life assumed to be 25-30 years has been extended by a programme of continuing engineering assessments and substantial repair and replacement of life expired components.

A number of coal plant units have "opted out" of the Large Combustion Plant Directive (LCPD) which required improved emissions controls. These units have either closed already, converted to other fuels such as biomass or are scheduled to close before 31 December 2015. In addition, the implementation of the Industrial Emissions Directive (IED) in January 2016 will require the remaining plants to meet new more stringent emission limits with respect to

- oxides of nitrogen (<200mg/m^3),
- sulphur dioxide (<200mg/m^3)
- particulates (<20mg/m^3)

In order to meet the new IED limits, owners must consider major plant upgrade investments or conversion to biomass or contemplate opting out of the new regime. This latter option will allow them to generate only for a further 17,500 hours across all units (based on usage of the plant stack(s)) before closing by the end of 2023 at the latest.

It is not known at this stage how many coal fired plants will ultimately elect to comply with the emissions requirements and therefore how many will be in existence in the mid-2020s. The following table shows the plants that are understood to remain in operation using coal after January 2016 and therefore will possibly be available post 2023:

Table 3 – UK Coal fired power stations post 2016

Plant	Units No.	Capacity MW
Aberthaw	3	1 665
Cottam	4	2 000
Drax	4	2 580
Eggborough	4	1 960
Ferrybridge	2	1 000
Fiddlers Ferry	4	1 987
Longannet	4	2 304
Ratcliffe	4	2 000
Rugeley	2	1 026
West Burton	4	2 000
TOTAL	35	18 522

Note Drax comprises 660 MW and Longannet 600 MW units

4.2 Start-up - Process

4.2.1 Operating a 500 MW generating unit is a large scale industrial process. The unit comprises a boiler circa 50 metres tall producing high pressure steam delivered to rotate a 30 metre long turbine train of some 200 tonnes at 3000 revolutions per minute. In addition there is a wide range of auxiliary equipment required to deliver pulverised coal to the boiler for combustion, to supply water for use in the boiler or the cooling systems and to transport electrical power to and from the unit.

Therefore the 500 MW generating sets use an established and relatively generic start up sequence which must be followed. This is designed to protect plant integrity but primarily to ensure safety from the inherent risks associated with a process which entails combustion of significant volumes of explosive substances and plant operating at high pressures and temperatures.

4.2.2 The duration of a start-up is dependent on the physical state of the unit and in particular the existing energy stored in the plant in terms of the temperature and pressures. Plant which has more recently been in operation will contain more energy and can be returned to service more quickly. Starts are therefore categorised as "hot", "warm" and "cold" and defined in Section 4.3.

4.2.3 Start-up times comprise two phases namely:

- Pre-synchronisation

The pre-synchronisation phase duration varies depending on whether the unit is being brought into service from a "hot" or "cold" start (see definition in Section 4.3) but in all cases the unit start-up consumes large quantities of energy (gas and electricity) before the plant is able to generate power and export from the site.

- Post synchronisation

Generating sets are brought on (synchronised) to the national grid system at 50 Hz and at the point where the steam turbine rotor is spinning at 3000 revolutions per minute. At this point the turbine is at the Fast Speed No Load (FSNL) point and whilst energy is being applied to rotate the turbine (no load heat requirement), there is no generation of electrical power.

Once synchronised, additional energy in the form of steam is applied to the turbine and the plant begins its ramp from zero MWh to full load.

4.2.4 A typical "hot" start up process for a 500 MW generating set requires the following steps:

Table 4 - Typical "Hot" start Process for Coal Fired Unit

Task
Adjust drum water level, bring Induced Draft (ID) and Forced Draft (FD) fans into service in order to purge the furnace of any potentially flammable gas which could otherwise result in explosion on ignition.
Ignite oil burners to start warming through the furnace, establish circulation and provide stability since coal will not ignite on its own.
Start the first coal mill and deliver pulverised fuel to the boiler for ignition and to begin the process of raising steam.
Blow down steam to drains, until desired degree of superheat is reached to match the steam pipework and turbine inlet conditions. Open boiler stop bypass valves to commence warming steam pipework, with pipework drains open. When steam pipework is up to temperature commence opening the turbine valves to raise temperature with drains open. Finally steam is admitted into the turbine for running the machine. This then progressively increases temperature and pressure and thereby avoids potentially damaging differentials.
The first mill is used to provide the steam required to move the turbine rotors to 3000 revolutions per minute prior to synchronising on to the Grid system. This point before any electrical load is produced is known as FSNL.
The second and third coal mills are brought into service as the output from the turbine is increased to over 200 MW.
As the mills are established the oil burners become less necessary to support combustion and can be progressively shutdown. In addition, the steam feed pumps and direct contact heaters are brought fully into service. The steam feed pumps are powered from the boiler and take over from electric pumps (fed from the station supply) used at start up.
When the furnace is considered stable enough, then the last oil burner is taken out, allowing coal to support combustion. This requires a minimum number of mills in service before stabilising oil can be shut off (generally 3 for a 5 mill station and 4 for a 6 mill station).
Minimum Stable Generation (MSG) is typically around 280 MW and will be reached when the boiler combustion is stabilised, the main boiler feed pump is established and the oil can be shut off.
Once the oil burners are no longer required, combustion will remain steady as long as load remains above MSG. The boiler output can then be increased and decreased within an allowable range by varying the quantity of fuel delivered by the full range of up to six mills.

Once the boiler is fully heated after approximately one hour of further operation, the minimum "stable operating point" (SOP) may at some sites be lower than the original MSG from the start-up sequence (see discussion of shut-down below).

4.2.5 FGD Plant

For boilers with flue gas desulphurisation (FGD) in place, the FGD equipment is initially kept offline during start-up, to avoid damage to the absorber linings and oil contamination of the gypsum by-product. At a point at or close to MSG the FGD dampers operate to route the flue gases through the FGD. This point is specified in operational guidance, as it is important that time is allowed for the FGD process to stabilise at a lower load before progressing to full load. The exact point of damper operation may vary from start to start, depending on operational factors.

4.2.6 "Cold" starts after the unit has been out of service for a longer period require a prolonged start up process with steps of the "hot and warm start" processes extended to safeguard the integrity of the plant and mitigate potential plant damage from mechanical processes such as creep and fatigue (see later).

Whereas a hot start may require oil burners in service for only 1-2 hours, a completely cold start, e.g. after returning from an outage, may require the boiler to be running on oil burners alone for pressure raising for several hours.

4.2.7 Shut down process for the unit is based on the following steps:

Table 5 - Typical Shut-down Process for Coal Fired Unit

Task
Individual mills are shut down and the turbine output allowed to reduce as the boiler pressure falls. In conjunction some oil burners may be commissioned to maintain safe and stable combustion.
Fuel input from the last 3-4 mills is reduced and the unit output falls below SOP.
Mill coal feeders are tripped and mills allowed to mill off the coal they contain. As the mills run short of coal, combustion becomes erratic and the oil burners are essential to keep the furnace alight.
Once the coal has milled off the oil burners are left in for a few minutes to ensure that no explosive coal mixtures are present and then the oil burners are shut down.
Reduce load on steam turbine to zero and desynchronise for the grid.
Check rundown of steam turbine to slow speed machine barring to allow for cooling.
Open all steam turbine and non-boiler main steam pipework drains.
Finally the FD and then the ID fans are shut down and the boiler boxed in by closing dampers to prevent the chimney suction drawing air through the boiler and cooling it.

The above actions particularly below the SOP are carried out quickly to ensure the large section components are not unnecessarily cooled so as to retain energy.

When the unit output falls below SOP the boiler is usually committed to shut-down. SOP is generally equivalent to the value of minimum "Stable Export Limit" (SEL) which is declared to the grid operator from time to time. However SEL may be varied relatively frequently, due to commercial considerations; it is more appropriate to specify SOP separately, although the values will usually be close or identical.

4.3 Start-up - Types, Timings and Cost

The definition of hot, warm and cold starts can vary between manufacturers, but basically refer to the metal temperature of the steam turbine. The table below shows the correlation between shutdown period and steam turbine metal temperature used to define each start up type.

Table 6 - Coal Plant Start Types

Start	Shutdown Period (hours)	ST Metal temperature (^{o}C)
Hot	< 8	> 400
Warm	8 to 48	250-400
Cold	> 48 Long term	<205

4.3.1 **Hot** starts are typically defined as those undertaken within 8 hours of coming off load and are generally seen during a period of two shifting. Some plants do extend the duration to 12 hours thereby enhancing their flexibility to respond to market demand) Most of the 500 MW units have seen much of this regime during the last 15 years where plant is called for the weekday morning peaks (05:00hrs) after having come off load in the previous late evening (22:00hours).

With this type of start the equipment has retained much of its metal temperatures and the steam condition can be returned to that required for synchronisation in a relatively short period. Typically the unit can be returned to fast speed no load (FSNL) and synchronisation on to the grid within 60-90 minutes.

4.3.2 **Warm** starts are typically defined as those undertaken within 8 to 48 hours of coming off load. With these durations it is not possible to maintain the plant near to operating conditions and the time and cost required to return the unit service is increased.

With this type of start the equipment has lost more of its heat and process temperatures and steam conditions have degraded significantly. The unit cannot be returned to service without significant input of heat and over a longer period. Typically the unit can be returned to FSNL and synchronisation on to the grid within 120 - 300 minutes depending on the interval since coming off load.

4.3.3 **Cold** starts are typically defined as those undertaken after 48 hours of coming off load. This may be after a short planned outage or plant breakdown and in some instances the boiler will have remained full. Although the plant will have lost much of its heat it is likely that the unit can be returned to service relatively quickly as the boiler is full of water and fuel ready. In such instances the unit can be returned to FSNL and synchronisation within 300 - 420 minutes.

If the unit has been on a longer term outage and the boiler has been drained, then the boiler has to be prepared and the range of auxiliary plant brought back in to service. On these occasions it can take much longer to return the plant to service.

4.3.4 Typically once a hot coal unit is synchronised, a block load of an immediate ~50 MW is applied to the machine and, on hot starts, followed by a loading rate of around 10 MW per minute thereafter. In the case of warm and cold starts a more conservative ramp rate is applied with no block load depending on turbine metal temperatures. This would entail ramping at circa 1-1.5 MW per minute up to around 130 MW with a subsequent increase to circa 5 MW per minute up to full load.

The following table summarises starts by type and shows indicative durations to synchronisation and then to full load:

Table 7 - Coal Indicative Start up Times

Start	Shutdown Period (hours)	Notice to Synch (minutes)	Synch to Full Load (minutes)
Hot	< 8	60-90	50
Warm	8 to 48	120-300	85
Cold	> 48	360-420	90
	Long term	420+	200

4.3.5 Start Cost

UK plants undertook a number of exercises to identify and evaluate the component costs of starts and synchronisation in their efforts to remain flexible and viable in the face of an increasingly competitive market. Costs include:

- Fuel for oil burners.
- Coal burnt to attain boiler stable operating point.
- Electricity used to drive auxiliary plant.

In addition operators assessed the associated non-energy costs including plant degradation/damage resulting from each additional start.

Appendix 1 shows the ramp rates submitted on a weekday in late January 2014 and demonstrates that once synchronised coal plant on a hot start can move from zero to full load 500 MW and above within one hour. It is also noted that certain units are restrained in their offer, providing slower ramp rates and deferred full load times. This may be to cater for specific plant conditions, reflecting the duration that the unit has been off-load or simply owners positioning their plant in the market in order to optimise their returns.

Shutdown of the coal fired units is typically much faster than starts. This is due to the absence of the technical limitations present during the start. The downturn rate is generally given by the ability of the operator to reduce the load to the system. Appendix 4 shows the ramp down rates for some coal fired units in the UK.

5 GUIDE TO GAS PLANT FLEXIBILITY

5.1 Types of Gas Plant

5.1.1 Pre-Existing CCGT

CCGT technology was introduced into the UK market in the early 1990s and some of the plant is therefore nearing the end, or in a few cases is already beyond, its original design life. At the time these power stations, such as Deeside and Little Barford,provided the latest technology for operators and there were close relationships with the original equipment manufacturers (OEM) which brought further enhancements. There has been subsequent investment in new gas plants in the UK since privatisation and more are nearing completion or cleared through planning ready for start on site when owners commit. The plant is significantly smaller in scale per MW capacity than a coal plant and the staffing levels required to operate and maintain the plant are much lower.

The “combined” technology utilises a HRSG which raises steam using the heat of the exhaust gases of the gas turbine. The steam is then used to drive a conventional steam turbine and generate electricity. This approach increases the efficiency of the process from below 40 per cent in a simple gas turbine to nearer 60 per cent in modern CCGTs.

The gas turbine rotor is rotating at a very early stage in the start-up process and able to synchronise to the Grid within 15 minutes of ignition. However the steam turbine takes longer as time is required to develop the right steam conditions in the HRSG and to “heat soak” the steam turbine before it is brought through to full load. In general, the unit is synchronised, generating and exporting power to the grid much sooner after ignition than a coal fired plant, taking shorter than a coal unit to reach full load from the point of synchronisation.

5.1.2 The definition of hot, warm and cold starts can vary between manufacturers, but basically refers to the metal temperature of the steam turbine. The table below shows the correlation between shutdown period and steam turbine metal temperature used to define each start up type.

Table 8 - CCGT Start Types

Start	Shutdown Period (hours)	ST Metal temperature (^{o}C)
Hot	< 8	>371
Warm	8 to 36/48	204 to 371
Cold	> 36/48	<205
	Long term	-

Table 9 - Existing CCGT Indicative Start up Times

Start	Shutdown Period (hours)	Notice to Synch (minutes)	Synch to Full Load (minutes)
Hot	<8	15	35-80
Warm	8 - 48	15	80+
Cold	48 - 120+	15	190-240

5.1.3 Modern CCGT

CCGT manufacturers have improved the efficiency of the CCGT process during the last 20 years and new proposals, seen at Marchwood and Pembroke for example, offer efficiency approaching 60 per cent. However in response to changes in power markets which have seen base load plants move to become mid merit/intermediate load, the OEMs are developing machines that offer improved flexibility:

- Fast start up and shut down.
- Fast load changes and load ramps.
- Start-up reliability and load predictability.
- Grid system support (frequency control and ancillary services).

This requirement had initially emerged in the UK with requests for more frequent starts and then for faster starts but is becoming more widespread across Europe particularly in the face of increasing and/or fluctuating renewable supplies. Improved flexibility will allow the owner to respond to the market, both coming to synchronisation, and ramping up through the range, more quickly and more often.

OEMs have sought to improve flexibility without compromising efficiency or plant life. They have modified the design of newer plants looking to retain temperature and pressures during short shutdowns by use of stack dampers and auxiliary steam feeds. In addition the high pressure drum used in previous CCGTs has been removed. This had been a critical high pressure component exposed to wide variations in temperature and which had to be managed during start up and shutdown to avoid the effects of thermal stress. In addition the OEMs have optimised the start-up procedures particularly in relation to the steam turbine. In the past the operator had to keep the machines during run up at specified hold points while steam conditions were managed for the steam turbine. Increasingly the hold points have been minimised or eliminated and for hot starts, steam turbines can be started up in parallel to the gas turbine using the first steam which becomes available after the hot start.

These CCGTs hot start up times improve from 95 (15 minutes from Notice to Synch plus 80 minutes from Synch to full load) to 40 minutes for a latest model 430 MW machine (15 minutes from Notice to synch plus 25 minutes from Synch to full load). Improvements have also been reported for warm and cold starts.

Table 10 - Modern CGGT Indicative Start up Times

Start	Shutdown Period (hours)	Notice to Synch (minutes)	Synch to Full Load (minutes)
Hot	<8	15	25
Warm	8 - 48	15	-
Cold	48 - 120+	15	190

It is noted that manufacturers allow operators a number of options with respect to starts, having automated the process to give "normal" and also "fast" and "cost-effective". The "fast" option can be selected by the operator but will bring forward the maintenance interval as it incurs additional factored / equivalent hours which reflect the stresses on the machine. The operator can make the commercial decision based on the cost of maintenance versus the benefits earned at prevailing power market prices. The "cost effective" option allows a more measured start and, although fast relative to normal, does not incur the maintenance penalty.

Appendix 2 shows the ramp rates submitted on a weekday in late January 2014. This demonstrates that CCGT plant generates quickly from synchronisation using the gas turbine only but that, particularly in the event of cold starts, there is a prolonged hold point while the plant specific steam turbine operating conditions are met.

Shutdown of the machines is typically much faster than starts. This is due to the absence of the technical limitations present during the start such as temperature of the materials. The downturn rate is generally given by the ability of the operator to reduce the load to the system. Appendix 5 shows the ramp down rates for CCGT plants.

It is also noted that certain units are restrained in their offer, providing slower ramp rates and deferred full load times. This is likely to be to cater for specific plant conditions, reflecting the duration that the unit has been off-load or simply owners positioning their plant in the market in order to optimise their returns.

5.1.4 Future Large Frame OCGT

OCGT use only the gas turbine component, there being no HRSG to capture the heat from the exhaust gases. As the plant comprises gas turbine only, they can be synchronised quickly and do not have to consider loading a steam turbine. These large scale industrial gas turbines are taken to be in the range of 100MW to 180MW and include General Electric's 9E, Siemens SGT5-2000E and Alstom's 13E2 machines.

Start times for large frame gas turbines are by nature longer than for aero-derivative gas turbines, due to management of expansion and thermal stresses in the heavier casings and components. Aero engines (see later) are much lighter in construction and more suited to rapid temperature changes during the start cycle.

Typically, heavy frame gas turbines undergo an inspection and blade replacement cycle based on the number of "normal" starts incurred. However when the plant has undertaken normal starts with subsequent fast loading the starts factor can double. In exceptional circumstances where there is both a fast start and fast loading, the starts factor can be increased by 10 – 20 thereby bringing forward the manufacturer's recommended inspection outage and associated costs.

This category of plant is taken to cover those units above 100 MW and have been utilised in the UK on a limited scale such as Indian Queens in Cornwall. Given the size of the plant and its poor efficiency relative to the combined cycle plant, it is likely that "new build" would be contemplated only where there is a requirement for system support or where a capacity agreement can be put in place.

One approach being considered is to operate existing CCGT plants in open cycle mode. Most CCGT plants in the UK are not capable since they cannot remove the exhaust gases from the gas turbine without passing them through the HRSG. Only those CCGT plants with a by-pass stack can divert the exhaust gases out of the process cycle by use of a damper plate.

It is understood that operators of older and less efficient CCGTs are considering the installation of a by-pass stack in order to offer short term capability. This modification can only be undertaken where there is sufficient space between the gas turbine and the HRSG and is not practicable on many of the more compact sites.

Table 11 - Future Large Frame OCGT Indicative Start up Times

Start	Notice to Synch (minutes)	Synch to Full Load (minutes)
Start	2.5	15-30

5.1.5 Future Small Frame OCGT

This type of plant, generally between 25 MW and 100 MW, has been in operation in the UK and modern engines can provide around 38 per cent efficiency in open cycle mode.

Table 12 - Small Frame OCGT Indicative Start up Times

Start	Notice to Synch (minutes)	Synch to Full Load (minutes)
Start	2.5	10-15

5.1.6 Aero-derivative OCGT

These machines, similar to aircraft turbines have been used for many years in the UK and often deployed on existing thermal and nuclear sites, primarily to provide black start capability. The units are typically in the range 60MW to 100MW and include Rolls Royce's Trent 60 and General Electric's LMS 100. Stand-alone sites also exist and new installations are being considered and developed to provide a short term flexible response for both grid support and power output. Owners are seeking capacity contracts in order to support the funding required and also looking to operate on a variety of fuels including gas, diesel and liquid biomass.

Table 13 - Aero Derivative Indicative Start up Times

Start	Notice to Synch (minutes)	Synch to Full Load (minutes)
Start	2-5	4-8

This is the time to go from a Grid call (if selected) by National Grid Transco (NGT) to low frequency then the start commences immediately.

Since OCGTs comprise a gas turbine only; there is only one type of start and does not require the hot, warm and cold start classifications used on coal and combined cycle units. In general since these machines are suited to more able to cope with rapid temperature changes there is no starts related maintenance penalty and outages are predicated largely on accumulated running hours.

In appendix 3 it is shown the start-up time for different OCGTs in the UK. The shutdown time for these units is given in Appendix 6.

5.2 CCGT Start-up - Process

A typical start sequence for the first gas turbine in a combined cycle plant is detailed below with hot, warm and cold all progressing through the same steps but of differing durations. A combined-cycle start-up procedure is separated into three primary phases:

- Purging of the HRSG.
- Gas turbine (GT) speed-up, synchronisation, and loading.
- Steam turbine (ST) speed-up, synchronisation, and loading.

Table 14 - Typical "Hot" start Process for CCGT Unit

Task
Establish cooling water systems and auxiliary boiler in service where applicable.
Ensure GT and ST's auxiliary systems are operational and release criteria are satisfied.
Confirm the HRSG is ready for start and gas path is clear.
GT is accelerated using the generator in motor mode with a static frequency converter (SFC) or with a separate starter cranking motor and the combustion system is purged by maintaining a low GT speed for a fixed period.
GT load held at, typically 25% load until HRSG pressure rises to the minimum operating pressure and drum levels are stabilised. The ST condenser vacuum raising sequence starts if there is no auxiliary boiler.
GT target load is raised to circa 50% after the minimum operating pressure has been reached. GT NOx steam or water injection system (where fitted) is warmed and put into service.
Once required steam parameters are met the ST run up sequence commences.
With the GT load held at circa 50% the ST reaches full speed and is synchronised.
For cold starts the ST can only be loaded at a low rate (discussed in next section) and will require several hours before all available steam is routed through the steam turbine and the ST bypasses are closed. For NOx steam or water injected GT units, this defines the Stable Export Limit.
Dry low NOx GTs has loaded to this point using diffusion burners for combustion stability. At (typically) 50-60% GTs load these units gradually change to premix operation. Once completed and stable operation (including the steam turbine) is achieved, this is the Stable Export Limit. This mode changeover point is firing temperature initiated with a "dead band" set between rising and falling temperature (load). This, together with the time lag between changing load and resultant changing temperatures, can result in significantly different loads for changeover to occur for start-up and shut down (dependant on the rate of loading or deloading). Also the firing temperature that is used to initiate the change is affected by ambient conditions.
SEL is achieved when a unit is operating within its design range, with stable combustion and operational NOx control measures. Stable readings are obtained from the continuous emissions monitoring (CEM) exhaust measurements, which confirm the low NOx operation.

The duration of the start-up sequence for gas turbines operating in open cycle mode can be shortened as the sequence of steps associated with the HRSG and steam turbine operations may not be applicable.

Stable Export Limit and Gas Turbine load control

The Stable Export Limit (SEL) is achieved when a unit is operating within its design range, with stable combustion and operational NOx control measures. Stable readings are obtained from the CEM exhaust measurements, which confirm the low NOx operation.

As Gas Turbines are available in a number of designs (both aero engine derivatives and industrial turbines) and can be operated in open cycle or as part of a combined cycle, there are a number of factors that can influence the durations of the above sequence steps. For example, the loading and control of the Gas Turbine will vary with combustor design and burner configuration.

Common types of combustor include annular, can-annular and silo style combustion chambers. For some designs, all of the burners fire continuously with the gas supply being modulated, for others the burners fire in groups that are turned on and off to control the load; some designs combine the two firing patterns. Sequential combustion is also available in which two combustion chambers are separated by a turbine section.

The burners may also have different modes of operation. In diffusion mode the gas to air ratio is high which produces a fuel rich flame which is more stable and is commonly used for start-up and low loads. In premix mode the gas to air ration is lower which results in a weaker flame but with lower emissions. Due to the weaker flame, operating in premix mode can only be used for higher loads. Steam or water injection can also be used to control NOx.

For more recent combustor configurations, the flame and acoustic pulsations will need to be continually monitored. Lean premix combustion relies on firing at a low flame temperature in order to achieve low NOx. In certain Dry Low NOx systems this increases the likelihood of combustion instability - resulting in an increased level of combustion dynamics (acoustic pulsations) with a significant risk of serious damage to the combustor. In addition to maintaining low emissions, the control system needs to navigate through operating windows that are prone to high dynamics.

Turbine exit temperature and spread are carefully monitored during run up and, at higher loads, the calculated firing temperature is usually the controlling factor. Turbine exit temperature may be used to trigger changes in burner modes or groups.

The number of Variable Inlet Guide Vane (VIGV) stages and their control varies with design. On some machines VIGVs are gradually opened as the load increases to match the increase in fuel. For other machines the VIGV only have two positions and open at a set firing temperature.

The Stable Export Limit is only reached once the Gas Turbine is loaded, has minimal exhaust temperature spread, using the optimal burner mode (i.e. premix, steam injection) and required steam properties and full Steam Turbine operation with no steam bypasses operating.

The limiting factor during turn-down is often elevated concentrations of carbon monoxide (CO) rather than increasing NOx. The combustion air flow is initially throttled back, in line with the reducing fuel flow, using variable inlet guide vanes at the compressor inlet or by bleeding off Compressor Discharge Air. However, below about 70 per cent load, the air-fuel ratio increases and the flame temperature falls. When combined with the higher design air-fuel ratio of lean-premix systems, these factors cause a rapid increase in CO that marks the end of normal operation. This is more severe for twin-spool aero-derivate designs.

Shut Down

The shutdown sequence will vary from site to site. An example for a Combined Cycle Gas Turbine is as follows:

- Reduce load to Stable Export Limit.
- Both Gas Turbine and Steam Turbine unit shut down sequences are initiated at the same time. As the output drops below the Stable Export Limit, this is considered to be the commencement of the shutdown period.
- The Steam Turbine rapidly de-loads and follows a controlled shut-down sequence.
- During the Gas Turbine de-load sequence the combustion system reverts to start-up mode with an associated short term increase in NOx and CO emissions.

6 MOTHBALLING/PRESERVATION

In the context of a power station the words mothballing or preservation apply to those techniques which could be applied to the plant in order to prevent or reduce deterioration when out of service.

When market economics are not favourable, the option to mothball the plant can be applied, but at this time it may not be known for how long the plant may be required to remain in the preserved state. Basically there are two categories or options for preservation, namely short term preservation and long term preservation. The techniques used for each option can vary significantly, together with the timescales required to successfully mothball the plant and reinstate the plant back to operational condition. These returns to service timescales can also vary significantly between technologies (Coal, CCGT or OCGT).

Basically the protection of plant from condensation, corrosion and seizure due to lack of intended use, is primarily a matter of good engineering practice and good housekeeping.

The most frequently used methods of preservation and plant protection are:

- The establishment of clean dry conditions - This is the most satisfactory practice since it allows the plant to be recommissioned with the minimum of delay. Normally the plant will be drained and fully dried out with the installation of dehumidifiers
- Cleaning, flushing and drying – This method can be applied when storage under dry air is not possible. Generally the system will require opening up, to enable the necessary work to be carried out correctly. This is the least satisfactory method to be applied to plant that requires long-term storage. It is however the only practical option available when shutting down plant for major maintenance activities.
- Plant can be stored wet when filled with suitably dosed demineralised water.
- The use of a protective gas – When it is not possible to achieve dry conditions, protection can be achieved by filling the system with nitrogen gas. Nitrogen blanketing is an effective method of plant storage. However unless the plant is absolutely gas tight, it is very difficult to achieve in reality.
- The use of inhibitors – For systems that cannot be drained, cleaned or blanketed etc, dosing the waterside of plant systems with corrosion inhibitors may be used as an alternative.
- Intermittent running of the plant – Auxiliary systems which contain non aggressive fluids such as lubricating oils can be run on a regular but intermittent basis to prevent corrosion and ensure filtration.
- Protection of essential live systems – For systems which need to remain available, but may be subject to damage through freezing, i.e. fire systems, applying insulation or trace heating may be an option.
- Removal of plant items – small high-risk items can be removed for storage in clean dry conditions.

6.1 Short Term Preservation

Short term preservation can be classed as a period of 3 -12 months and typically the boilers/HRSGs are retained full of de-oxygenated water. The access doors on the steam turbine and condensers are removed to allow dehumidifiers to be installed which circulate dry air through the airspaces to prevent corrosion.

Station staff are normally retained and are given alternative duties principally relating to plant preservation. The plant being out of service also provides the opportunity to carry out more routine or planned maintenance that would otherwise requires an individual unit or station outage.

Due to the short term nature of the plant preservation, emphasis is required at all times on the ability for a rapid return to service of the plant, in order to capitalise on changes in market economics.

The ability to achieve a successful and rapid return to service relies on the station having a detailed recommissioning plan which includes the cancellation of safety documentation, proof testing of safety systems and running of essential lubrication systems to allow hand turning or machine barring.

6.2 Long Term Preservation

Long term preservation techniques (>12 months) are far more detailed than short term preservation techniques and require the boilers/HRSGs to be fully drained and dried out. Main generators are to be stored under dehumidified air and large electrical motors are to be kept dry using in built heaters where installed. Small high risk components should be removed and stored under clean dry conditions. Live water systems will require protecting against freezing by applying insulation or trace heating. External surfaces normally covered by insulation where rainwater, condensation or leakage could lead to concealed corrosion occurring.

Where advanced information on the long term preservation (>1year) is available, it is common to reduce the number of site staff down to a minimum level. These staff are then given preservation inspection and maintenance duties. One major disadvantage of this approach is the timescales required to recruit and train new operations staff, when the plant is required to return to service.

6.3 Miscellaneous Preservation Costs

Even when the plant is fully mothballed, there are a number of costs which will still continue, in order for the unit to be capable of return to service. These can be summarised as:

- Minimum staffing cost.
- Maintenance costs of: Fire systems, Heating Ventilation and Air Conditioning (HVAC), building structures etc.
- Pressure Systems Safety Regulations (PSSR) Inspections.
- Transmission Entry Capacity payment (TEC).
- Insurance.
- Water Fees.

The decision to mothball the plant may have been taken to avoid or defer the expense of a major overhaul. In this case a major overhaul would be required before the plant is returned to service.

6.4 Timescales

The timescales to mothball the plant in the first instance and then for return to service will depend upon a number of factors, the main two being the method of preservation (short or long term) and technology type (Coal, CCGT and OCGT). Typical periods that a plant would need to be taken out of the market to justify the costs of long-term mothballing and reinstatement would be > 12 months. While the option for long term mothballing is available to both coal and gas fired plant, the cost of mothballing is significantly higher for coal fired plant, due to the physical size and additional equipment.
Coal Plant

With the typical UK coal fired unit being sized at 500 MW, the time taken to fully mothball a unit of this size would be longer than for a significantly smaller gas fired unit. Typical durations for the mothballing activities are as follows:

Table 15 - Coal Plant Preservation Timescales

Period	Activity	Duration (days)
Short Term	Mothball	4
	Reinstate	4
Long Term	Mothball	30-42
	Reinstate	30-42
	Staff Recruitment & Training	90
	Major outage Duration (if required)	84

Based on the common “F” Class gas turbine technology of nominal 300 MW size, the time taken to fully mothball a unit of this size would be significantly shorter than a coal fired unit, but longer than for an OCGT Unit. Typical durations for the mothballing activities are as follows:

Table 16 - CCGT Preservation Timescales

Period	Activity	Duration (days)
Short Term	Mothball	2
	Reinstate	2
Long Term	Mothball	15-30
	Reinstate	15-30
	Staff Recruitment & Training	90
	Major outage Duration (if required)	42-56

With the majority of existing UK OCGT units being of a smaller size than the coal and CCGT units, typically <40 MWe, typical durations for the mothballing activities are as follows:

Table 17 - OCGT Preservation Timescales

Period	Activity	Duration (days)
Short Term	Mothball	1
	Reinstate	1
Long Term	Mothball	5
	Reinstate	5
	Staff Recruitment & Training*	-
	Major Outage Duration (if required)**	10

* Due to the minimal staff employed on OCGT sites it is unlikely that there would be any significant manpower reductions.

** Duration based on 5 days to install and remove an exchange engine.

APPENDIX

REPORT APPENDICES

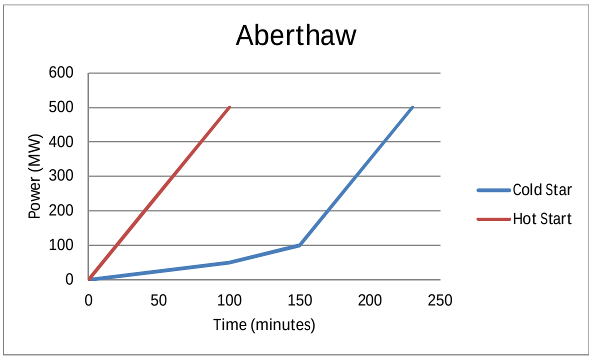
Appendix 1

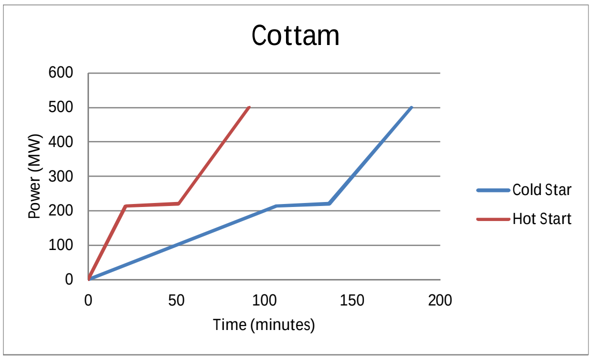
Tables and Graphs Showing Coal Fired – Declared Hot & Cold Start Times (from synchronising to Full Load)

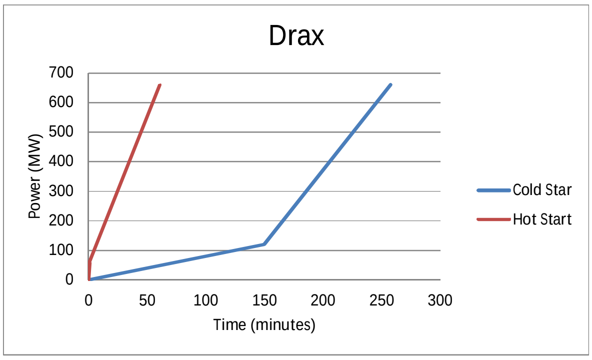
Power plant	Start	Rate1	Elbow2	Rate2	Elbow3	Rate3	TOTAL
Aberthaw	Cold	1	50	1	100	5	230
Cottam	Cold	2	214	0	220	6	184
Drax	Cold	1	1	0.8	120	5	258
Ferrybridge	Cold	15	15	0.2	46	5	247
Fiddlers Ferry	Cold	40	80	4	200	6	82
Longannet	Cold	5	220	0.5	250	5	174
Rugeley	Cold	3	90	3	245	10	107
Ratcliffe On Soar	Cold	0.5	50	5	230	5	190

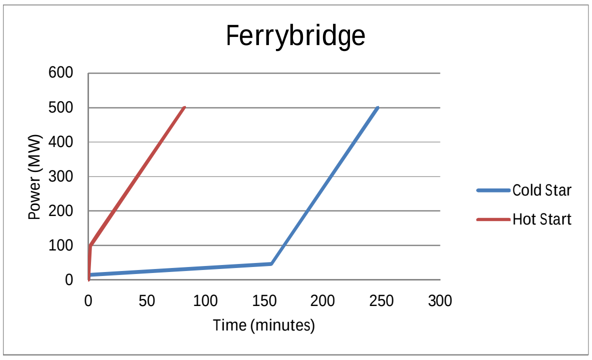
Power plant	Start	Rate1	Elbow2	Rate2	Elbow3	Rate3	TOTAL
Aberthaw	Hot	5	100	5	190	5	100
Cottam	Hot	10	214	0	220	7	91
Drax	Hot	60	60	10	300	10	61
Ferrybridge	Hot	50	100	5	130	5	82
Fiddlers Ferry	Hot	50	100	9			46
Longannet	Hot	5	220	0.5	250	5	174
Rugeley	Hot	25	90	8	245	10	48
Ratcliffe On Soar	Hot	5	243	0.2	250	10	109

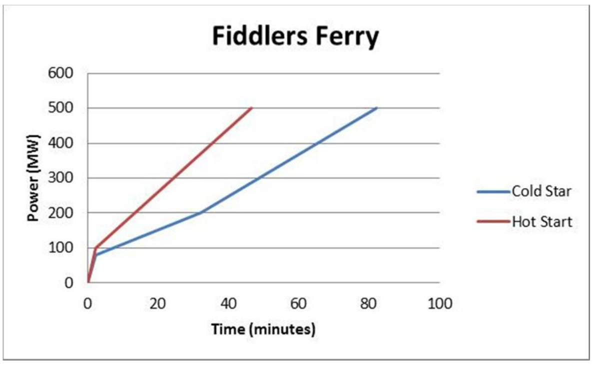
Source of information: Balancing Mechanism Reporting System website (BMRS), http://www.bmreports.com/

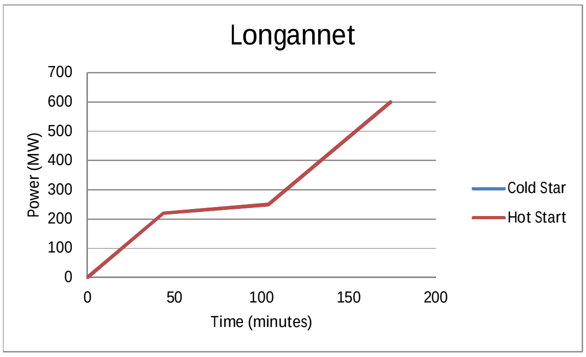

Aberthaw
Power (MW)
600
500
400
300
200
100
0
0
50
100
150
200
250
Time (minutes)
Cold Star
Hot Start

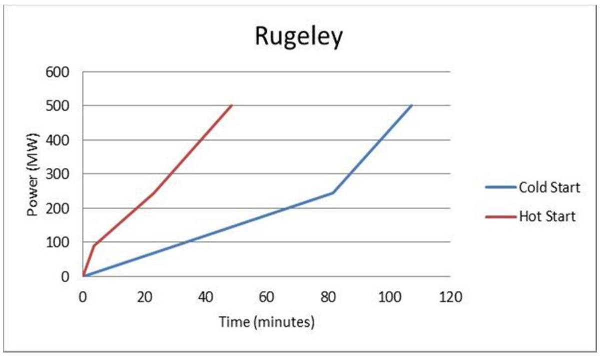

Cottam
Power (MW)
600
500
400
300
200
100
0
0
50
100
150
200
Time (minutes)
Cold Star
Hot Start

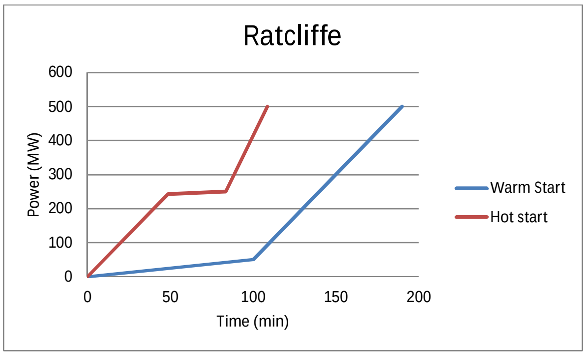

Drax
Power (MW)
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
Time (minutes)
Cold Star
Hot Start


Ferrybridge
Power (MW)
600
500
400
300
200
100
0
0
50
100
150
200
250
300
Time (minutes)
Cold Star
Hot Start


Fiddlers Ferry
Power (MW)
600
500
400
300
200
100
0
0
20
40
60
80
100
Time (minutes)
Cold Star
Hot Start


Longannet
Power (MW)
700
600
500
400
300
200
100
0
0
50
100
150
200
Time (minutes)
Cold Star
Hot Start


Rugeley
Power (MW)
600
500
400
300
200
100
0
0
20
40
60
80
100
120
Time (minutes)
Cold Start
Hot Start


Ratcliffe
Power (MW)
600
500
400
300
200
100
0
0
50
100
150
200
Time (min)
Warm Start
Hot start

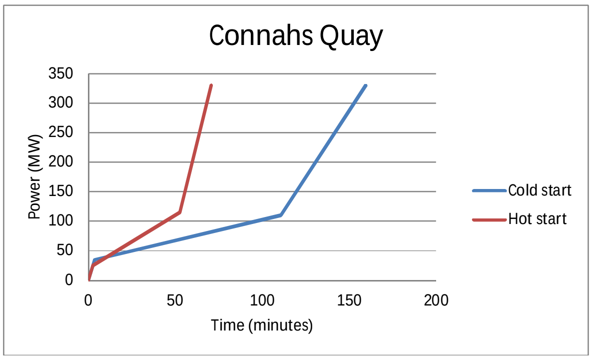
Appendix 2

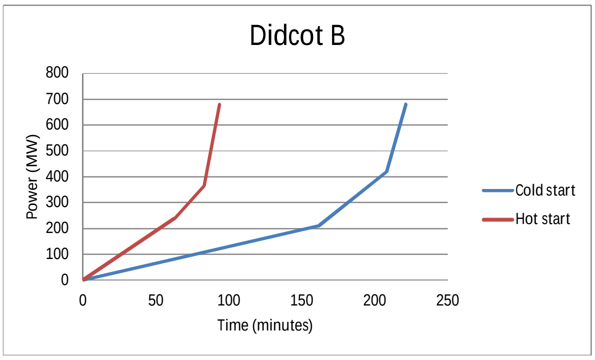
Tables and Graphs Showing CCGT - Declared Hot & Cold Start Times (from synchronising to Full Load)

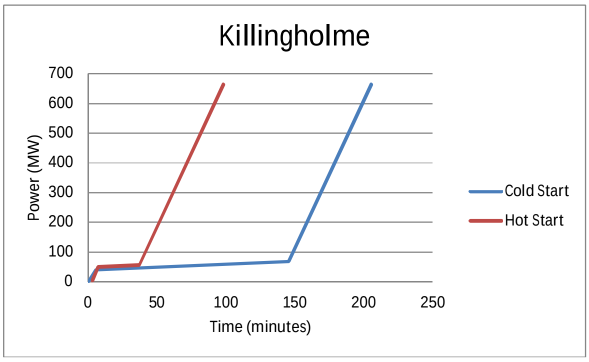
Power plant	Start	Rate1	Elbow2	Rate2	Elbow3	Rate3	TOTAL
Connahs Quay	Cold	10	35	0.7	110	4.5	160
Didcot B	Cold	1.3	210	4.5	420	20	221
Killingholme	Cold	7	40	0.2	68	10	205
Staythorpe	Cold	0.3	0.3	0.3	0.3	0.3	233
Pembroke	Cold	0.3	43	4	191	17.5	192
Deeside	Cold	8	49	0.2	58	2.6	240
Marchwood	Cold	5.5	5.5	5.5	5.5	5.5	327
Little Barford	Cold	5	110	0.3	140	20	149

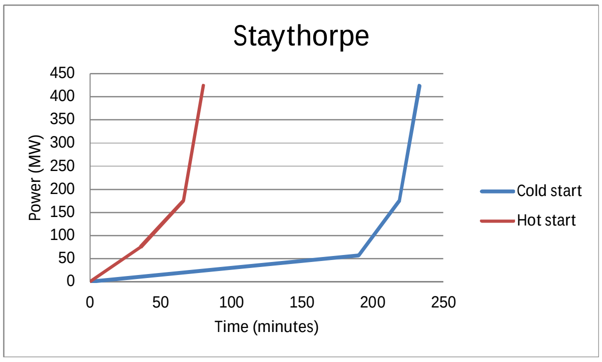
Power plant	Start	Rate1	Elbow2	Rate2	Elbow3	Rate3	TOTAL
Connahs Quay	Hot	10	25	1.8	115	12	70
Didcot B	Hot	3.8	305	30	710	5	88
Killingholme	Hot	7	60	0.2	62	10	79
Staythorpe	Hot	2.1	2.1	2.1	2.1	2.1	80
Pembroke	Hot	11	178	0.3	191	17.5	71
Deeside	Hot	24	360	30	475	5	34
Marchwood	Hot	10	10	10	10	10	70
Little Barford	Hot	10	60	20	240	20	37

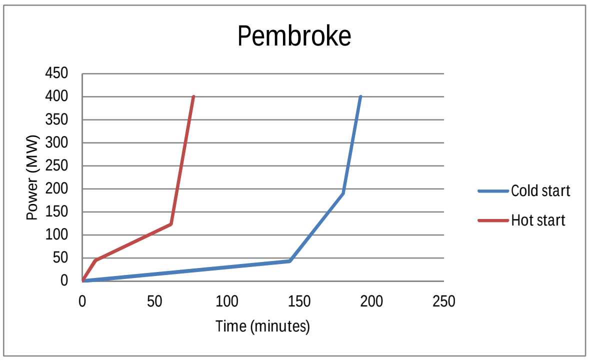
Source of information: Balancing Mechanism Reporting System website (BMRS), http://www.bmreports.com/

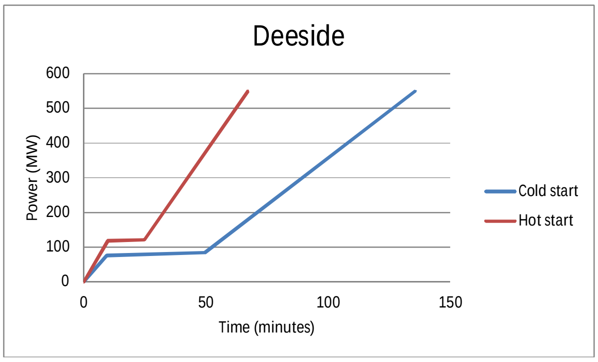


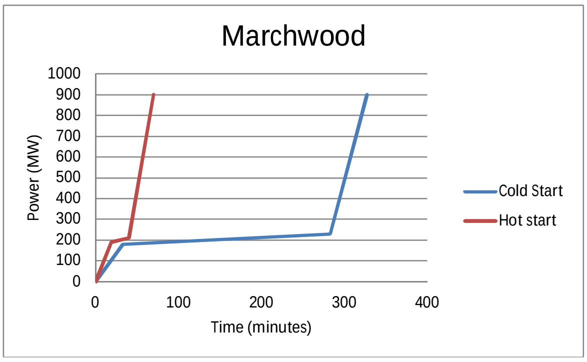


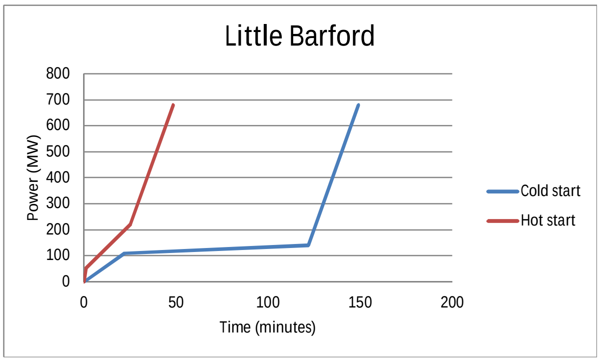

Killingholme
Power (MW)
700
600
500
400
300
200
100
0
0
50
100
150
200
250
Time (minutes)
Cold Start
Hot Start


Staythorpe
Power (MW)
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
Time (minutes)
Cold start
Hot start


Pembroke
Power (MW)
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
Time (minutes)
Cold start
Hot start


Deeside
Power (MW)
600
500
400
300
200
100
0
0
50
100
150
Time (minutes)
Cold start
Hot start


Marchwood
Power (MW)
1000
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
Time (minutes)
Cold Start
Hot start

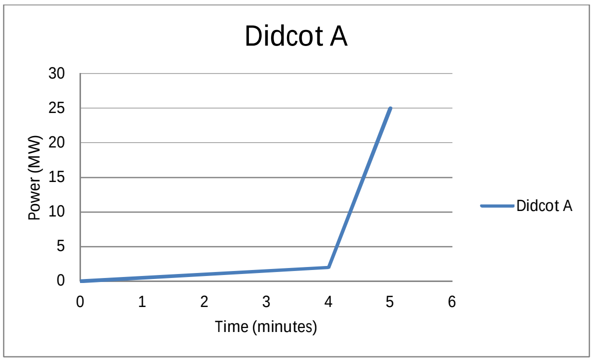

Little Barford
Power (MW)
800
700
600
500
400
300
200
100
0
0
50
100
150
200
Time (minutes)
Cold start
Hot start

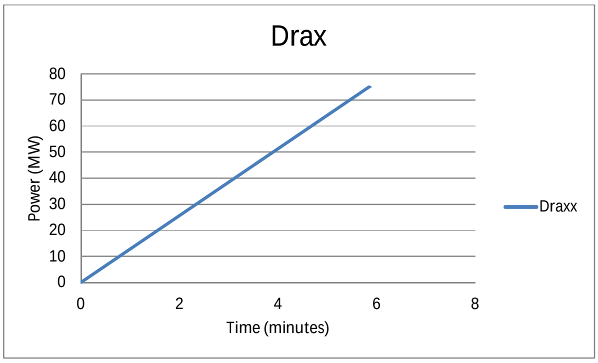
Appendix 3

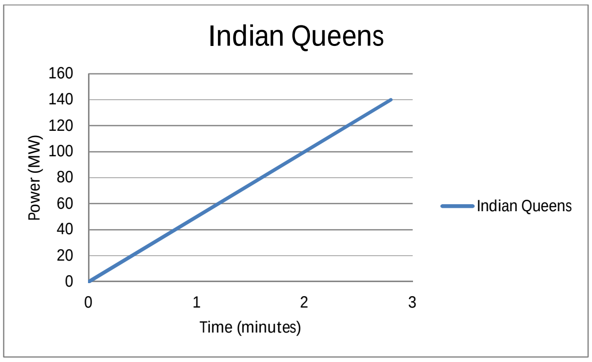
Table and Graphs Showing OCGT - Start Times (from synchronising to Full Load)

Power plant	Rate1	Elbow2	Rate2	Elbow3	Rate3	TOTAL
Didcot A	0.5	2	23	0	0	5
Indian Queens	50	130	50	140	50	2.8
West Burton	10	10	10	20	1	12
Drax	12.8	0	0	0	0	2.5

Source of information: Balancing Mechanism Reporting System website (BMRS), http://www.bmreports.com/





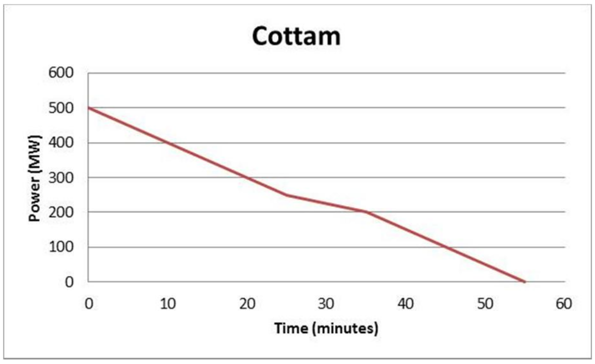


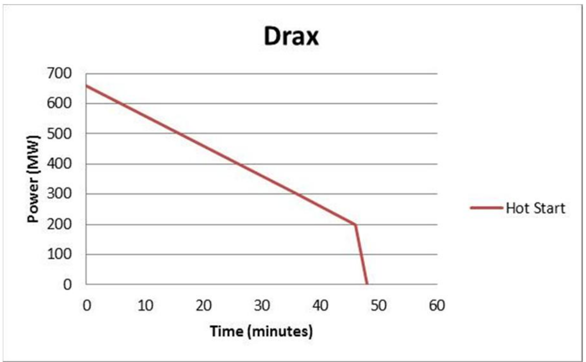
Appendix 4

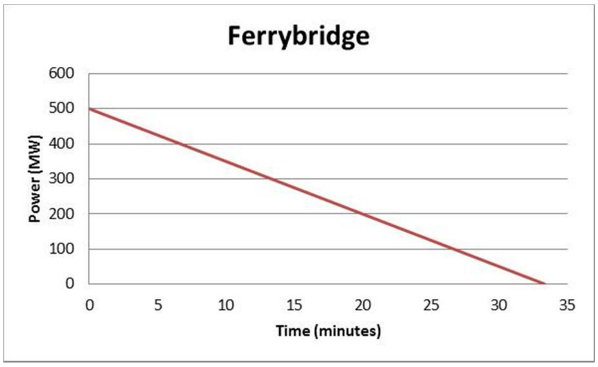
Table and Graphs Showing Coal Fired – Declared Run-Down Rate Export

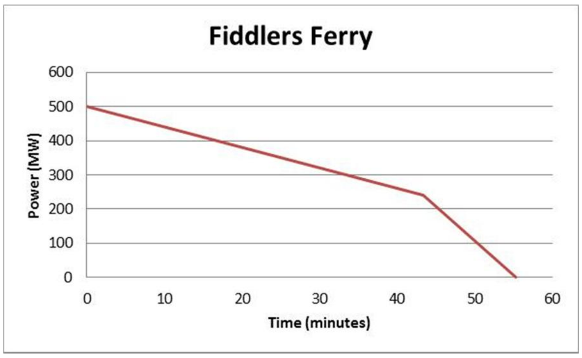
Power plant	Rate1	Elbow2	Rate2	Elbow3	Rate3	TOTAL
Aberthaw	5	240	4	180	45	71
Cottam	10	250	5	200	10	55
Drax	10	300	10	200	99	48
Ferrybridge	15	490	15	280	15	33
Fiddlers Ferry	6	240	20			55
Longannet	7					86
Rugeley	10	245	10	200	25	38
Ratcliffe On Soar	10	230	10	80	40	44

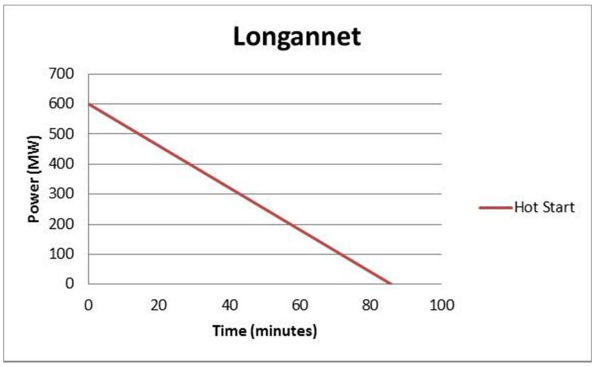
Source of information: Balancing Mechanism Reporting System website (BMRS), http://www.bmreports.com/

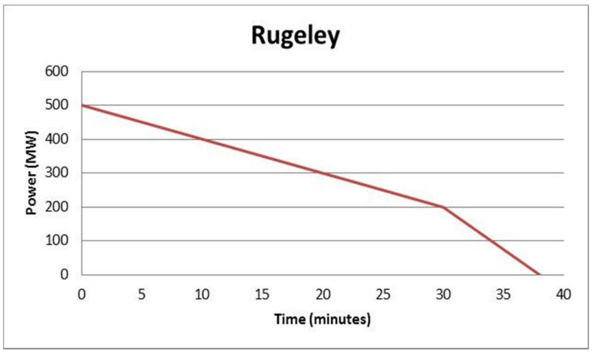


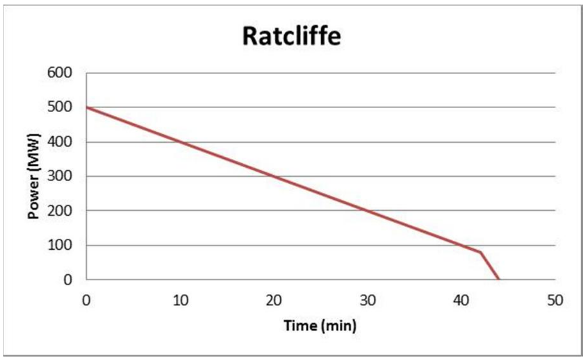





Fiddlers Ferry
Power (MW)
Time (minutes)
600
500
400
300
200
100
0
0
10
20
30
40
50
60


Longannet
Power (MW)
Time (minutes)
Hot Start
700
600
500
400
300
200
100
0
0
20
40
60
80
100


Rugeley
Power (MW)
Time (minutes)
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40

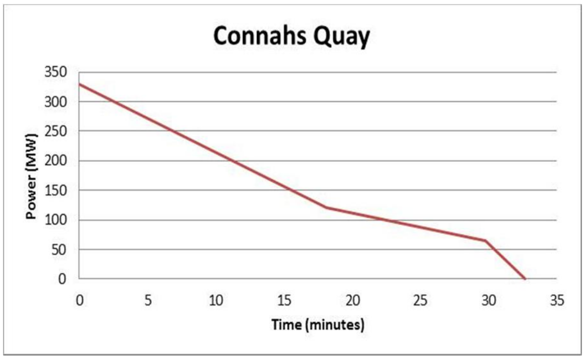

Ratcliffe
Power (MW)
Time (min)
600
500
400
300
200
100
0
0
10
20
30
40
50

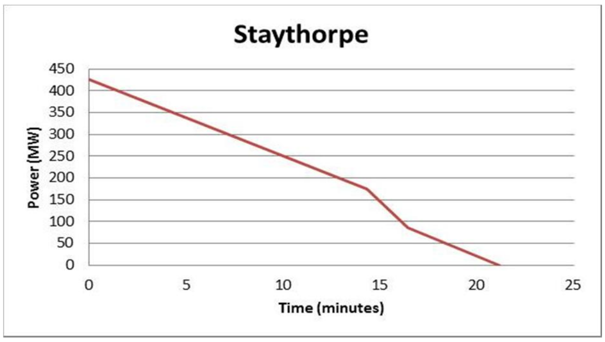
Appendix 5

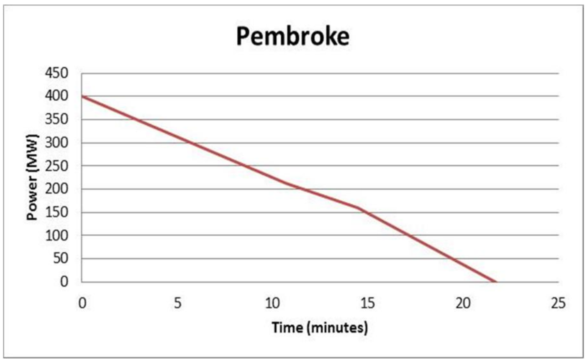
Table and Graphs Showing CCGT - Declared Run-Down Rate Export

Power plant	Rate1	Elbow2	Rate2	Elbow3	Rate3	TOTAL
Connahs Quay	10	35	0.7	110	4.5	33
Didcot B	16	200	12	120	7	54
Killingholme	30					22
Staythorpe	17.5	174	43	85	18	21
Pembroke	17.5	213	14	160	22	22
Deeside	9	260	53	100	20	40
Marchwood	27.5	390	13.6	200	12	49
Little Barford	20	65	10	2	2	38

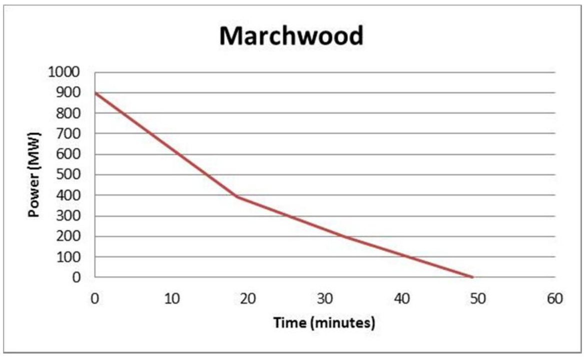
Source of information: Balancing Mechanism Reporting System website (BMRS), http://www.bmreports.com/

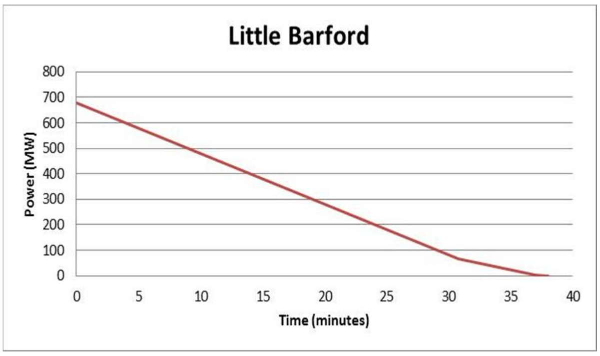





Pembroke
Power (MW)
Time (minutes)


Deeside
Power (MW)
Time (minutes)


Marchwood
Power (MW)
Time (minutes)


Little Barford
Power (MW)
Time (minutes)

Appendix 6

Table and Graphs Showing OCGT - Declared Run-Down Rate Export

Power plant	Rate1	Elbow2	Rate2	Elbow3	Rate3	TOTAL
Didcot A	40					1
Indian Queens	10	2	10	1	10	14
West Burton	5					6
Drax	32					1

Source of information: Balancing Mechanism Reporting System website (BMRS), http://www.bmreports.com/