Optimization of Fossil-Fired Power Generation Unit Start Ups

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Abstract

When market forces require fossil-fired power generation units to cycle rather than base-load, it is important to maximize the cost benefits accrued from shutting down during unprofitable periods of generation by minimising the plant damage and fuel costs associated with the subsequent unit start up. In addition to these operational factors, significant commercial penalties can also be incurred when unit start ups do not proceed according to plan and the generated MW output fails to match the submitted MW schedule.

This paper will present results obtained from the application of a novel framework for optimising power generation unit start ups, in which the costs associated with unit start up are minimised through a combination of good planning and automated execution of the start up procedure. The key idea is that the start up plan is continuously evaluated based upon pressures and temperatures as the unit cools during the shutdown period and is therefore well matched for when the unit is required to begin the start up procedure. In the case of combined cycle gas turbine plants, weather forecast data are also incorporated in order to predict the MW output of the gas turbine units.

Case studies will be presented from 500 MW and 660 MW coal-fired power generation units in the UK, and 350 MW and 700 MW combined cycle gas turbine power generation units in the US. These recent applications present two innovative features. The first one is a single continuously-variable plan that has been developed to deal with the common start up situations which follow overnight and weekend shutdowns. There is therefore no need for separate hot, warm and cold start procedures. The second innovation reported in the paper will deal with how the system relays the predicted start up profile to a remote trading room, thus allowing a trader to submit in the "day-ahead" market a MW schedule for the unit start up that can be followed with a high degree of certainty.

1. Background

In the case studies presented in this paper, a common theme is that de-regulated electricity markets have forced fossil-fired power plants to move away from a continuous base-load operational regime and into the arena of discrete peak-load generation. This change means that stopping and starting power generation units is no longer an infrequently encountered situation, but rather it becomes the daily norm. It is important therefore that these major transient operations are performed effectively in order that the fuel savings obtained from overnight and weekend shutdowns are not diminished by the costs incurred during the subsequent unit start up. This paper will first of all discuss the types of costs associated with unit start ups on two coal-fired and two combined cycle gas turbine power plants that the authors have been involved with over the past five years. It will then describe the common approach that has been applied to optimizing the start ups at the different plants, highlighting the advantages of the method, and illustrating the architecture of the technical solution. Each plant will then be dealt with in turn, listing the particular objectives that applied and the weightings that were placed upon them. Innovative features of the application will be presented along with results that have been obtained. Finally the paper will discuss the lessons learned from the four projects and indicate future directions for the approach.

2. Costs Associated with Unit Start Ups

The main cost categories associated with unit start ups in coal-fired and combined cycle plants are:

<u>Fuel:</u> the operation of oil burners and coal mills prior to synchronization represents a significant cost in the start up of a coal-fired unit. For combined cycle gas turbine plants, the gas burnt prior to synchronization plus the low efficiency operation of the plant in simple cycle until the steam turbine can be loaded, represents a major cost. Fuel prices are normally readily available, although in coal-fired units it can be difficult to calibrate accurately the amount of coal delivered at a given mill feeder speed. The accuracy of oil burner fuel consumption estimates depends largely on the instrumentation on the oil supply lines. In gas turbine plants, the composition and mass flow rate of the fuel gas supply are normally tightly monitored.

<u>Electrical Power:</u> the operation of fans, pumps and mills on coal-fired power plants prior to the unit becoming self-sufficient in electrical power does represent a cost, although here the issue is usually one of maximum imported power into the plant. There is usually little scope for reducing the maximum level and the additional cost of running fans after they have started can be relatively minor in comparison to fuel and damage costs. On gas turbine plants, the electrical power required to spin up the compressor to ignition speed is significant and again the issue here can be one of maximum power import. On plants with multiple gas turbines, it may prove

most economical to start one gas turbine and then start subsequent ones only after the plant has become self-sufficient.

Demineralized Water: on plants which are not fitted with steam turbine bypass lines, there is little option but to use steam drainage to manage pressure and establish steam flows in the boiler. When the steam is vented to atmosphere, this can require a significant amount of make-up water to be added. On plants with steam turbine bypasses this cost is usually insignificant.

Plant Damage / Lifetime Reduction / Consumption of Equivalent Operating Hours: thermal stresses incurred during start up are usually much higher than those seen during normal load operation and these can cause plant damage, the cost of which can be an order of magnitude greater than fuel costs, when the total cost of repair/replacement is attributed on a per start basis. Unfortunately these costs only after manifest themselves after extended periods of time and it can be difficult to compare their future impact against more immediately visible costs like fuel and power consumption. Plant damage on the coal-fired plants can be caused by excessively high temperatures being reached during start up or stress damage caused by excessively high rates of change of temperature or large metal-steam temperature mismatches when re-establishing steam flows. In the short term, the damage can manifest itself as tube leaks, the repair of which represents a significant cost. In the medium to long term, cracking in steam legs and headers will result in the extremely expensive replacement of these sections of the boiler. Stress monitoring thermocouples on thick metal components can be useful in establishing/controlling the magnitude of damage incurred during a start, but it is always a difficult task to transform this into a monetary value. On the gas turbine plants, stress damage incurred during stop/starts are accounted for as lifetime reduction (equivalent base load operating hours), and built into formulae for determining the timing of the next major overhaul.

Environmental: steam drainage flows during start up may cause noise complaints from surrounding residents and may require drain valve openings to be limited, thus affecting the rates at which the boiler can be warmed up.

Commercial Penalties: can result when the unit synchronizes early or late and the delivered power output in the load ramp does not meet the contracted schedule. For the combined cycle power plants dealt with in this paper, the complex start up must be accurately predicted using temperature forecast data and plant cooling curves if penalties are to be avoided when ramping to full load.

3. Description of the Approach

The approach to optimisation can be summarised as a combination of good planning and execution of the start up procedure. The start up procedure is configured using a project planning methodology and the main user interface is a real-time Gantt chart display. The key idea is that the start up plan is continuously evaluated based upon pressures and temperatures as the unit cools during the shutdown period and is therefore well matched for when the unit is required to begin the start up procedure. In the case of combined cycle gas turbine plants, weather forecast data are also incorporated in order to predict the MW output of the gas turbine units. The design approach goes further than traditional project planning software tools by having actions and checks associated with individual tasks, and these actions and checks result in data transfers with the unit control systems in order to write the command actions to the plant actuators and read back the sensor values. The advantage of this technique, as opposed to a flow chart based approach, is that timing is fundamental and it is trivial to determine when actions must happen in order for deadlines and/or schedules to be met. It has additional advantages in that it produces a system that is much simpler to construct and maintain since the problem is sub-divided into understandable blocks of functionality.

4. Case Study No.1 – 2 x 500 MW Coal-Fired Power Plant (UK)

This plant was commissioned in 1970 and designed for base load generation. The main objective of the startup optimization here was to avoid any further plant damage, especially in the main steam legs at the exit of the boiler and also to avoid tube leaks that were frequently being caused by the existing procedure. At the time when this project was initiated, the cost of replacing of the steam legs could not have been justified by the UK power market conditions and would have led to the closure of the unit. The startup plan was therefore designed to ensure that sufficient time was allowed to boil off the condensate that formed in the U-bends of the superheater tubes before allowing the steam to flow out of the boiler. The plan also precisely coordinated the opening of the main steam drain at the boiler exit with the introduction of the first coal mill, and the subsequent transfer of drainage to a similar sized drain valve at the bottom of the steam legs. The other novel feature of this application was the spatial control of the 24 oil burners in the wall-fired furnace in order to avoid hot spots in the radiant superheater section during the boiler warming phase (Figure 1). The project resulted in the elimination of tube leaks and the reduction of thermal shocks at the boiler main steam exits.

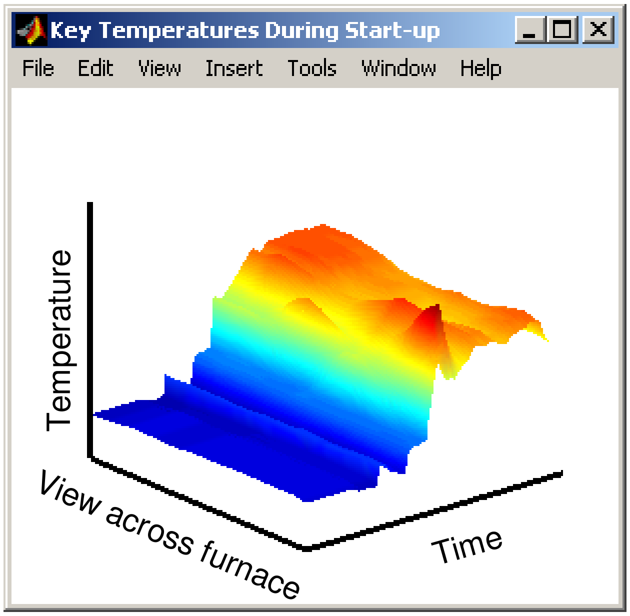

Figure 1: radiant superheater tube metal temperatures with spatial oil burner controller

5. Case Study No.2 – 1 x 235 MW GT + 1 x 120 MW ST Combined Cycle Plant (USA)

This plant was commissioned in 2001 and operates in the ERCOT (Electric Reliability Council of Texas) day-ahead market in the USA. The main objective of the project was to produce a system that was capable of predicting a feasible start up MW profile several hours in advance, and then running the plant up according to this profile. The significant cost benefit here was the avoidance of market penalty payments, which were being incurred when actual output did not match the submitted schedule. The project also had secondary objectives which were: minimisation of fuel costs, start up duration and plant damage.

The start up profile for the plant is complex because the gas turbine (W501G) cannot be loaded greater than 20% until steam cooling of the combustor transitions has been initiated. The procedure for starting the plant therefore requires a load hold at 20% output whilst steam is raised in the boiler and the switchover from air cooling to steam cooling has completed. The profile is further complicated because, like all gas turbines, the MW output is heavily dependant on ambient temperature and therefore accurate temperature forecasts are also needed in order to predict the various gas turbine MW hold levels. Finally, the particular type of steam turbine employed at this plant exhibits challenging differential expansion behavior during roll up and loading, and the rates of change of speed and MW output must be carefully planned in order to avoid tripping the unit on a high differential expansion condition.

The solution that was put in place here involved the creation of a single continuously variable plan which catered for hot, warm and cold starts (see Figure 2, Figure 3, Figure 4 respectively). The other key innovation here was the implementation of a graphical tool which allows a remotely located trader to see the predicted start up schedule and also to monitor the progress of the actual versus submitted schedule. The project had performance guarantees for schedule error (within ±15 MW for 95% of the startup duration) and these targets were achieved in the first test starts and are now consistently obtained or improved upon. Subsequent auditing of the starts also showed that fuel costs were consistently lower than previous best practices, and that the startup durations had been maintained. Stress damage was being minimized in the Heat Recovery Steam Generator (HRSG) due to controlled raising of saturation temperature in warm and cold starts, and steam turbine stress damage was also being minimized because of the planned matching of steam and metal temperatures prior to turbine run up. No unscheduled delays or trips due to high differential expansion have been experienced when following the planned MW profiles.

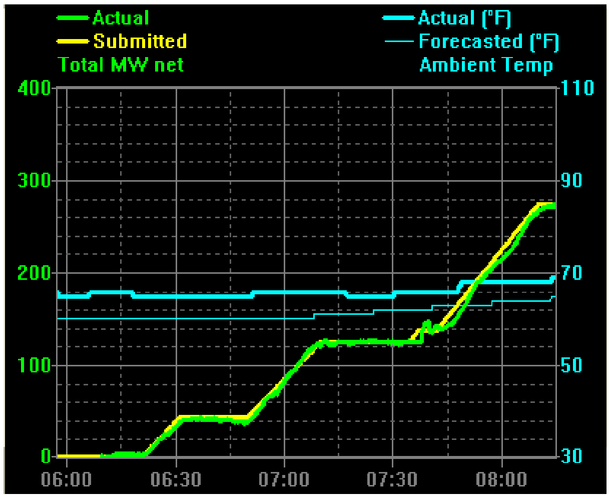

Figure 2: hot start profile for 1 x 235 MW GT + 120 MW ST combined cycle plant

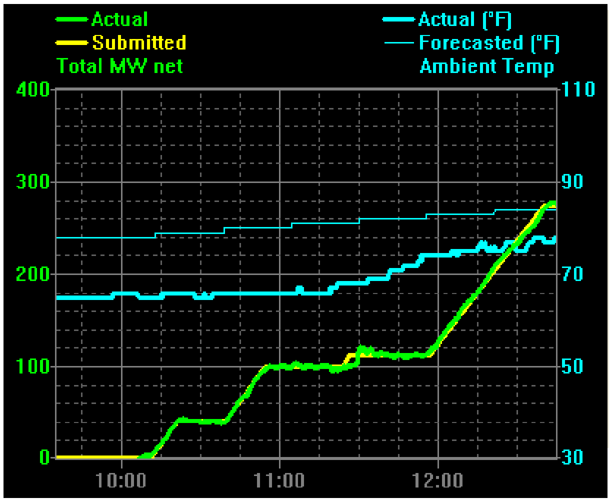

Figure 3: warm start profile for 1 x 235 MW GT + 1 x 120 MW ST combined cycle plant

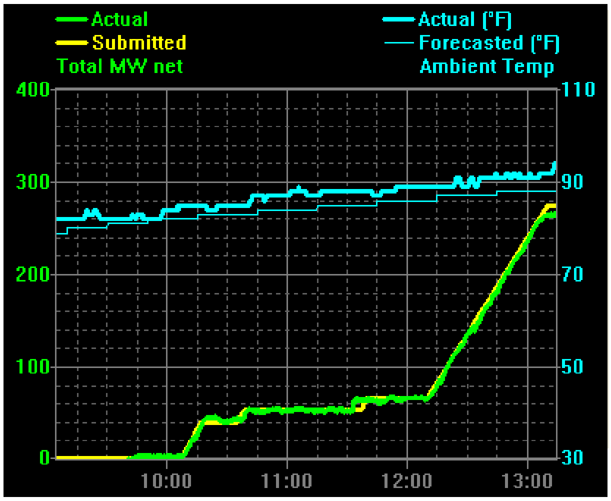

Figure 4: cold start profile for 1 x 235 MW GT + 120 MW ST combined cycle plant

6. Case Study No.3 – 2 x 235 MW GT + 1 x 240 MW ST Combined Cycle Plant (USA)

This plant was commissioned in 2004 and also operates in the ERCOT (Electric Reliability Council of Texas) day-ahead market in the USA. The main objective of the project was to minimize fuel consumption during starts whilst also delivering the same predictability of start up profile as in the previous case study. The plant comprises twin W501G gas turbines plus individual HRSG's and a single 240 MW "KN" steam turbine, which exhibits superior rates of change both in terms of rolling up and loading.

The design of the optimized start up plan involved first of all examining how the plant was currently started and, using knowledge gained from the previous case study, an alternative procedure was recommended which generated fuel savings of $1.5x10^9$ BTU on typical hot starts and $3.4x10^9$ BTU on typical warm starts. These BTU savings represented reductions of 28% and 49% respectively in comparison to current best practices, shown graphically in Figure 5. The startup profile was complicated further by the starting of two gas turbines in sequence, due to maximum power import constraints. In addition three different startup scenarios had to be planned for: (a) starting both gas turbines plus the steam turbine, see Figure 6, (b) starting one gas turbine plus the steam turbine, see Figure 7, (c) starting the second gas turbine whilst the first gas turbine and steam turbine are already running, see Figure 8.

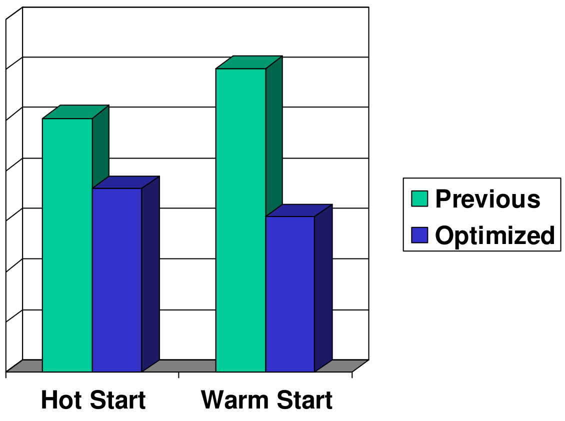

Figure 5: fuel savings with optimized starts with reference to previous best practice

The results obtained from initial starts were in line with the magnitude of fuel savings that had been predicted and the system was also able to deliver the same level of predictability of startup profile. The same trader interface tool is employed at the remote trading floor and provides the single trader with a consistent method of scheduling the output of all plants equipped with the optimized start system.

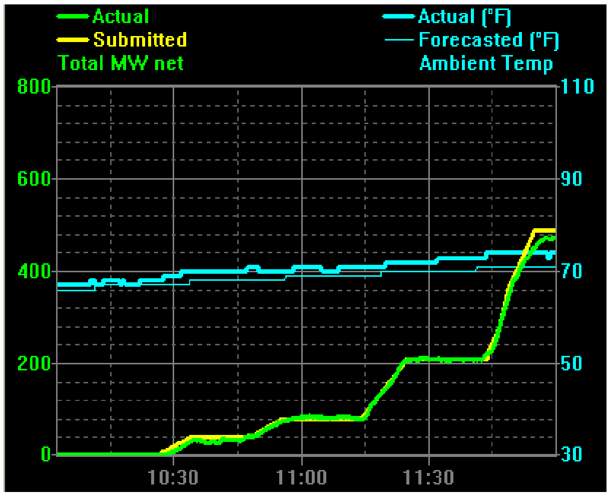

Figure 6: warm start profile for 2 x 235 MW GT + 1 x 240 MW ST combined cycle plant

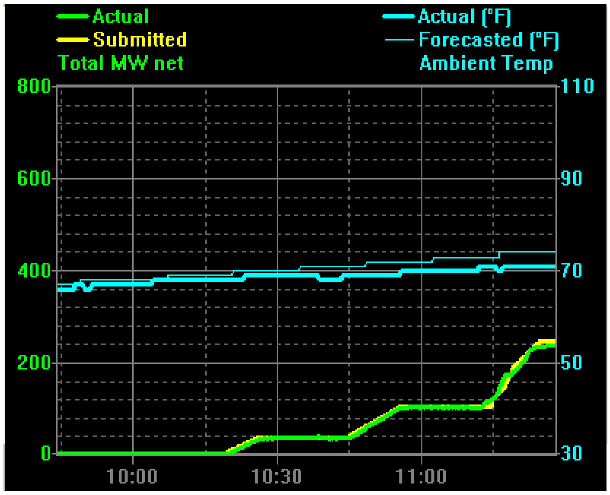

Figure 7: warm start profile for 2 x 235 MW GT + 1 x 240 MW ST combined cycle plant (single GT)

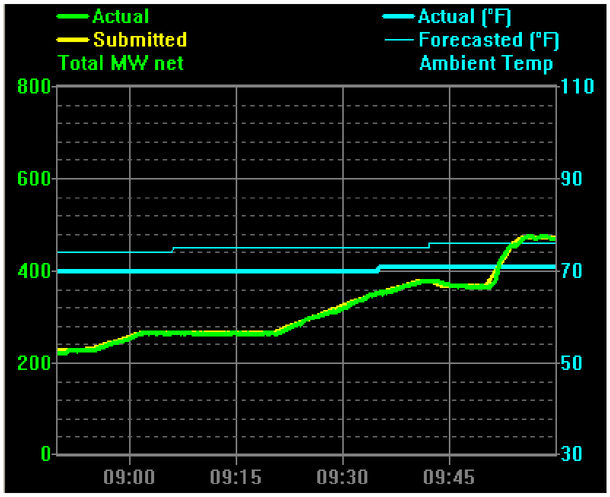

Figure 8: profile for 2nd GT starting and blending with 1st GT and ST already running

7. Case Study No.4 – 6 x 660 MW Coal-Fired Power Plant (UK)

This plant was commissioned in two stages, the first in 1974 and the second in 1986. This case study deals with one of the newer units, where the main objective was to deliver consistent, low-damage start ups, with the additional objectives of minimizing fuel costs and overall duration, as well as respecting environmental noise constraints. This project has built upon the previous ones by incorporating and extending the spatial oil burner controller to manipulate the 60 oil burners located on the front and rear walls of the furnace, and also by having a single continuously variable plan which caters for hot and warm starts, which are the two most frequently occurring situations following overnight and weekend shutdowns respectively. The plan delivers minimum damage starts by actively managing high absolute temperatures in the radiant superheater section and high rates of change of temperatures in the superheater steam headers. In addition, the matching of boiler steam to leg metal temperatures, and subsequently to turbine metal temperatures is carefully planned and controlled. The noise constraints place a limit on the maximum drain valve openings and the system takes these into account when planning the warming phase. This application has also extended the scope of the startup plan to include management of drum level throughout the start up phase. Initial commissioning starts demonstrated the system delivering these benefits.

8. Discussion

The project planning methodology has been successfully applied to a variety of fossil-fired power generation plants, each with their own individual sets of objectives and constraints. The main advantage of the approach is that timing is fundamental and it is therefore easy to predict when actions must take place in order to synchronize the unit at a given time, or to predict the loading profile of a combined cycle plant. The task building blocks also simplify the design, configuration and maintenance of the system. Automated execution of the programmed plan allows a level of consistency to be achieved that is rarely possible with manually executed start ups. This consistency in turn permits further understanding and optimization of the procedure. Finally, the specification of the procedure as a plan provides a concise notation and preserves the knowledge of more experienced operations staff in a manner that is easily accessible to new or less experienced personnel. Future directions for the system include the management of unit shutdowns, and the incorporation of current and future market price data to enable the plan to automatically maximize cash flow during the start up period.

9. References

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