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Unit Maneuvering is Costly

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It is surprising, but undeniably true, that the immense costs of maneuvering generating units remain largely ignored in the design of most of the AGC software on the market today. Frequent generation changes, most of them unnecessary or even detrimental, squander away hundreds of millions of dollars every year in potential savings and profits. And yet, lack of proper analysis of the fundamental principles governing generation control in an interconnected operation has kept the power industry at a standstill on this front of the struggle to improve the efficiency of the generation control process. The fact remains that reduction of unit maneuvering (UM) is developing into one of the most profitable paths to energy generation efficiency improvement.

The losses stemming from excessive UM have three major components. The first, and most obvious, is the increased wear and tear on generating unit parts. The effect is noticeable at several points across the unit and results in significantly increased maintenance and unit outage costs. The second is the deterioration in the unit heat rate due to inefficiencies in the energy production process. The impact on fuel costs of a control area is quite substantial and makes frequent UM a very expensive luxury. Last, though not least, UM is the cause of a noticeable increase in harmful emissions.

Maintenance Costs of Unit Maneuvering

In the case of fossil fuel units, the wear and tear resulting from UM mainly occurs in three places: the control valves, the boiler, and the turbine control stage. The damage to the valves is largely mechanical and is directly related to the amount of movement. Changes in valve position during periods of AGC maneuvering create wear in many of its parts, including the valve plugs, valve stems, balance chamber, valve plug seal, etc [1]. Frequent reversals imposed by the majority of existing AGCs accelerate this wear, especially in the hydraulic mechanism and the valve stem. Consequently, reducing UM would significantly prolong the period between expensive overhauls of control valves.

The damage related to the boiler is most readily apparent in the tubing, which endures the brunt of steam temperature variations due to UM. Generation changes even at the ramp rate of 1% of the unit rated capacity per minute can induce temperature swings of tens of degrees in some components, aggravating the effects of thermal fatigue. The result is the accelerated appearance of cracks and leaks in the affected boiler components. Most vulnerable is the superheater tubing, where steam temperature reaches its peak. Operational data from fossil fuel units has shown that unit reversals and the resulting excess maneuvering can substantially reduce the time between boiler outages.

Another major source of increased maintenance costs is the mechanical and thermal wear on the first stage nozzles and blades. The chief culprits are the variations in steam temperature at the turbine due to the dynamics imposed on boiler output by UM. Typical AGCs continually force transients in the boiler and, over time, cause significant wear on the first stage of the turbine due to thermal and pressure fatigue.

It is difficult, mainly due to the immense differences between generating units, to give a general formulation of the maintenance costs associated with UM. In recent years, however, the need for pricing ancillary services has spurred the creation of methodologies for online and historical analysis of such costs. Information we have gathered for one type of 500 MW unit, equipped with four control valves, indicates that, as a result of reducing UM by 50%, the time between overhauls of the control valves could be extended by 25%-35%. The result is potential savings of several tens of thousands dollars per year for this unit alone.

A more significant impact of increased wear and tear on the unit is the resulting increase in its equivalent forced outage rates (EFOR). Outside of the required maintenance costs, every outage means a great deal of lost opportunity. Excessive UM increases EFOR considerably and every single day a unit is off-line could be costing the company hundreds of thousands of dollars.

Interviews with experts in the field, including John C. Westcott, Jens Kure-Jensen of Encotech Inc., and Steven A. Lefton of Aptech Engineering Services, Inc., have greatly contributed to the development of this section. Further information on the subject may be obtained from [1, 2] and several Aptech publications including [3, 4].

Heat Rate and Emissions Performance Deterioration

The second major source of UM costs, the efficiency decline in the conversion of heat to electrical energy, has an immediate and tangible economic impact. The efficiency decline resulting from UM is mainly due to inherent limitations in boiler controls as well as the transients in the control valves. It leads to an increased unit heat rate and pollutant emission.

For every output level of a generating unit, there exists a correct mixture of air and fuel, which would result in the lowest possible heat rate. In the best case scenario, when the output is maintained at a specific level for a long time, boiler control has ample opportunity to set fuel and air at the optimum mixture and then maintain it as long as requested generation remains constant. This mix will provide just enough air to burn the fuel completely, producing the best attainable heat rate. Any air supplied beyond the optimum level is needlessly heated and disposed of through the stack, while a deficit of air will leave some fuel not fully burned. In both cases, efficiency deteriorates. The optimum mixture allows fuel to burn completely without wasting valuable heat, thus maximizing energy conversion efficiency.

The above situation, ideal as it is, occurs exceedingly rarely in nearly all AGC-controlled generation management systems. In most cases, unit generation is in a constant state of flux, making it impossible to achieve the perfect state for any significant period of time. Since the correct setting depends on feedback from furnace sensors, whenever boiler control is required to move a unit in either direction it will take some time to settle the mixture at its new optimum point. During that transient period, there will be either incompletely burned fuel or unnecessarily heated air released through the stack. Figure 1 shows the typical boiler efficiency loss curve during a change in generation. Curtailing unit reversals and maneuvering would allow boiler control to maintain an optimum mixture of fuel and air over longer intervals, thereby decreasing fuel consumption.

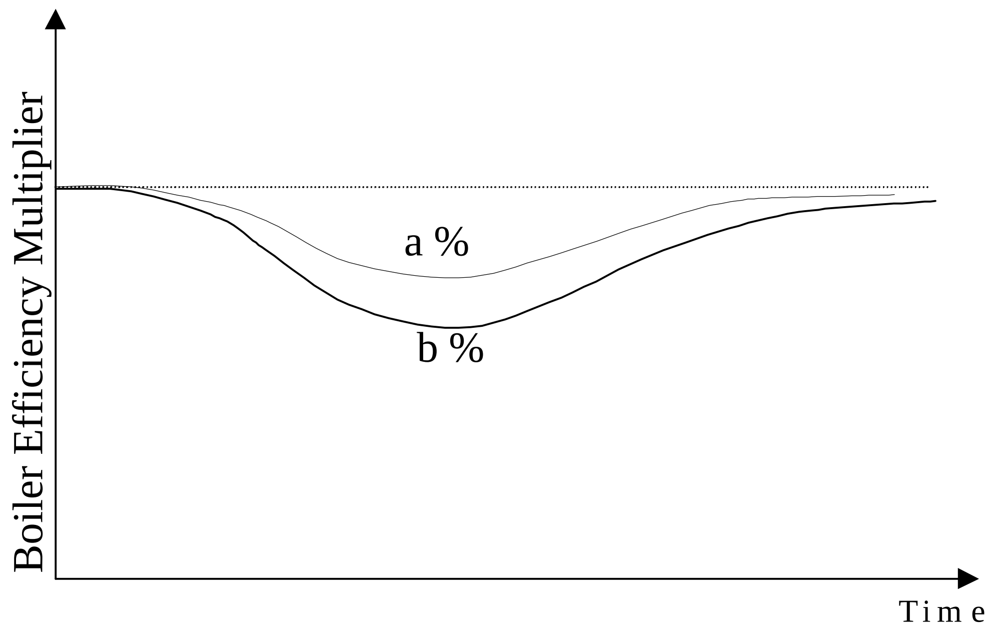

Figure 1. Graph of the boiler efficiency curve following a step generation change request of **a%** or **b**%, where **b > a,** applied at origin.

A side effect of the efficiency losses at the boiler is a noticeable increase in the volume of expelled pollutants. Consumption of excess fuel necessarily increases the undesirable emissions at the stack. Moreover, whenever fuel is incompletely burned, the result is an increase in the output of harmful pollutants, such as carbon monoxide. Consequently, the deterioration in a utility's emissions performance due to UM can be quite sizable.

An additional factor in the heat rate deterioration is the loss due to transient turbulence in the control valves. Changes in generation cause movement in the valves of governor motor units. This movement, in turn, triggers turbulence in the steam flow, reducing steam energy and thus lowering the efficiency of the energy conversion process.

The dynamics imposed by frequent unit reversals and maneuvering, including turbulence in the steam flow and non-optimum mixture of fuel and air, give rise to a noticeable decline in thermal efficiency [1]. The increase of the unit heat rate is generally in the range of 1-2% [5]; certain generation unit owners, however, bid for the provision of regulation services based on figures close to 3.5%. In fact, a major control area in the Eastern Interconnection dominated by fossil-fuel generation has reduced its heat rate by 1% mainly due to a decrease of about 50% in daily UM. For the average control area, this means millions of dollars a year in potential fuel cost savings.

Market Valuation of UM

A growing consensus has thus emerged among the experts in the field of power generation that there is a significant cost associated with UM. The generation markets have effectively responded by providing a separate pricing model for the provision of ancillary services. In one such market the New England ISO has, in fact, taken the initiative to price regulation as a separate contract item. Since they pay the generating unit owners for every MW of generation change requested, they possess a very good estimate of the market value of UM (http://www.iso-ne.com/mrp/MRP-07_Automatic_Generation_Control_Market/MRP-7_Effective_2002-06-01.doc). According to PCE research, from May to August 1999 the average hourly market clearing price in New England was $1.80 per MW requested generation change, a substantial amount of money considering the amount of maneuvering imposed by the typical AGC (more recent data can be found at http://www.iso-ne.com/Historical_Data/hist_data.html). It should also be noted that the New England ancillary services market is dominated by hydroelectric generation; when fossil-fired units set the price, it routinely exceeds $3.00 per MW of regulation.

Priority-based Generation Control

With the advent of CPS1 and CPS2 in 1997, the opportunities to reduce the losses associated with UM became greater than ever. The new control criteria were designed at PCE specifically with the idea of allowing the industry reduce expensive unit maneuvering without sacrificing the frequency performance of the interconnection. At the same time, a new theory emerged as the most mathematically effective approach to controlling to CPS1 and CPS2 with miminal UM [6].

PCE’s Priority-based Generation Control (PGC) has proven itself by far the best AGC algorithm on the market. Its basis is the theory of *Priority-based Control*, a breakthrough concept that outperforms all known methods of control. It has been put to the test against many of the principal existing AGCs and time and again it has demonstrated its ability to tremendously reduce UM.

In summary, the reduced UM that PGC can realize for a CA will:

1. Require less variation in the rate of fuel flow into the boiler. On this basis, PGC will:
   - Prolong the time during which a unit operates with an optimum mixture of fuel and air and, hence, allows fuel to more fully burn in the boiler without heating surplus air. This allows the unit to:
     - Reduce fuel consumption for generating the same energy demand. Therefore, PGC will:
       - Realize savings in fuel costs.
       - Reduce emissions.
     - Reduce the level of pollutants in burning the same volume of fuel.
   - Reduce mechanical and thermal stress on the plant equipment. This will result in:
     - Increased time between boiler outages.
     - Diminished wear on the turbine control stage.
2. Require less movement in throttle valve in GM units. On this basis, PGC will impose less turbulence in steam flow and, hence, will:
   - Increase efficiency in the energy conversion process. Therefore, PGC will:
     - Realize savings in fuel costs.
     - Reduce emissions.
   - Reduce mechanical stress on the plant equipment, realizing savings in maintenance costs.

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References

[1] “Cost of Providing Ancillary Services from Power Plants”, prepared by Encotech, Inc., Schenectady, NY, (Principal Investigator: J. Kure-Jensen), EPRI, TR-107270-V2, 4161, Final Report, April 1997.

[2] “100 Years of Power Plant Development” Heinz Termuehlen, ASME Press, New York 2001.

[3] “Understand What It Really Costs to Cycle Fossil-fired Units”, S. A. Lefton, P. M. Besuner, G. P. Grimsrud, Power Magazine, March/April 1997.

[4] “A Methodology to Measure the Impact of Cyclic Operations and Power Derations on Plant Life and Reliability”, Steven A. Lefton, TP018, received September 2002 from Aptech Engineering Services, Inc.

[5] “Tracking Evolutionary Trends in Generation Control”, V. Brandwajn, A. Ipakchi, V. Sherkat, IEEE Computer Application in Power, January 1993.

[6] “Control Performance Standards and Procedures for Interconnected Operation”, prepared by Priority-based Control Engineering (PCE), Dublin, OH, (Principal Investigators: Nasser Jaleeli and Louis S. VanSlyck), EPRI TR-107813, 3555-10, Final Report, April 1997.