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EFFECTS OF PARTIAL LOAD REJECTION ON FOSSIL FUEL UTILITY STEAM GENERATORS

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Abstract - This paper presents a discussion of the effects of partial load rejection by utility turbine-generators on fossil fuel fired steam generator systems. Available surveys on reliability of steam generators undergoing large decreases in load are examined. Also, specific examples of load rejection are discussed.

INTRODUCTION

A recent survey of partial load rejections was presented at the 1980 Joint Power Generation Conference by P. Kundur (1).

Several papers on turbine response to partial load rejections were given at the prior Joint Power Generation Conference by H. Termuehlen (2) and H. Kurten and H. Termuehlen (3). Very little has been presented in the technical press on the reactions of steam generating units to partial load rejection in utility service. In response to this situation, the IEEE Working Group on Power Plant Response has asked several of the fossil fuel boiler manufacturers to reply to this need. Technical exchange is required in the area of steam generator response to sudden decreases in demand when coupled to a large turbine-generator.

This paper will present the views of Riley Stoker Corporation on this subject. Due to the paucity of the data on this subject, the paper will be largely tutorial in nature.

REVIEW OF STEAM GENERATOR RELATED TRIPS

The causes of the trips given in reference (1) have been put into four (4) categories and are shown in Table I. The categories have been selected by functions, and many of the causes are related through interlocks. As can be seen from the table, the turbine-generator related causes comprise 30% or the largest portion of the trips. The combination of operator error and unknown categories comprise 28% of the trips, tied for second place with the boiler alone category, also at 28%.

It is useful to consider the category of boiler-turbine interlocks together with the boiler alone category. This shows the maximum potential for failure due to steam generator sources to be 42% of the total. This grouping then shows the boiler-turbine to be less reliable than the turbine-generator.

Reference (1) also lists 10 more plant problems that can be broken down into similar categories, which are shown in Table II. This table shows additional boiler related problem areas, and also indicates that the boiler auxiliaries are more sensitive to plant type problems than other plant auxiliaries. During upset conditions, following load reduction, the safety valves often lift and sometimes do not reseat. To protect the safety valve seats from erosion during extended blowing periods and to prevent large losses of makeup water, the boiler is usually taken off the line. Also, during rapid load reduction, coal pulverizers are taken out of service quickly and if the burner lines are not adequately purged, fires can start in the idle coal pipes. This in turn can cause a cascade of incidents in the burner management system which may bring about a boiler trip, due to main fuel tripping (MFT).

Types of Steam Generators

In order to further examine the causes of boiler trips, it is important to recognize the main types of steam generators in utility service. In the USA, the single reheat cycle is almost universally used in fossil units larger than 1 x 10⁶ pph (454 metric tons/hr) of steam output. These reheat units are broadly classified as either once-through steam generators or as recirculation steam generators. Table III shows a breakdown of the sub-types and some of the features of each.

In once-through supercritical operation, there is no change of phase at constant temperature, therefore, no water level. Only if pressure is dropped below the critical pressure does a water level exist in the unit. In sub-critical once-through units, a variable water level exists and its position is dependent on load and pressure. However, this level does not pose a problem as long as it can be contained within the design range. In drum-type steam generators of both types, a fixed water level exists. Phase separation for

TABLE I

ANALYSIS OF 47 TRIP EVENTS DURING PARTIAL LOAD REJECTION

	Unknown or Operator Error	Turbine/ Generator	Turbine/ Boiler	Boiler Alone
High Frequency		11		
Operator Error	7			
Boiler Instability				3
Gas Feed Interlock			2	
Combustion Control Problem				2
Unstable Boiler Control				2
Turbine Lockout Relay			2	
Failure to Purge After Boiler Trip				2
Boiler Going Subcritical				1
Loss of Water Level Control				1
Large Power Swing After Boiler Trip				1
Low Frequency and Voltage		1		
Unknown	6			
Intercept Valve Closure			3	
High Wall Pressure				1
Under Frequency and Over Excitation		1		
Unit Isolated at Bus		1		
Total	13	14	7	13
% of Total	28	30	14	28

TABLE II

PLANT PROBLEMS

	Unknown or Operator Error	Turbine/ Generator	Turbine/ Boiler	Boiler Alone
Circulating Water Pump Failure		2		
Fire in Coal Pipe				2
Failure of Boiler to Purge				1
Failure of Boiler Safety Valve to Reset				1
Condenser Leak		1		
Loss of Instrument Air				1
Total	0	3	0	5

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TABLE III

TYPES OF REHEAT STEAM GENERATORS

Once-Through	Recirculation
a. Supercritical, pressure over 3,191 psig	a. Natural circulation
b. Sub-critical, pressure less than 3,191 psig	b. Assisted circulation (with recirculation pumps)
Neither a nor b have drums, but may have low load recirculation pumps.	Both a and b feature drums for steam water separation.

recycling of water can only be accomplished within a narrow range of drum levels. This level is closely monitored and is interlocked with the main fuel trip (MFT). Loss of level is therefore a cause for tripping the boiler. High drum level often trips the turbine to protect the latter from gross carryover.

It is not known how many once-through steam generators were contained in the survey of reference (1). However, Table I shows two causes that are related to supercritical or once-through boilers, namely, the boiler going subcritical and high wall pressure. Other differences between the once-through and recirculation boilers are shown in the next section.

Boiler-Turbine Interlocks

Most fossil fired steam generators currently in US service were designed for base load and are not generally equipped with large HP and LP bypass systems. As a result of this, several interlocks are placed between boiler and turbine. Typical causes of boiler trip as a result of turbine actions, in systems without large bypasses, are:

a. Closure of intercept valve. This stops flow to reheater and thus the recirculation steam generator is tripped after a short time delay to prevent overheating of reheater tubing system.

b. Closure of main steam valve. This stops flow to the superheater and causes it to overheat, thus tripping the steam generator after a short time delay.

c. Closure of turbine valves, generally tripping once through steam generators without time delay.

d. Closure of intercept valve on once-through units. This results in the same steam starvation in the reheat system, and the tripping of the steam generator after a short time delay.

Improvement in this area would follow two general paths; faster valve action to control the speed of the turbine and the use of large bypasses around the HP and LP to protect both the turbine against overspeed and the boiler against overheating. The condensor will have to be sized accordingly and an internal distribution system provided.

Use of Large Steam Bypass

In Europe, due mainly to isolation of power plants with limited grid interconnections, it has been found very beneficial to install large bypass sytems. Such installations allow rejection of load from full load to house load and rapid return to full load. This system is also very useful for rapid starts after shutdowns with good turbine metal and superheater/reheater steam temperature matching capability. Figure 1, redrawn from information in reference (6), shows two successful load rejections, on a 630MW unit equipped with large turbine bypasses. The first, marked with a 1, was a sudden loss of load from 400MW to 9MW, with the bypasses opening immediately and the fuel being run back to 30% at a rate 15%/min. Steam temperature rose slightly and then dropped about 40°F (22°C). Reheat steam temperature followed the same pattern, but dropped about 80°F (44°C). The second load rejection, marked with a 2, was from 600MW to house load with similar results. This constitutes total load rejection load and is a more severe case. It is apparent that this method of load rejection by use of large bypasses would be much more reliable with less potential problems than systems without bypass and would allow better matching of steam temperature and turbine metal temperature on a restart.

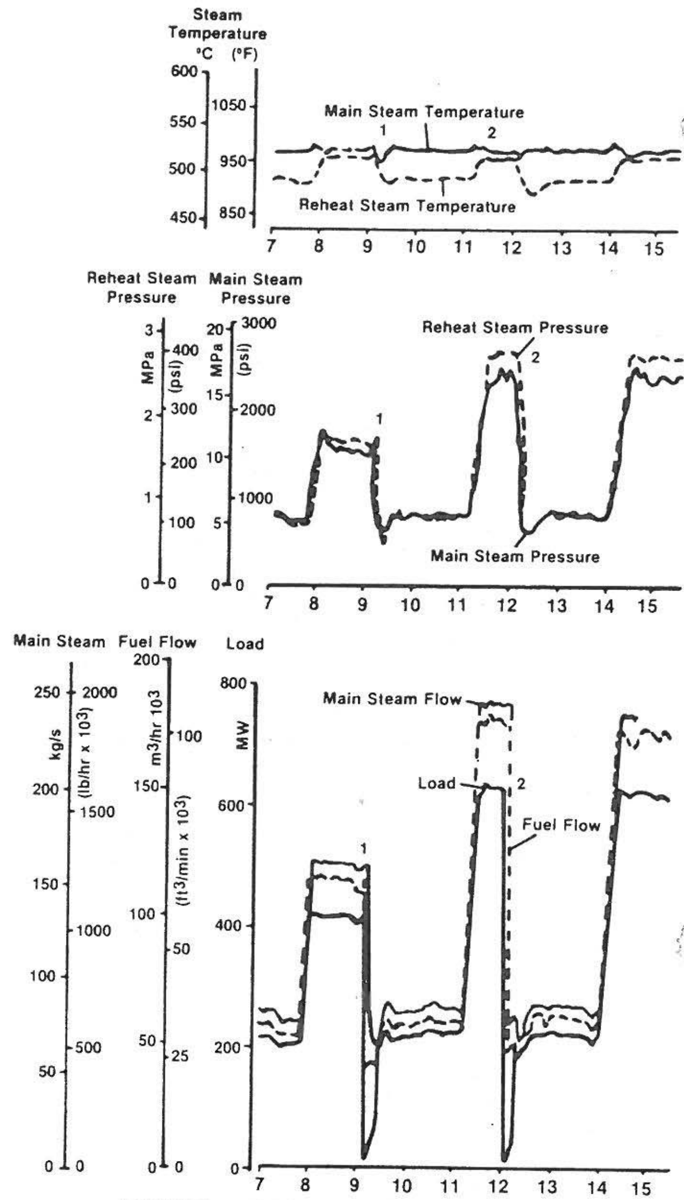

FIGURE 1—PARTIAL LOAD REJECTION DATA OF A 630 MW UNIT WITH LARGE TURBINE BY-PASSES

LOAD REJECTION EXAMPLE - 600MW OIL FIRED EXAMPLE

The conventional controls supplied for this Riley natural circulation steam generator (Reference (5)) were only slightly modified to prepare the boiler to survive a partial or full test. Two instances of load rejection are available to demonstrate the behavior of this control during turbine trips or load rejections. These will be discussed below.

Control Description

The following features were designed to keep the boiler in service on a turbine trip or load rejection:

1. On a turbine trip contact closure, an automatic burner shutdown signal is produced in the burner management system, shutting down burners until only the six burners of the lowest row remain in service.
2. On a load rejection contact, a low drum level trip action is inhibited for a short time delay (15 S). This inhibition only takes place if the boiler load is greater than 30%, and prevents an MFT due to a transient loss of water level.
3. On a turbine trip contact, a signal is sent to the combustion controls to activate fast runback action on fuel and air. This is accomplished by transferring the load demand, normally developed as a function of steam flow and trimmed by the throttle pressure controller, to a ramp generator initially set at a rate of 8 seconds and ending in an adjustable minimum value of load.

4. On a main fuel trip or load rejection, the furnace draft controller is removed from service when problems occur with furnace pressure. A deviation between set point and furnace pressure is sensed and on a large deviation, the inlet vanes will be immediately positioned to correct the error on a feedforward proportional basis.
5. On main fuel trip, load rejection, turbine trip, or low steam flow, the reheat and superheat spray block valves will close.
6. Two main steam bypass paths to the condensor have been furnished: a path before the final superheater to the condensor and a turbine bypass path to the condensor. Each path has a steam capacity of approximately 8% of full steam flow and is supplied with a control valve and a means to estimate the steam flow through it. Although the primary function of these paths is that of fast matching of steam and turbine temperature during start up, they can also provide a low capacity steam path on a load rejection. On a decrease of steam flow (1st stage pressure) below a minimum value (5% load) the turbine bypass loop is activated and steam is bypassed to maintain 8% steam flow through the boiler surfaces. Therefore, on a turbine trip or a load rejection ending in less than 5% HP steam flow, the bypass path will be open.

   This action, plus the combination of reduction of burners in service, fast load runback, maintenance of low drum level trip and proportional correction of large furnace pressure error, should prevent the boiler from tripping.

The controls described above have been somewhat modified since initial operation of the plant: the automatic energization of the bypass valve control loop on low steam flow has been cancelled because, on a boiler trip, the opening of the bypass path triggered by low steam flow would produce the depressurization of the boiler. This loop is now used exclusively on manual control with good success.

The burner executive system command, designed to place two burners in service simultaneously, has been modified so that the light off of the two burners takes place at a 45 second interval to prevent excessive furnace pressure upset.

The utility reports that, thanks to the combined effect of the burner and load runback and the digital override control of furnace pressure, the boiler has been able to ride through load rejections of all magnitudes as well as turbine trips without experiencing simultaneous boiler trips. On certain occasions, but not on all occasions, the safety valves have lifted.

Abnormal Load Rejection

Figure 2 shows a relatively large load rejection of 97MW which took place during start up, at a time when the unit was being ramped at the rate of approximately 7% load per minute. A failure in the stator coolant initiated this fast runback in load, from 182MW to 85MW in about 46 seconds. As can be seen in Figure 2, the drum level remained within the prescribed limits for about 140 seconds. However, an oscillation and gradual increase in level ensued, which tripped the boiler on high drum level and thus the turbine. Under a normal runback, the drum level will characteristically drop to a low value for two reasons: first, because of normal instantaneous drop in level produced by the bubble collapse and second, by the action of the feed water control system which will cut back feedwater flow on a sudden decrease of steam flow. This did not happen in this case.

A typical three-element system was supplied for this unit. The variable speed pump's RPM is modulated following deviations between steam flow and feedwater flow. The cascaded system also accounts for deviations in drum level; however, drum level influence is cancelled during transients by the action of a lag circuit in the drum level controller; in this way the distrubing, erroneous drum level signals, present due to "swell and shrink" during fast load changes, are not taken into consideration.

On a load rejection, the drum level set point is automatically reduced by means of a derivative amplifier. The system includes the feature of initiating a load runback on large deviation between steam flow and feedwater flow. Should the steam flow drop below feedwater flow by a certain amount, the runback signal will be sent to the combustion controls and the boiler firing rate will be cut back.

Under normal operation, a sudden drop in steam flow would be accompanied by a fast cutback in feedwater flow due to an excess water flow signal (the drum level correction is not yet introduced). The drum level as indicated would have a tendency to show low, until the drum level correction acted later on.

An oscillation ending in a high level trip could be explained by any of three possibilities:

a. The feedwater flow turbine speed regulating controls malfunction.
b. The start-up feedwater control valve is left in service and overcorrects drum level.
c. The feedwater control loop is on manual and the operator is overfeeding boiler.

Normal Response

Figure 3 shows a controlled test, performed the next day, showing a normal runback over the same range and restoration of load in a normal manner, without any changes to the system. It is concluded therefore, that the most likely causes of the trip are operator related as in (b) and (c) above.

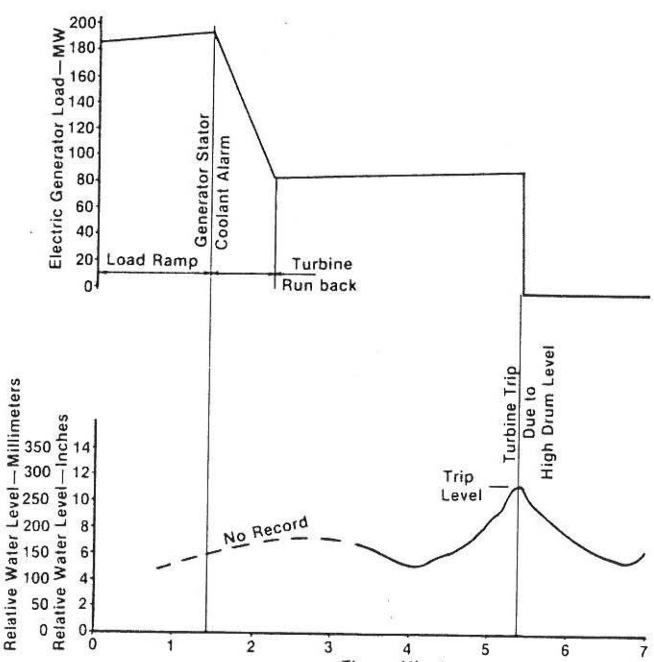

FIGURE 2—ABNORMAL RESPONSE TO RUN BACK 600 MW OIL FIRED UNIT

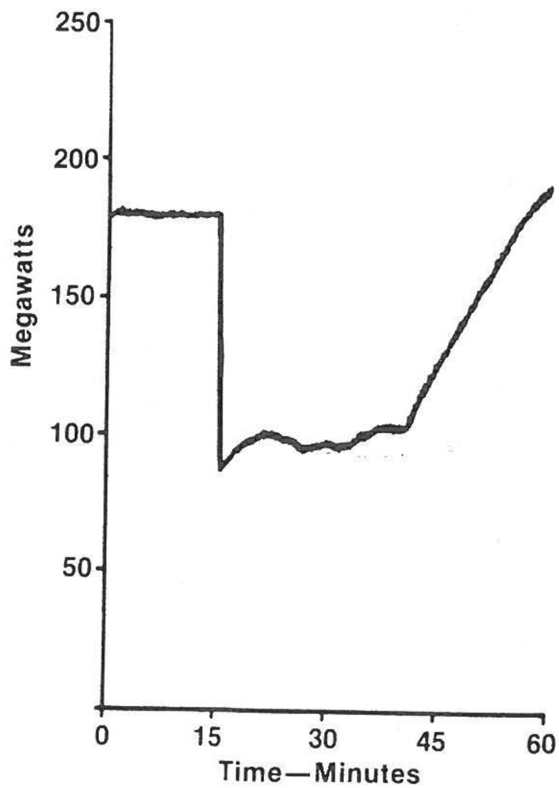

FIGURE 3—NORMAL RESPONSE TO RUNBACK 600 MW OIL FIRED UNIT

NORMAL RESPONSE TO RUNBACK - 276MW COAL-FIRED UNIT

Reference (6) has supplied information on a controlled runback on a turbine-generator, with steam supplied by a natural circulation coal fired steam generator. At the start of the load rejection sequence, the two pulverizers supplying fuel to the lowest tier of burners were tripped, and the transfer of the feedwater pump from turbine drive to electrical drive was accomplished automatically. Load was rejected to approximately 120MW. Figure 4 shows the reaction of the boiler system to these events. The unit was 250MW before rejection and dropped to 120MW in about 1.3 minutes or roughly at a rate of 100MW/min. or 36% per minute. Steam pressure rose nearly 100 psig (650 KPa) and water level dropped 10" H_2O (250 mm).

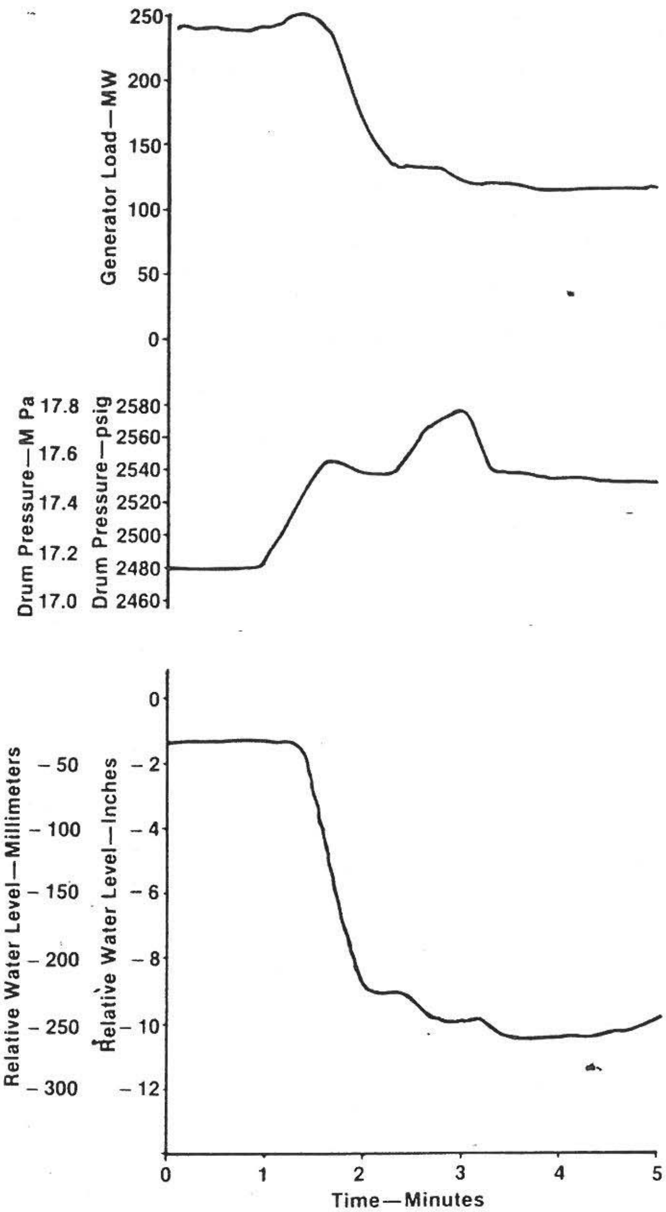

FIGURE 4—NORMAL RESPONSE TO LOAD REJECTION 275 MW COAL FIRED GENERATOR

CONCLUSIONS

From the foregoing, it is concluded that the load rejection reliability of the steam generator system is about the same as the turbine-generator, but the reliability of the boiler-turbine system together is less than that of the turbine-generator. It is also concluded that operator error is a serious problem. Although the average US designed fossil fuel plant may not be designed to handle as large and as frequent load rejections as European designed units, load rejection has been accomplished and for the most part in a reliable manner. The number of successful runbacks compared to unsuccessful runbacks was not found in the literature search for this paper. Large turbine bypass systems (greater than 10%) appear to offer increased reliability. As new fossil fired units are ordered which have been designed for cycling duty, we may anticipate a more flexible boiler design, an increase in the number of large turbine bypass systems, and thus, an increase in reliability of the system for partial load rejection.

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A. H. Rawdon (ASME member 1947) was born in Worcester, Massachusetts on April 26, 1923. He received his B.S. degree in mechanical engineering in 1947 and M.S. degree in mechanical engineering in 1961, both from Worcester Polytechnic Institute, Worcester, Massachusetts. From 1948 to 1959, he was with Riley Stoker Corporation in various engineering capacities in design of steam generating equipment. From 1960 to 1964, he was with Arthur D. Little in cryogenic engineering and engineering for space vehicles. From 1965 to the present, he has returned to Riley Stoker, and has worked in engineering management of research and product development. Currently, Mr. Rawdon is a staff consultant for Riley Stoker Corporation. He holds four patents and has authored or co-authored nine technical papers or book sections.

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