NRC Form 366 (9-83)

U.S. NUCLEAR REGULATORY COMMISSION
APPROVED OMB NO. 3150-0104
EXPIRES: 8/31/85

LICENSEE EVENT REPORT (LER)

FACILITY NAME (1)	DOCKET NUMBER (2)	PAGE (3)
PALISADES PLANT	0 5 0 0 0 2 5 5	1 OF 7

TITLE (4) Licensee Event Report 94-017-01 - Emergency Diesel Generator, EDG 1-1, Degraded Load Carrying Capability - Supplemental Report

EVENT DATE (5)			LER NUMBER (6)			REPORT DATE (8)			OTHER FACILITIES INVOLVED (8)	
MONTH	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REVISION NUMBER	MONTH	DAY	YEAR	FACILITY NAMES	DOCKET NUMBER(S)
0 9	0 2	9 4	9 4	0 1 7	0 1	1 1		9 4	N/A	0 5 0 0 0
									N/A	0 5 0 0 0

OPERATING MODE (9): N

POWER LEVEL (10): 1 0 0

THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: *(Check one or more of the following)* (11)

20.402(b)	20.405(c)	50.73(a)(2)(iv)	73.71(b)
20.405(a)(1)(i)	50.36(c)(1)	50.73(a)(2)(v)	73.71(c)
20.405(a)(1)(ii)	50.36(c)(2)	50.73(a)(2)(vii)	OTHER (Specify in Abstract below and in Text, NRC Form 366A)
20.405(a)(1)(iii)	50.73(a)(2)(i)	50.73(a)(2)(viii)(A)	
20.405(a)(1)(iv)	X 50.73(a)(2)(ii)	50.73(a)(2)(viii)(B)	
20.405(a)(1)(v)	50.73(a)(2)(iii)	50.73(a)(2)(x)	

LICENSEE CONTACT FOR THIS LER (12)

NAME	TELEPHONE NUMBER
Paul J Gire, Staff Licensing Engineer	AREA CODE 616 764-8913

COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT (13)

CAUSE	SYSTEM	COMPONENT	MANUFAC-TURER	REPORTABLE TO NPRDS	CAUSE	SYSTEM	COMPONENT	MANUFAC-TURER	REPORTABLE TO NPRDS

SUPPLEMENTAL REPORT EXPECTED (14)

		EXPECTED SUBMISSION DATE (15)	MONTH	DAY	YEAR
YES *(If yes, complete EXPECTED SUBMISSION DATE)*	X NO				

ABSTRACT *(Limit to 1400 spaces, i.e., approximately fifteen single-space typewritten lines)* (16)

On September 2, 1994, while the plant was operating at 100% power, and during maintenance testing, it was discovered that the Emergency Diesel Generator 1-1 (EDG 1-1) maximum output was below the maximum required design basis load. A misadjusted engine governor output linkage and engine performance degradation limited the EDG 1-1 output. The engine problems were corrected and an electrical load test was completed on September 4, 1994 to verify design basis maximum load carrying capability. A similar load test and minor linkage adjustments were completed for the alternate EDG 1-2 on September 7, 1994. The as-found load carrying capability of the EDG 1-2 was found slightly below the maximum analyzed design basis load.

The causes for this event were inadequate design basis testing, failure to effectively monitor for engine performance degradation, and failure to adequately control modifications made to engine governors in the past. Corrective actions for this event include periodic peak load testing for EDGs, and enhanced EDG performance monitoring, to include engine governor performance. Also, an engineering evaluation has determined that the safety consequences of the reduced load carrying capability are minor. The engine would have remained running during the peak load period, and the safety functions of the associated electrical loads would have been fulfilled.

Event Description

On September 2, 1994, while the plant was operating at 100% power, and during maintenance testing, it was determined that the load carrying capability of Emergency Diesel Generator 1-1 (EDG 1-1),[EK], was degraded. A misadjusted engine governor output linkage and minor engine performance degradation combined to limit the EDG 1-1 output to below the maximum analyzed load, which is elevated for the first half hour period after a large break loss of coolant accident, LBLOCA. An engine tune-up and fuel linkage adjustments were completed and followed by a design basis load test on September 4, 1994. This test and two subsequent monthly peak load tests have verified design basis maximum load carrying capability. Also, an engineering evaluation has determined that the reduced load carrying capability would not have adversely affected core cooling or containment cooling following a postulated LBLOCA. The engine and its safety loads would have remained running, but at reduced frequencies, during the peak load period. The safety functions of the associated electrical loads would still have been fulfilled at the reduced frequency.

A similar load test and minor linkage adjustments were completed for the alternate EDG 1-2 on September 7, 1994. The as-found load carrying capability of the EDG 1-2 was equal to the maximum analyzed design basis load. However, when instrument inaccuracies are factored into the comparison, the EDG 1-2 performance was 12 KW below the analyzed load demand. In the as-found condition, it is evident that EDG 1-2 was fully capable of performing its design function.

The diesel engines were restored to operable status within the Technical Specification allowed equipment outage period. The reactor remained at 100% power during the testing and repairs. Due to the fact that EDG 1-1 had been incapable of performing its full design function for a significant period, this event was reportable in accordance with 10CFR50.73(a)(2)(ii)(B) as a condition outside the design basis. There have been times recently when EDG 1-2 had been taken out of service for maintenance and testing. Thus, during these times both emergency diesel generators were concurrently inoperable.

Cause Of The Event

The causes of this event were; inadequate design basis testing, failure to effectively monitor for engine degradation, and failure to adequately control modifications made to the engine governors in the past. Beginning in 1986, the analyzed peak accident loads surpassed the continuous load rating of 2500 KW for both EDGs. During this period, implications of the peak loading values were evaluated. Load testing above the continuous rating of the engine was considered potentially damaging to the engines, and pre-operational testing in 1971 had verified load capabilities above 2700 KW, with additional fuel rack travel still available. Also, monthly testing at the continuous rated load of 2500 KW appeared to provide appropriate performance monitoring. This evaluation was not totally correct, and was not appropriately conservative to provide the ultimate assurance that the EDGs were capable of performing their design function. A current evaluation of peak load testing has determined that infrequent diesel operation at elevated loads is acceptable as well as necessary to verify EDG capabilities.

Analysis Of The Event

Accident Load Analysis History

Palisades has two independent and redundant emergency EDGs with continuous load ratings of 2500 KW and two hour maximum load ratings of 2750 KW. (Refer to Attachment 1 which summarizes EDG loading information.) Technical Specification Surveillance Test requirements have always required monthly starting and load testing at 2400 KW plus or minus 100 KW.

Beginning in 1986, as a result of plant modifications, the maximum analyzed accident loads required to be supplied by the EDGs after a design basis accident exceeded their continuous rating of 2500 KW. The accident loads are elevated above 2500 KW for the first half hour period following a LBLOCA, and then decrease below 2500 KW for the remainder of the event. However, the monthly load test requirements for the EDGs remained at 2400 plus or minus 100 KW. (Refer to Attachment 2 for the historical depiction of maximum analyzed EDG loads.) At that time, peak load testing of the EDGs was considered potentially damaging to the engines, and also Plant Technical Specifications, Section 4.7.1.d., restricted loading of the EDGs to below 2500 KW. The Plant Technical Specifications, Section 4.7.1.d., was revised in 1987 to clarify the diesel load restriction to 750 amps at 2400 volts.

Discovery Of The Problem

The first indication of a EDG load capability problem occurred during routine monthly testing of EDG 1-1 on July 19, 1994. The maximum output of the engine was unexpectedly limited to 2340 KW, (acceptable range is 2300 to 2500 KW). Operations personnel attempted to load the engine to the nominal test load of 2400 KW. However, the electrical governor upper limit prevented further loading. Operations personnel recognized the implications of the reduced load carrying capability and a prompt operability evaluation was completed at this time. EDG 1-1 was determined to be operable. The operability call was based on the fact that the design basis function of the engine is to provide emergency power to safety related components in the "Unit" mode. Monthly engine testing is only performed in the "Parallel" mode, which is with the engine paralleled to the electrical grid. The load carrying capability of the engine in the "Unit" mode is not affected by the electrical governor upper limit, which provides a control function solely in the "Parallel" mode. The engine performance data was also reviewed at this time and all parameters were normal. System Engineers and Operations personnel were convinced that the condition only affected the load carrying capability during testing, and that the upper limit simply needed adjustment. This would allow future monthly testing to be performed at the higher nominal test value of 2400 KW. A Condition Report was initiated to document the operability call and provide for further control and review of the electrical governor limit adjustment.

On July 29, 1994, EDG 1-1 was removed from service to complete the adjustments to the electrical governor limits and to gather additional testing data. The upper limit could not be completely adjusted due to unexpected interference from the speed control setting of the mechanical governor. The partial adjustment did allow the EDG 1-1 to be loaded to an improved value of 2400 KW. Also, several other findings from the ongoing evaluation continued to support the initial conclusion that the reduced loading capabilities were associated solely with the "Parallel" mode of operation. Specifically, the speed droop setting was incorrect for the EDG 1-1, which limited its output in the "Parallel" mode. Also, an additional 3/16" of engine fuel rack travel was measured at the 2400 KW loading and would supposedly be available in "Unit" mode for EDG 1-1 to provide the additional accident loading required. Further planning was required to make the final adjustments to all of the engine governor settings.

On August 30, 1994, the EDG 1-1 was removed from service and planned adjustments were made to the electrical and mechanical governors. The adjustments improved the EDG 1-1 output to 2438 KW, but at this time it became apparent that the governor settings were no longer limiting the engine output. The mechanical governor output shaft was found to be at its full travel. The results of this test were unexpected and indicated that the engine capability in both "Parallel" and "Unit" modes was mechanically limited to the 2438 KW value. Additional instrumentation was used during this testing to ensure that accurate load indications were being obtained. The EDG 1-1 was declared inoperable, and a troubleshooting team was organized to determine the root cause for the reduced load carrying capability.

The troubleshooting on EDG 1-1 resulted in the discovery that fuel rack linkage configuration was improperly limiting full rack travel and, thus, there was available engine output that could be gained by correcting this problem. Initial adjustments of the linkages were completed to allow the engine to supply up to 2500 KW, and further adjustments would be needed during a planned design basis test that was under development. Also, it became apparent that the engine performance had degraded because it was not providing the expected power output at the measured fuel rack travel, with respect to the original pre-operational test in 1971. Inspections, adjustments, and replacement of suspected components provided minor improvements in engine performance, but no specific component degradation was found to explain the lower engine output.

On September 3, 1994, the initial design basis load test was performed for EDG 1-1 and the maximum output was measured at 2685 KW. Based on the results of the test and observation of the fuel rack positioning, further rack adjustments and testing were completed until full rack travel resulted in an output of 2714 KW. This value includes an instrument inaccuracy penalty of 17 KW. The fuel rack linkage adjustments appear to have resulted in the majority of the total performance improvement (276 KW) that was gained during the troubleshooting and repairs. Based upon review of the final test results, the EDG 1-1 was declared operable on September 5, 1994. Additional peak load tests for EDG 1-1 were completed on 10/6/94 and 11/2/94 in conjunction with the normal monthly testing. The output of EDG 1-1 was observed to be 2722

KW and 2735 KW, respectively, using precision instrumentation and accounting for instrument inaccuracies. Thus, all peak load testing results, after the adjustment of the governor linkage, exceed the peak load of 2688 KW that could exist during the first half hour period after a LBLOCA.

On September 7, 1994, a design basis load test was performed for the alternate EDG 1-2 to verify its ability to supply maximum analyzed loads. The as-found load carrying capability of the EDG 1-2 was 2651 KW, which includes a 15 KW instrument inaccuracy penalty. This as-found performance was 12 KW below the maximum analyzed design basis load of 2663 KW. The root cause for the EDG 1-2 reduced load carrying capability was an improperly positioned fuel rack travel hard-stop. The hard-stop was adjusted and a second peak load test was performed. An improved output of 2697 KW was recorded during the test, which includes an instrument inaccuracy penalty. During the second EDG 1-2 peak load test, the electrical grid was experiencing slight fluctuations in voltage and frequency, and thus the load output of the EDG 1-2 was unsteady. The engine output was observed at times to be over 2750 KW. Thus, the actual maximum output for the EDG 1-2 is higher than the value recorded in this test. The EDG 1-2 was declared operable on September 8, 1994, based on its ability to provide the maximum design basis load of 2663 KW. Additional peak load tests for EDG 1-2 were completed on 10/10/94 and 10/27/94 in conjunction with the normal monthly testing. The output of EDG 1-2 was observed to be 2794 KW and 2736 KW, respectively, using precision instrumentation and accounting for instrument inaccuracies. Also, for EDG 1-2 there was additional fuel rack travel available at the loads recorded for these tests. The present output of EDG 1-2, based on a comparison of fuel rack positions, is approximately equivalent to the output recorded in the original pre-operational testing in 1971. Thus, engine degradation does not appear to exist on EDG 1-2, but further evaluations and testing are planned.

Several maintenance and modification activities from the 1970s and 1980s are primarily responsible for the reduction in peak load carrying capability below the initial 2800 KW for both EDGs. The mechanical governor was replaced on EDG 1-1 in 1979 and again in 1982. The electrical governor was replaced on EDG 1-1 in 1989. Similarily, the mechanical governor was replaced on the EDG 1-2 in the early 1980s. It is suspected that, during the governor modification work, output linkage misadjustments occurred that limited the engine output to a value below the original capability of 2800 KW, but still above the 2500 KW rating. The impact upon the total load carrying capability of the engines remained undetected at that time due to the existing operability test criteria of 2400 KW, plus or minus 100 KW.

The EDG 1-1 engine performance degradation issue remains under investigation at this time. The present maximum output of EDG 1-1 is approximately 100 KW below the original pre-operational testing results from 1971. The comparison is somewhat difficult to fully evaluate due to the inability to determine the potential inaccuracy of the instruments used in the pre-operational test.

Safety Significance

An engineering evaluation of the impact of EDG 1-1 reduced load carrying capability has been completed. The evaluation of the EDG 1-1 degraded performance has determined that the EDG would have remained running at a reduced frequency. The evaluation has determined that the individual safety related loads on the EDG supplied safety buses would also remain running and provide their design function at the anticipated reduced flow rates. This result is based on the fact that slightly reduced safety related pump and fan flow rates for the first half hour following a LBLOCA, would only lead to a negligible delay in recovery from the event. During a LBLOCA, peak fuel clad temperatures and peak containment pressures occur within the first minute of the event. The peak values that these safety limit parameters reach are not impacted significantly by the pump or fan flow rates assumed in the analysis. Thus, the slightly reduced flows caused by the 30 minute operation at reduced frequency have negligible impact. Attachments 4 and 5 provide the evaluation results which were also independently reviewed by Sargent and Lundy technical experts. This review included discussions with equipment vendors and industry specialists, and the final report will be retained within the final Palisades corrective action document package at the plant site.

The EDG design basis accident load profile is a depiction of the postulated electrical load that will exist at a certain time after a worst case design basis accident. The accident load profile is a combination of the automatically sequenced loads and any operator manually initiated loads allowed by our Emergency Operating Procedures,(EOPs). Attachment 3 provides the time dependent LBLOCA accident load profiles for both EDGs. The load profiles were recently revised on 10/5/94. The difference between the present versions and the past versions is a timing change for the manual initiation of control room ventilation condensing units and containment hydrogen recombiners by control room operators. The past versions assumed that the two mentioned loads were initiated at thirty minutes after the start of the event. The present versions assume that the loads are initiated at sixty minutes from the start of the event. The two manually initiated loads were conservatively placed in the past load profiles well in advance of their need, and also well in advance of their realistic starting times during the initial stages of an accident. Thus, the past versions of EDG loading profiles contained approximately 104 KW of conservatism at the critical thirty minute period after the start of the event. The difference between the present and past load profiles is considered conservative margin that exists to be considered in the total overview of this issue. The reduction in the actual loading was not factored into this evaluation of safety significance because past EOPs did not restrict the manual loading from occurring at the earlier time. EOP changes have been completed and an increased margin is now reflected in the load profiles.

NRC Form 366A
(9-83)

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LICENSEE EVENT REPORT (LER) TEXT CONTINUATION

FACILITY NAME (1)	DOCKET NUMBER (2)	LER NUMBER (3) YEAR	SEQUENTIAL NUMBER	REVISION NUMBER	PAGE (4)
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Corrective Action

Corrective action for this event includes the following actions:

1. Complete short-duration peak load tests for both EDGs during the next two monthly tests. The monthly testing will monitor engine performance and establish trend information, pertaining to fuel rack position relative to KW loading, at loads of 2300 KW and above.

2. Upon the completion of Action 1, (monthly peak load testing), establish operability criteria in the monthly EDG test procedures to ensure that EDG load carrying capability for design basis loads is verified. At this time it is anticipated that available fuel rack travel at a given load, with a known correlation between available travel and load output, will provide an accurate method to monitor design basis capabilities.

3. Establish periodic design basis testing for both EDGs. The anticipated testing interval is once each refueling cycle, and will be based on the results from the trending and testing from Actions 1 and 2.

4. Determine the root cause for the apparent minor engine degradation that has occurred on EDG 1-1 with respect to the original 1969 engine testing. Enhance the present performance monitoring program for the EDGs to maintain the engines at or near peak performance.

5. Establish preventative maintenance controls to periodically monitor engine governor performance and control setpoints to ensure governors perform as expected in both "Parallel" and "Unit" modes.

6. Establish administrative controls to ensure that changes to the plant design basis that occur through analysis are properly controlled and evaluated for potential verification testing.

7. Evaluate the design margin that exists for both EDGs with respect to the maximum accident required loads and determine the possible alternatives that exist to increase the margin.

8. Perform a detailed assessment of safety system testing to ensure plant design basis requirements are being properly verified. The order in which the safety systems are assessed will be in accordance with their PRA ranking.

9. Perform further EDG dynamic load model analyses to determine; the capability of an EDG to support the largest electrical transient motor start that results from a sequencer malfunction, and the approximate maximum transient motor start that results in an EDG trip,(to provide further validation of the EDG load model).

ATTACHMENT 1

Consumers Power Company
Palisades Plant
Docket 50-255

EMERGENCY DIESEL GENERATORS KILOWATT TABLE

NOVEMBER 22, 1994

1 Page

ATTACHMENT 1
EMERGENCY DIESEL GENERATORS KILOWATT TABLE

PARAMETER	D/G 1-1	D/G 1-2
TWO HOUR ACCIDENT RATING	2750 KW	2750 KW
CONTINUOUS RATING	2500 KW	2500 KW
TECHNICAL SPECIFICATIONS MONTHLY LOAD TEST RANGE	2300 TO 2500 KW	2300 TO 2500 KW
MAXIMUM ANALYZED POST DBA ACCIDENT LOADING	PRESENT - 2584 KW PREVIOUS - 2688 KW	PRESENT - 2559 KW PREVIOUS - 2663 KW
MAXIMUM LOAD CARRYING CAPABILITY-SEPTEMBER 1994 (reference notes 1, 2, and 3)	AS FOUND - 2438 KW AS LEFT - 2714 KW INCLUDING - 2722 KW RECENT TESTS - 2735 KW	AS FOUND - 2651 KW AS LEFT - 2697 KW INCLUDING - 2794 KW RECENT TESTS - 2736 KW
ORIGINAL VENDOR PEAK LOAD TESTING- 1969 (reference note 3)	2810 KW	2827 KW
PALISADES PRE-OPERATIONAL TESTING-1971 (reference note 3)	2730 KW	2720 KW

NOTES:

1. The as-found and as-left data includes an instrument inaccuracy penalty of 0.5 % of the reading. The original vendor and pre-operational testing results are not penalized for instrument inaccuracy.

2. The first as-left recorded value for the EDG 1-2 is the best estimate of steady state engine output. The first peak load test was performed during a period when the electrical grid was unsteady. The additional EDG 1-2 peak load test results shown above are more indicative of its full load capability.

3. During the as-left testing for EDG 1-2, the original vendor testing, and the Palisades pre-operational testing there was additional fuel rack travel available. For the as-left testing results for EDG 1-1, the engine was essentially at full fuel.

ATTACHMENT 2

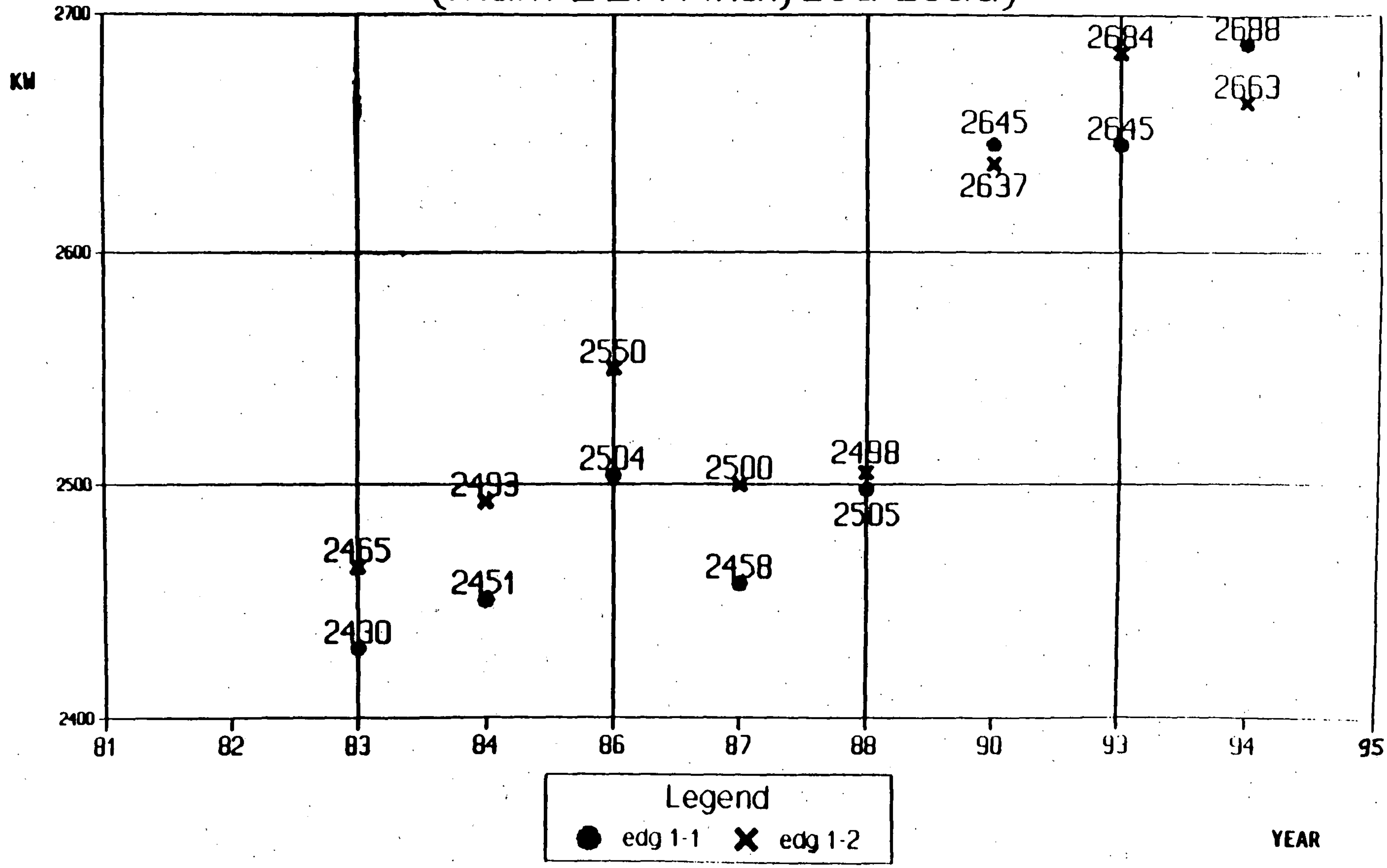
Consumers Power Company
Palisades Plant
Docket 50-255

EDG HISTORICAL LOADINGS

NOVEMBER 22, 1994

1 Page

EDG Historical Loadings
(Max. DBA Analyzed Load)



ATTACHMENT 2

ATTACHMENT 3

Consumers Power Company
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Docket 50-255

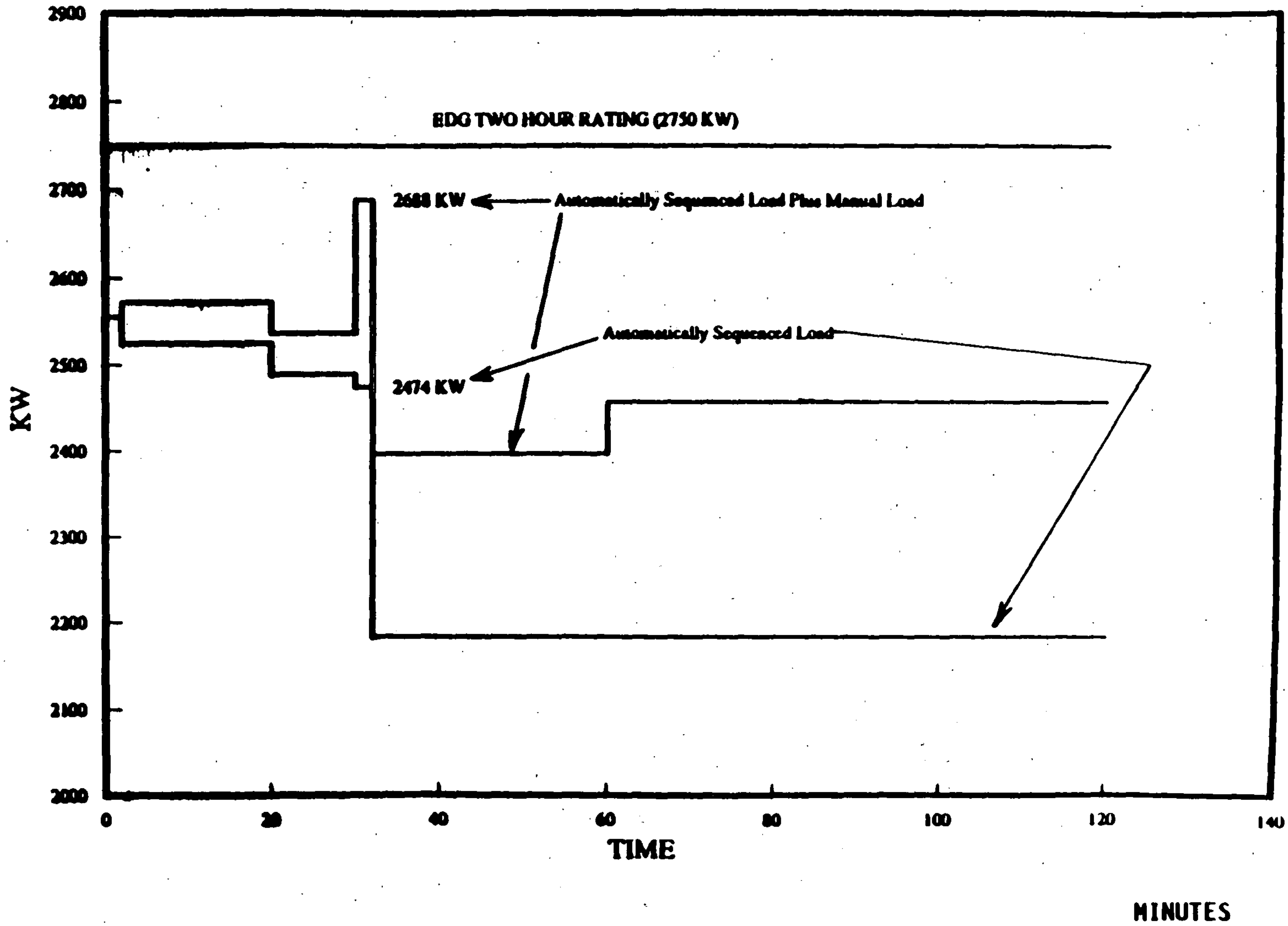
EDG STEADY STATE LOADINGS

NOVEMBER 22, 1994

4 Pages

EDG 1-1 STEADY STATE LOADING

KILOWATTS VS TIME



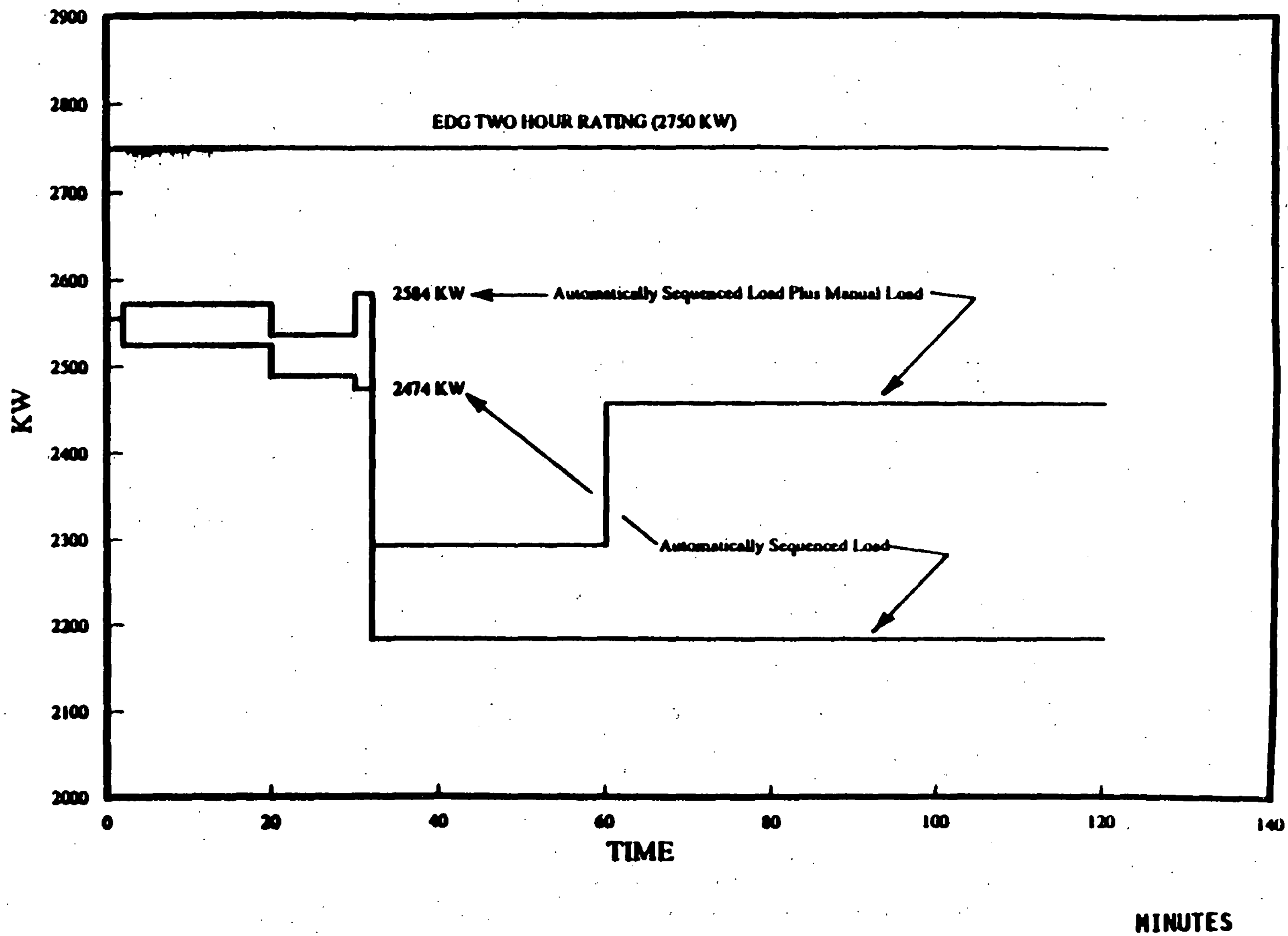
ATTACHMENT 3

PREVIOUS EDG 1-1 LOAD PROFILE

ATTACHMENT 3

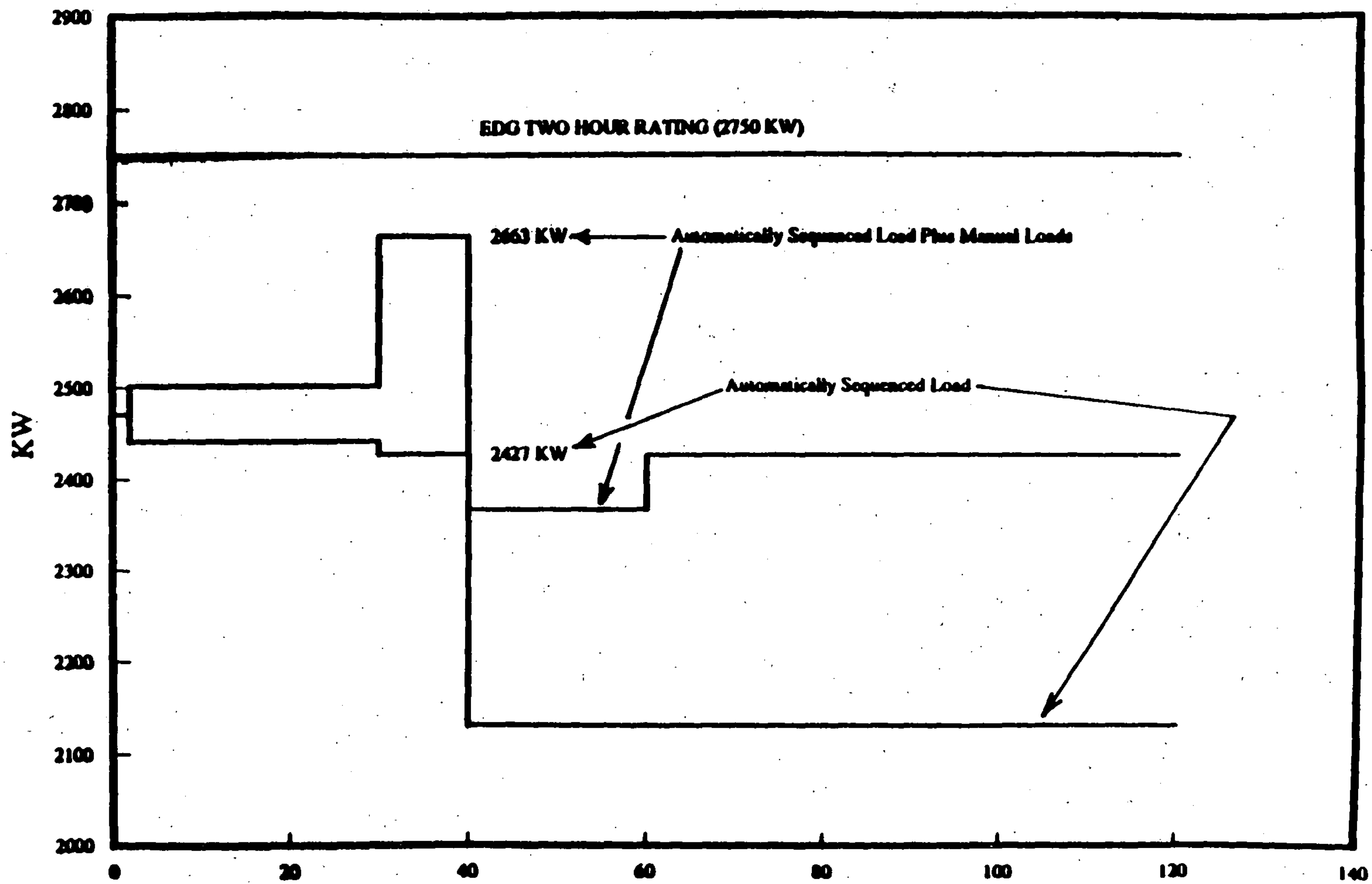
PRESENT EDG 1-1 LOAD PROFILE

EDG 1-1 STEADY STATE LOADING



EDG 1-2 STEADY STATE LOADING

KILOWATTS VS TIME



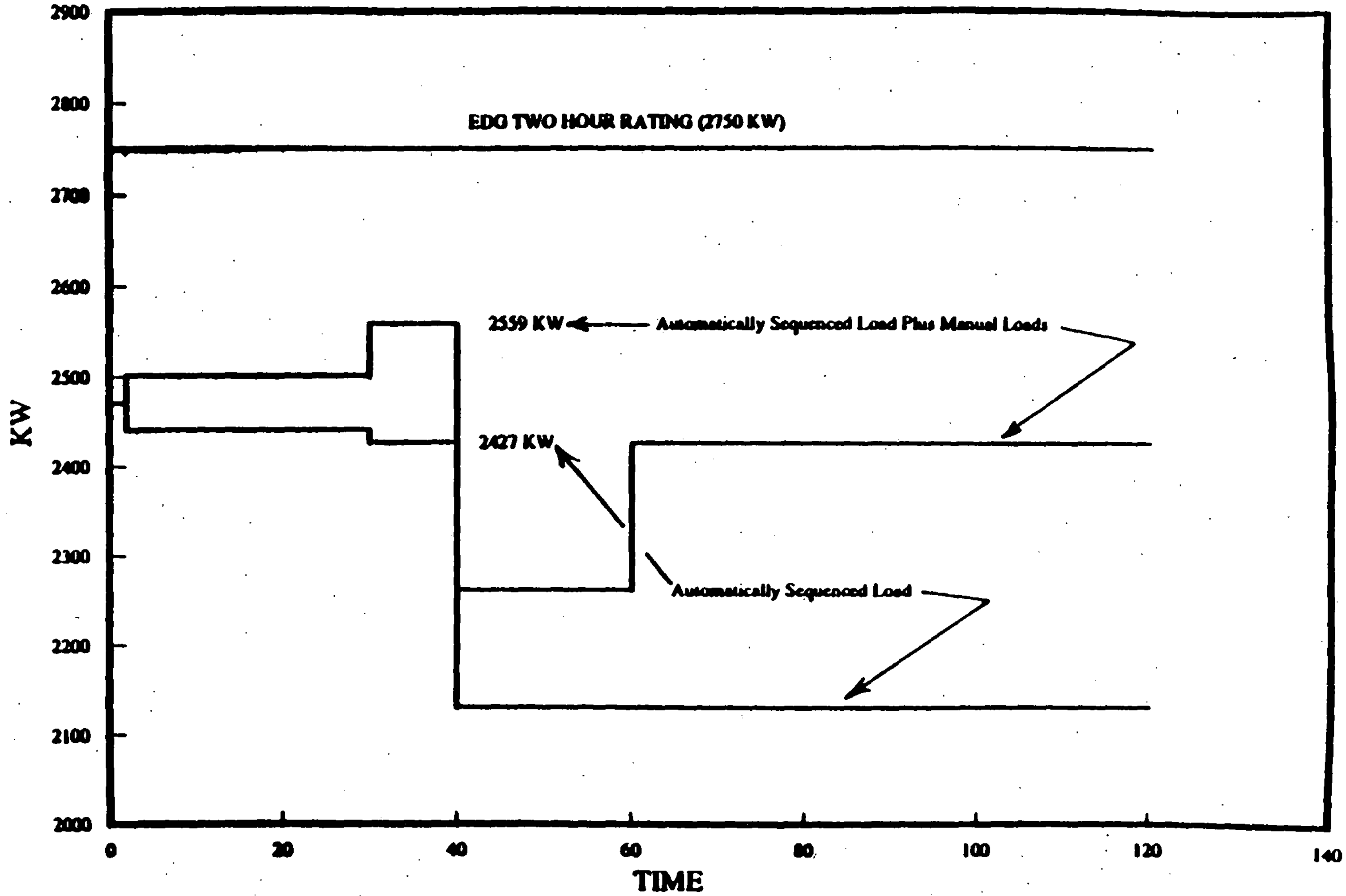
MINUTES

ATTACHMENT 3

PREVIOUS EDG 1-2 LOAD PROFILE

EDG 1-2 STEADY STATE LOADING

WITH PROPOSED EOP CHANGES



MINUTES

ATTACHMENT 3

PRESENT EDG 1-2 LOAD PROFILE

ATTACHMENT 4

Consumers Power Company
Palisades Plant
Docket 50-255

EDG 1-1 DEGRADED PERFORMANCE EVALUATION

NOVEMBER 22, 1994

26 Pages

EDG 1-1 OPERATION DURING STEADY STATE AND TRANSIENT CONDITIONS WITH 2438 KW OUTPUT CAPABILITY

GENERAL OBSERVATIONS

EDG 1-1 steady state capability was determined, based on a precision transducer, to be 2438 KW on 8/30/94. Automatically sequenced loads are 2556 KW prior to EOP manually actuated loads. Total peak automatic + manually added loads are estimated to be 2688 KW from 30-32 minutes after the design basis event. This loading drops to 2397 KW at 32 minutes due to RAS.

The significance of the 2438 KW maximum capability of EDG 1-1 resides in (1) the resulting reduced frequency steady state operation during accident conditions and (2) the reduced engine short time response capability during induction motor starting transients. These two items are discussed in this evaluation.

STEADY STATE CONDITIONS

As shown in Figure 1, EDG 1-1 load demand will be 2556 KW immediately following DBA sequencing, rise to 2573 KW from 2 to 20 minutes, fall to 2537 KW between 20 and 30 minutes, and then briefly rise to 2688 KW for a 2 minute duration. Load demand will drop to 2397 KW at 32 minutes and eventually rise to 2457 KW for the remainder of the first two hours of the accident. Load will remain below 2500 KW for the remainder of the accident.

Since the EDG engine cannot fully supply these steady state KW loads, the engine will reduce in speed which in turn results in a reduction in system operating frequency for the connected 2400 and 480 volt loads. A reduction in reduced operating frequency will directly affect motor and connected pump and fan speeds. Pump flows and fan outputs will be reduced which in turn will result in lower KW loading on the EDG. The exact reduced KW loading is difficult to determine since the connected loads will not all react the same to the reduction in system frequency. Existing inhouse models have limited engine and pump models to accurately simulate such a steady state event.

Induction motors can operate successfully with frequency variations of 5% if voltages are maintained at 100% (ANSI C50.41-1982). Thus, assuming the static excitation system can sustain 100% voltage during reduced frequency operation, steady state conditions at 57 hertz would be assumed to be acceptable to connected induction motor loads. While motor currents will slightly rise on large induction motors due to reduced frequency operation, the increase in current will be offset by the reduction in connected pump or fan load. No adverse affects on equipment or tripping of individual loads are expected. Tables I and II, attached, summarize the effects of small frequency changes on equipment and the present EDG trips.

It is estimated and verified by modeling that EDG 1-1 frequency will be approximately 58 hertz following automatic sequencing of DBA loads and will remain at 58 hertz until 30 minutes when loading increases to 2688 KW. At this time, EDG 1-1 frequency will most likely decay to approximately 56 hertz for the 2 minute loading period and then return to 60 hertz at 32 minutes when EDG load demand drops to 2392 KW (which is below the EDG 1-1 2438 KW capability). Voltages are expected to remain at 2400 volts due to adequate excitation system response. No adverse motor currents or EDG response is expected since 56 hertz is only slightly below the -5% frequency rating of the connected induction motors. Pump flows and thus connected loads will be slightly reduced. Operation at 56 hertz will occur for only a 2 minute duration after which frequency will return to 60 hertz since load demand drops to 2392 KW at 32 minutes into the accident.

In summary, electrically EDG 1-1 is expected to be fully operable during the reduced steady state frequency operation at 58 hertz and over the 2 minute period when frequency may decay to 56 hertz. However, the effects of reduced pump flows on accident mitigation must be determined. What are the effects of a 2-4% reduction in pump speeds (operation at 58 hertz) and subsequent reductions in pump flows during the first 30 minutes of an accident? Similarly, what are the effects of a 4-6% reduction in pump speeds (operation at 56 hertz) and subsequent reductions in pump flows for a 2 minute duration? Answers to these questions will determine the safety significance of the reduced 2438 KW steady state output capability of EDG 1-1.

TRANSIENT CONDITIONS

The short time output torque of the engine at rated speed is only as great as engine fueling will permit. If momentarily overloaded, the engine will lose speed. It will slow if instantaneous fuel supply is not sufficient to drive instantaneous load. Some stored energy is available due to angular velocity and mass of the engine and generator which will aid in engine response to an applied transient load. The static excitation system used on the EDGs is relatively fast and sized to handle the large starting transient currents demanded by the induction motors during starting.

It is estimated that the worst case transient step load could occur when EDG 1-1 is loaded to 2334 KW and Auxiliary Feedwater P8A starts due to delayed AFAS. This results in an initial momentary transient load demand of 397 KW which is 293 KW above the EDG maximum output capability of 2438 KW. Two things may occur due to this short time transient overload demand:

(1) The excitation system is able to overcome the voltage reduction due to loss in engine speed and the motor will start and, once the starting transient is over, the engine will recover in speed at a reduced steady state system operating frequency as previously discussed.

(2) The excitation system cannot sustain adequate voltage during the motor start. Engine speed and voltage continues to decay resulting in "voltage collapse." Individual loads and the EDG trip on overcurrent.

Based on engineering judgement it is felt that EDG 1-1 would be capable of starting and accelerating all DBA loads (including P8A) with a 2438 KW output capability (scenario (1) above). This conclusion is based on the following observations and later verified by dynamic simulations of the event as summarized in the next section of this evaluation:

(1) Per ALCO information, the "engine is capable of accepting a 1000 KW step load."

(2) Typically, diesel engines are sized to accept a step load of 50% rated (1250 KW)

(3) The maximum step load in this case in 397 KW / 2500 KW or 16% of continuous EDG output rating

(4) Measurements of frequency during motor sequencing in 1987 (Attachment A) indicated less than 1% deviations indicating the present engine/governor is very capable of handling the KW demand of the induction motors being started during DBA sequencing.

(5) The static excitation system has been sized to handle the large inrush current demanded by the induction motors which is primarily reactive load during starting. It would most likely be capable of sustaining adequate voltage during reduced engine speeds.

DYNAMIC SIMULATIONS OF WORST CASE STARTING TRANSIENT

Computer models have been developed of the Palisades emergency diesel generators and their associated emergency core cooling system induction motors during sequencing and results compared with field tests. Attachment A of this evaluation documents the IEEE Paper which was published in September, 1993 documenting the inhouse models. In order to examine the frequency excursions experienced by EDG 1-1 while starting Auxiliary Feedwater Pump P8A, computer simulations were completed starting the motor during each of the loading plateaus as shown in Figure 1. In each case the prestart loading prior to starting P8A was assumed to be 354 KW lower than the given loading plateau. Table 1 summarizes the results of the dynamic simulations. Included in Table 1 are the results of a dynamic simulation assuming an engine output capability of 2714 KW - the final maximum output capability following corrective actions. As can be seen in Table 1, with EDG 1-1 output capability of 2438 KW, P8A is successfully started in all cases with a subsequent reduction in EDG steady state frequency. The steady state frequencies from the computer simulations are very close to the predicted frequencies previously discussed i.e. 58 hertz for the first 30 minutes declining to a minimum of 56 hertz for only a 2 minute period. Motor speeds (pumps and fans) decay 2-6% below normal operating values during the first 32 minutes of EDG 1-1 loading.

Figures 2-5 summarize the response of the engine mechanical power, generator excitation system, and engine speed/frequency when starting P8A at the various loading plateaus. As can be seen in these plots, the generator excitation system responds and maintains voltages at 2400 volts during the motor starting transient. Subsequent engine transient response and resulting system steady operating speed/frequency is dependent on the preload prior to starting the motor. In each case, the generator and engine, as predicted, maintain the connected loads at minimal reductions in operating frequencies (reductions of only 2-4 hertz). No problems were identified as summarized in Tables I and II.

Figures 6-9 document the ability of the EDG to start and load P8A with the maximum as left EDG 1-1 output capability of 2714 KW. As can be seen in these plots, the EDG is capable of starting P8A during all loading plateaus. Steady state frequencies return to 60 hertz following the P8A motor starting transient. No operating problems were found.

S&L REVIEW OF EDG RESPONSE DUE TO REDUCED ENGINE OUTPUT CAPABILITY

The following summarizes the scope of an independent S&L review of CPCo efforts to determine the EDG capabilities to perform their design functions during accident conditions. It will include a review of past operability (steady state and transient) when EDG 1-1 maximum output capability was 2438 KW as well as its present capability of 2714 KW and when EDG 1-2 maximum output capability was 2651 KW as well as its present capability of 2697 KW.

1. Review industry experience at other Nuclear Plants such as Salem. Determine if a similar problem has been experienced and what was done to resolve it. Include a search of industry publications such as IEEE on such a topic. (Paul Gire, CPCo Licensing has submitted a search of other Nuclear Plants regarding the subject and would be a good first contact.)

2. Review the completed EDG dynamic simulations of DBA sequencing which were performed using the inhouse CPCo PSS/E dynamic model of the EDG from a qualitative perspective (do not repeat computer modeling or simulations). Are the results adequately predicting engine and system response? Do they appear reasonable? (KE Yeager is the contact for this area of review.)

3. Review the effects of reduced motor speeds on motor pump flows which are being determined by the Palisades Reactor Engineering Dept from a qualitative perspective (Do not repeat computer modeling or simulations). Are the predictions reasonable? (TC Duffy is the contact for this aspect of the system response.)

4. Contact industry vendor experts and review the expected engine response for the steady state and transient conditions. Does it agree with the conclusions drawn from the CPCo dynamic simulations of EDG response? Are the predictions of pump flows

acceptable?

5. Review the effects of reduced frequency operation on the associated induction motors connected to the safety buses.

6. Develop a summary report of the S&L review of the EDG response due to reduce engine output capability for items 1-5 above. ***Draw conclusions*** on EDG and system operability based on the information reviewed which can be presented to the NRC in upcoming discussions (Enforcement Conference).

KE YEAGER
10/27/94

Table I
Summary of the Effects of Reduced EDG Operating Frequency on Connected System Components

Componet	effect	reference
2300 and 460 volt Induction Motors	Overall reduction in Runing I due to reduced pump/fan flows	PSS/E Simulations, discussions with PTI, S&L
	Increase in No Load current (estimated to be 3-8%)	GE Bulletin
	Increase in Locked Rotor Current (estimated to be 3-8%)	GE Bulletin
480 volt AC Contactors	Slight increase in current. AC Contactors are dual frequency rated; 50/60 hz	S&L Review, and Cutler Hammer Bulletin
Motor overcurrent relays, differential relays, undervoltage relays	Reduction in relay sensitivity - pickup	Generating Station Protection - GE info
Safety Related MOVs	None. Started in first 60 seconds of DBA at 60 hertz	DBA sequencing logic
Safety related relays/controls	None. Fed by preferred AC or Class 1E DC	P&ID Drawings, schematics
Battery Chargers	None. SCR controlled, no effect from input frequency variations of 3-7%	JD Slinkard, System Engineer

KEJ 10/26/94

Table II
Summary of EDG Trips

EDG Trip	Description
Engine Overspeed	At 10% engine overspeed a single sensor actuates the overspeed relay which energizes the SDR
Low Lube Oil Pressure	Enabled on both engine start circuits after jacket water pressure switch is closed (at 10psig and 35 sec delay). If two oil pressure sensors see <40 psig (approx 1/2 engine speed - 450 rpm) the SDR will be actuated
Overcrank	When starting you have 35 sec to obtain: start ckt A: >10 psig or 120rpm start ckt B: >10 psig
Field shutdown timer	If the tach pack senses engine rpm less than 600 RPM, the field shutdown timer will trip the output breaker and shutdown the generator field within 120 seconds unless engine speed recovers above 600 rpm
Overcurrent relaying	x phase - 824 amp pickup y phase - 824 amp pickup z phase - 752 amp alarm only
Generator differential relaying	differential relay settings

Kég 10/27/94

TABLE 1

EDG 1-1 REDUCED ENGINE CAPABILITY

	2714 kw max		2438 kw max CAPABILITY							
	2688 kw load(1)		2556 kw load(2)		2573 kw load(3)		2537 kw load(4)		2688 kw load(5)	
			0-2 min load		2-20 min load		20-30 min load		30-32 min load	
Equipment	I(A)	Sp(pu)	I(A)	Sp(pu)	I(A)	Sp(pu)	I(A)	Sp(pu)	I(A)	Sp(pu)
CCW P52A	67	0.99	60.6	0.96	59.8	0.96	61.6	0.97	54	0.93
SW P7B	89	0.99	80.5	0.96	79.5	0.96	81.8	0.97	72	0.93
AF P8A	104	0.99	95.7	0.96	94.4	0.96	97.1	0.97	86	0.93
CCW P52C	67	0.99	60.6	0.96	59.8	0.96	61.6	0.97	54	0.93
LPSI P67B	99	0.98	90.0	0.96	88.8	0.95	91.4	0.96	81	0.93
CSP P54B	50	1.0	45.7	0.97	45.1	0.96	46.4	0.97	41	0.94
HPSI P66B	91	0.98	83.0	0.96	81.9	0.95	84.2	0.96	75	0.93
CSP P54C	50	1.0	45.7	0.97	45.1	0.96	46.4	0.97	41	0.94
CHG P55C	102	0.99	97.8	0.96	97.3	0.96	98.4	0.97	94	0.93
BA P56B	39	0.99	36.3	0.96	35.9	0.96	36.8	0.97	33	0.93
CCF V4A	46	1.0	44.3	0.97	44.1	0.96	44.5	0.97	42	0.94
EDG 1-1	718	1.0	656	0.97	654	0.97	659	0.98	623	0.94
		60 Hz		58.4 Hz		58.1 Hz		58.6 Hz		56.4 Hz
	Pmech=2688 kw		Pmech=2371 kw		Pmech=2361 kw		Pmech=2381 kw		Pmech=2293 kw	

References:

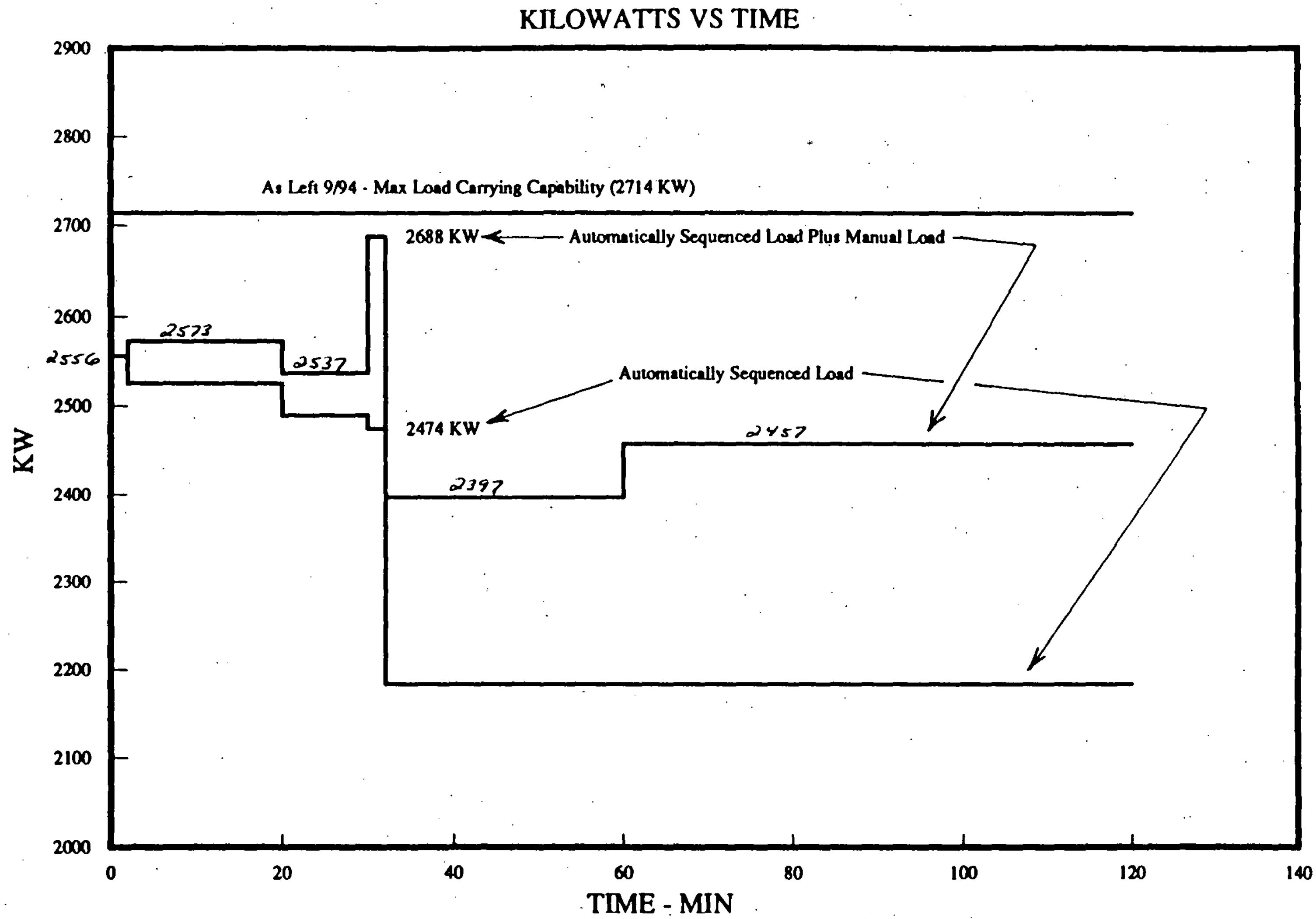
1) D2714kw.out,d2714kw.prn,d2714comp.sav.
2) d14.out, d14.prn, d14comp.sav, d14a.out, d14a.prn, d14acomp.sav.
3) d13.out, d13.prn, d13comp.sav, d13a.out, d13a.prn, d13acomp.sav.
4) d15.out, d15.prn, d15comp.sav, d15a.out, d15a.prn, d15acomp.sav.
5) d11.out, d11.prn, d11comp.sav.

GJBrock
9/30/94

Kez 10/3/94

Fig. 1

EDG 1-1 STEADY STATE LOADING



Key 10/3/94

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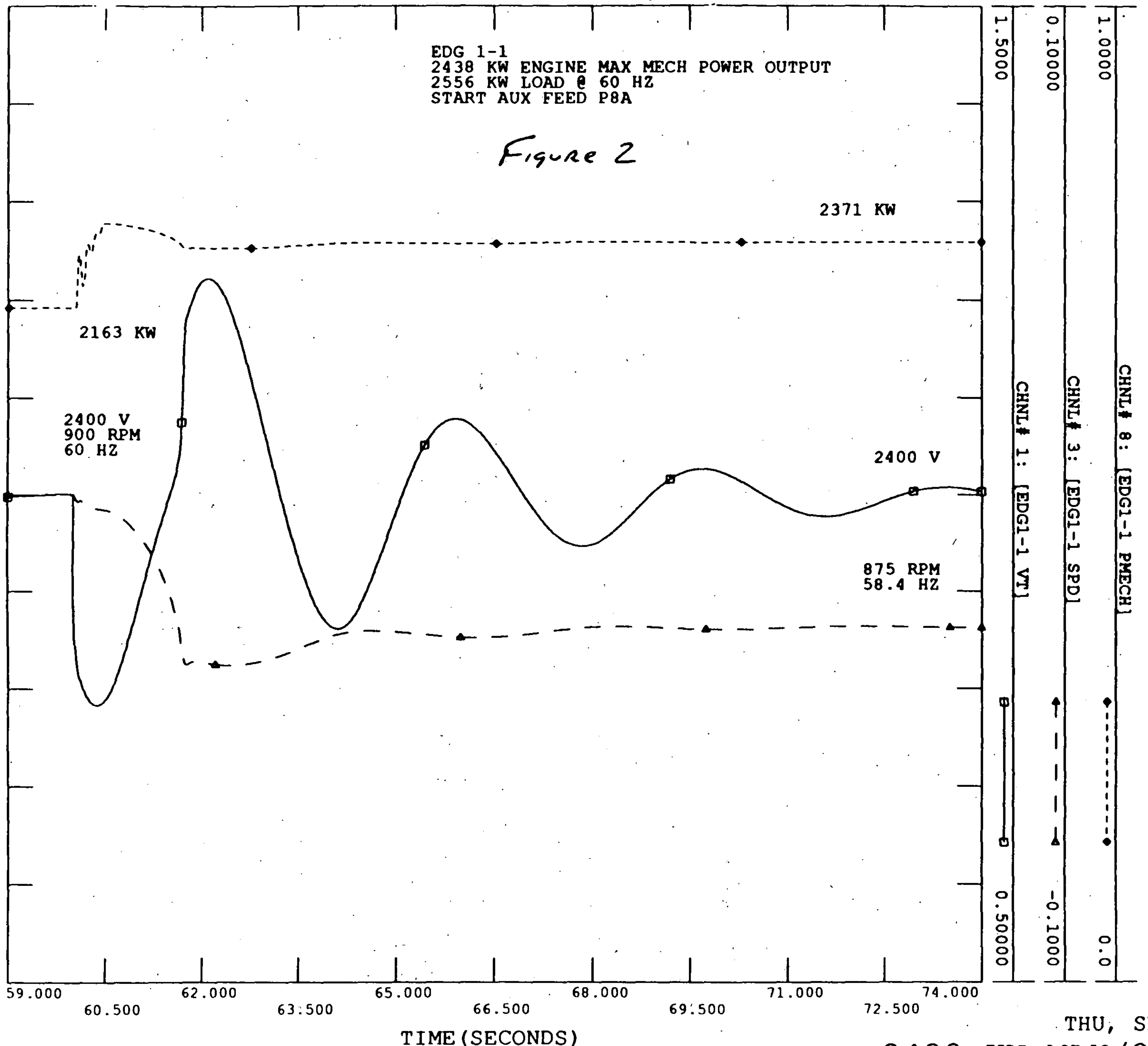

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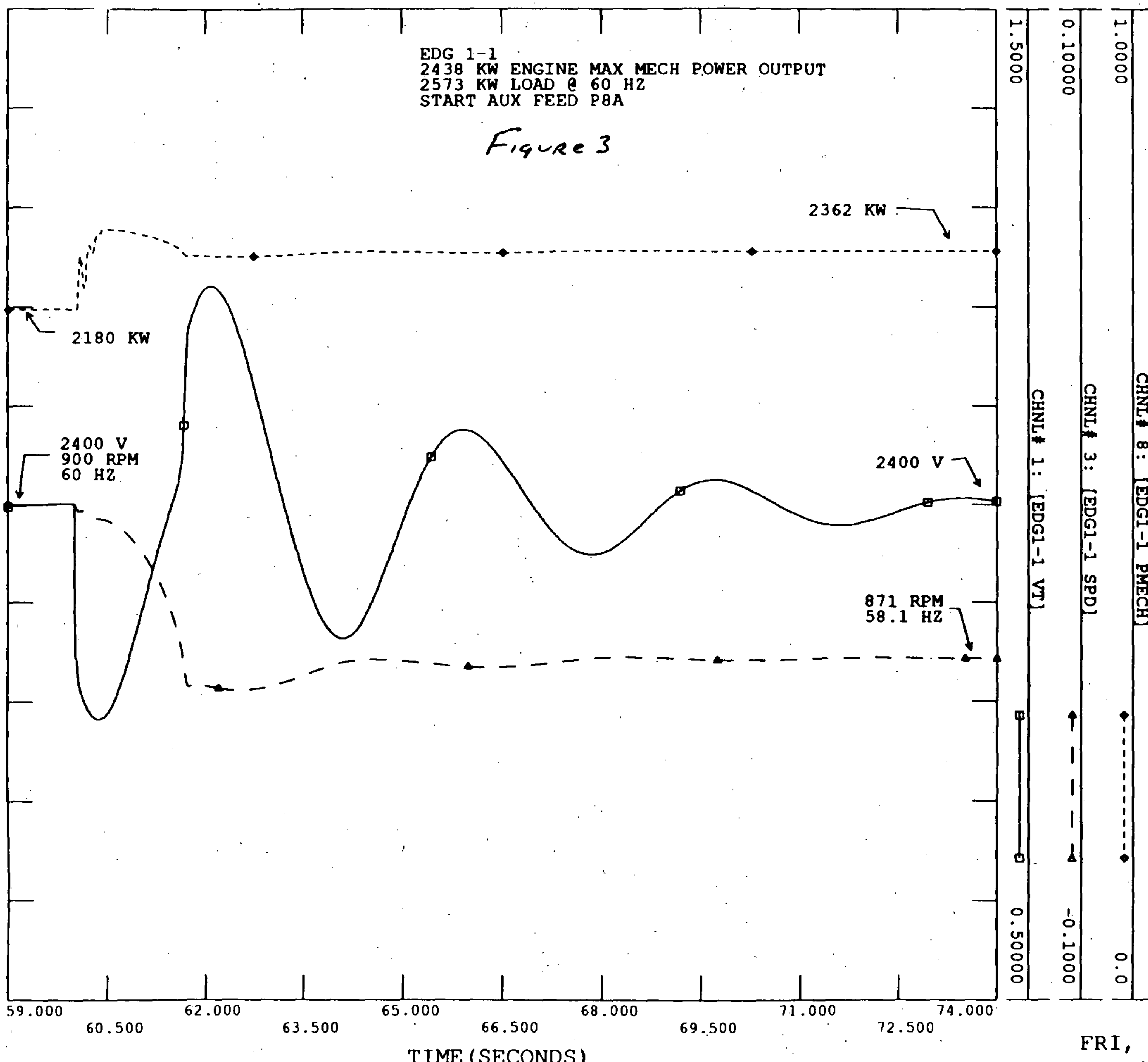
2438 KW MAX/2556 KW LOAD



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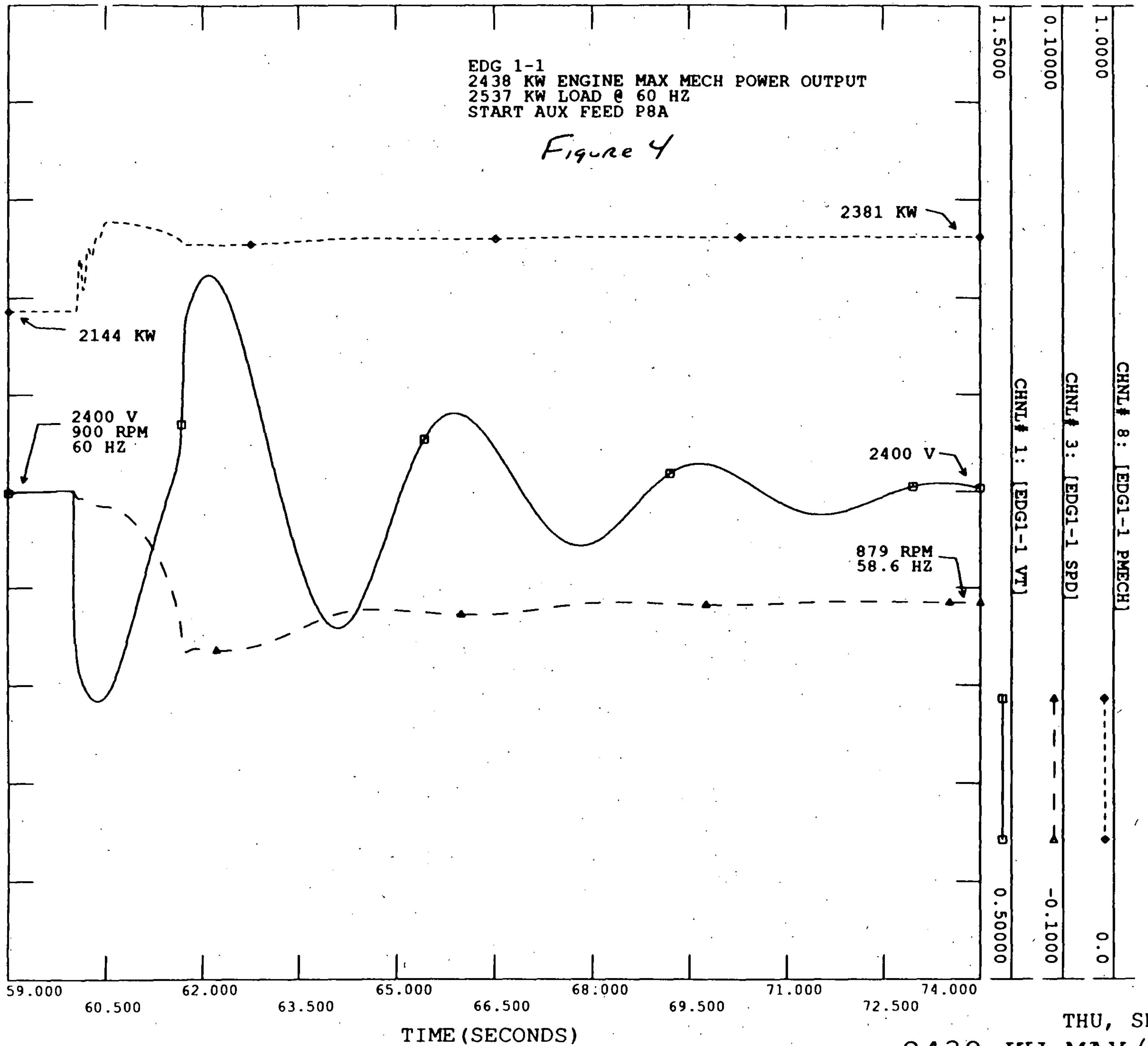

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2438 KW MAX/2537KW LOAD

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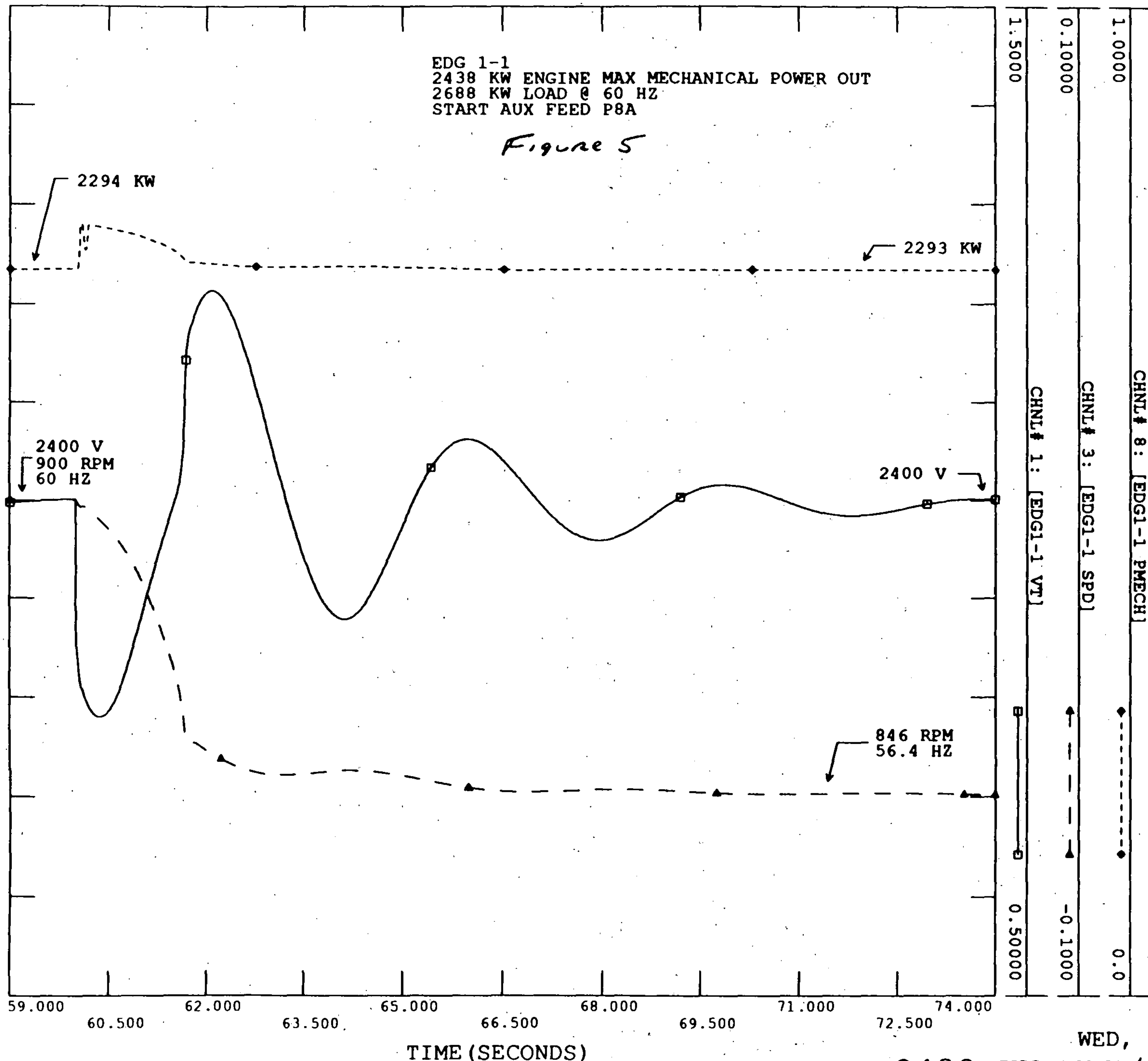

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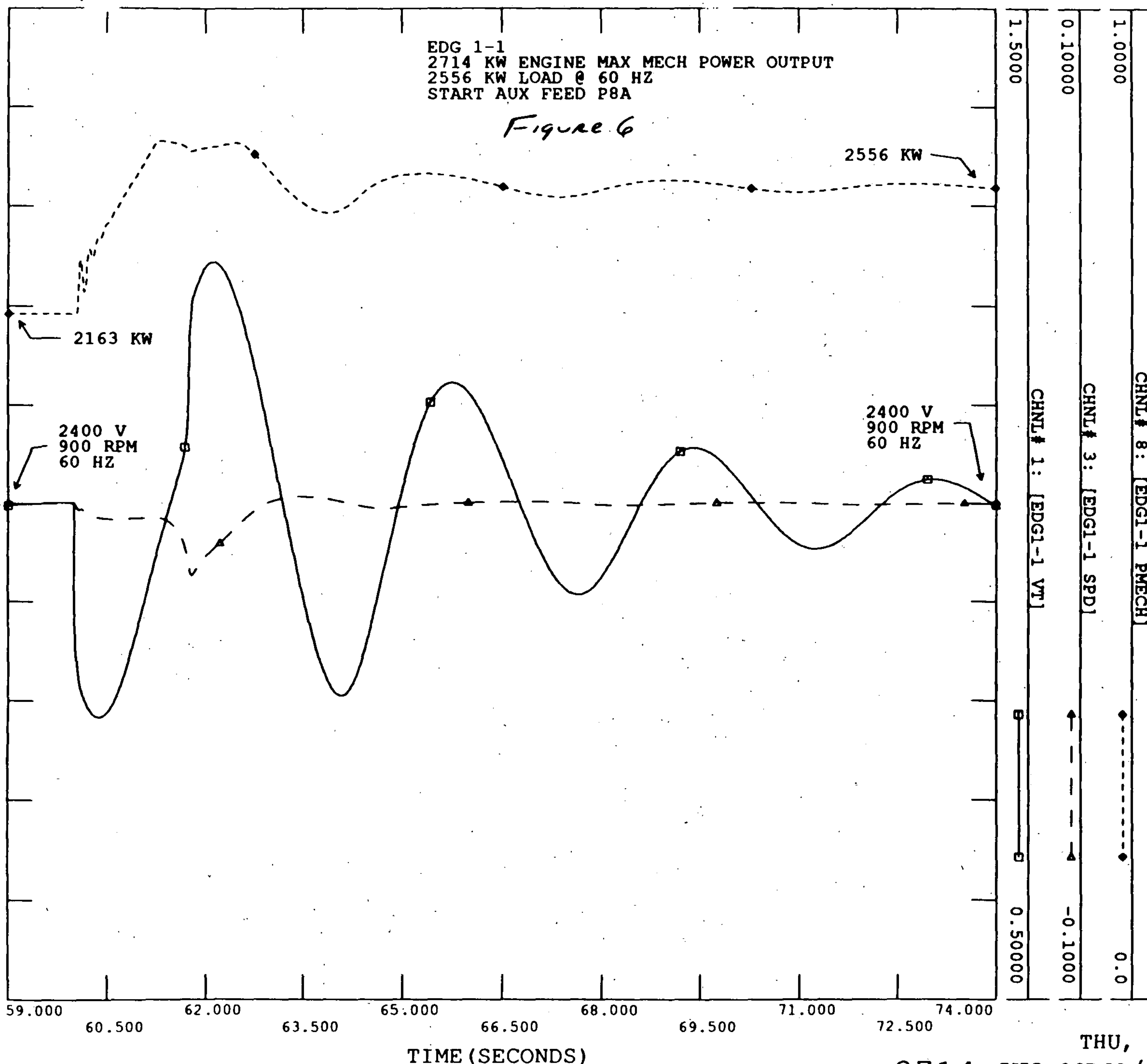

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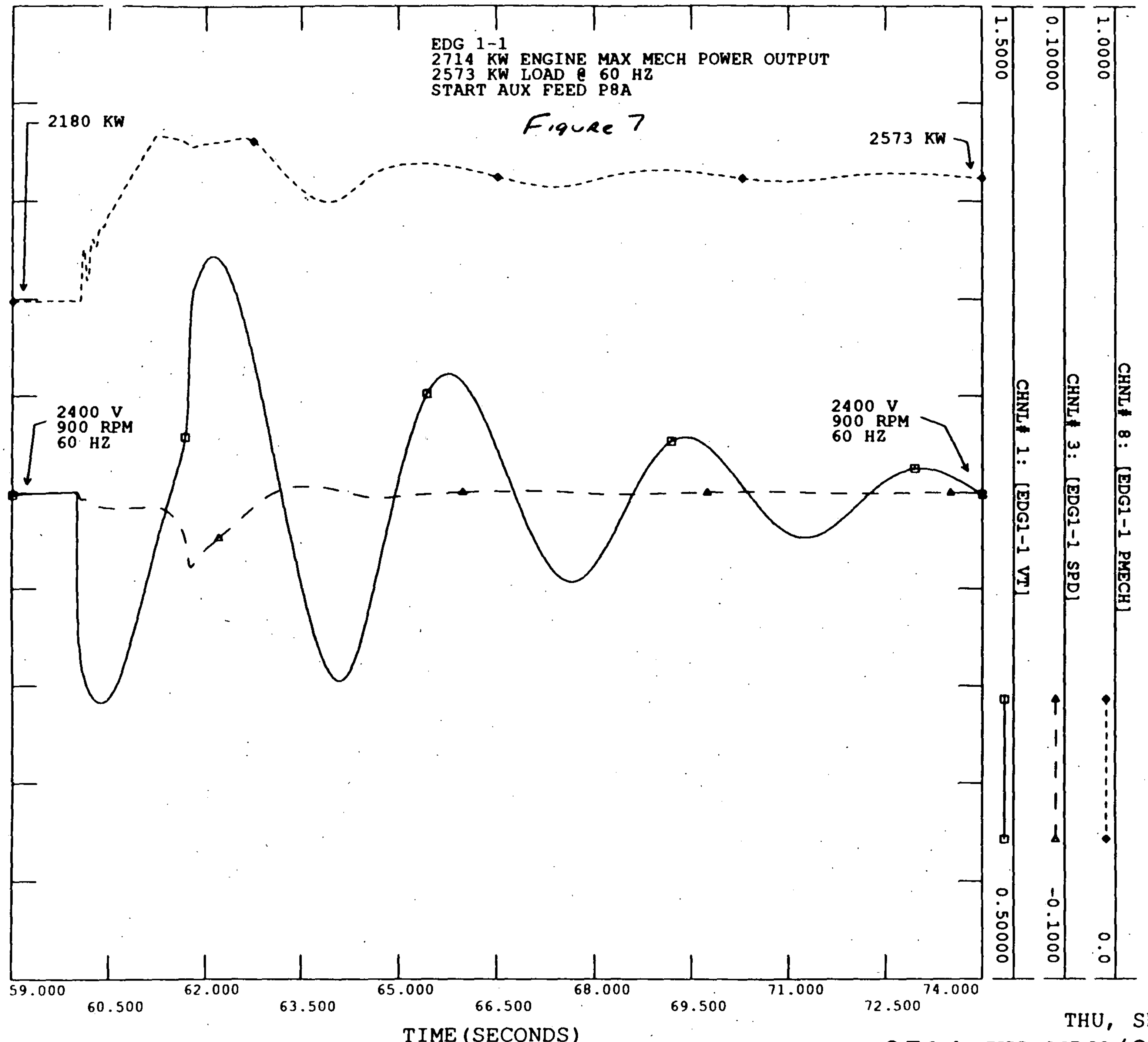
2714 KW MAX/2556 KW LOAD



EMERGENCY DIESEL GENERATOR 1-1
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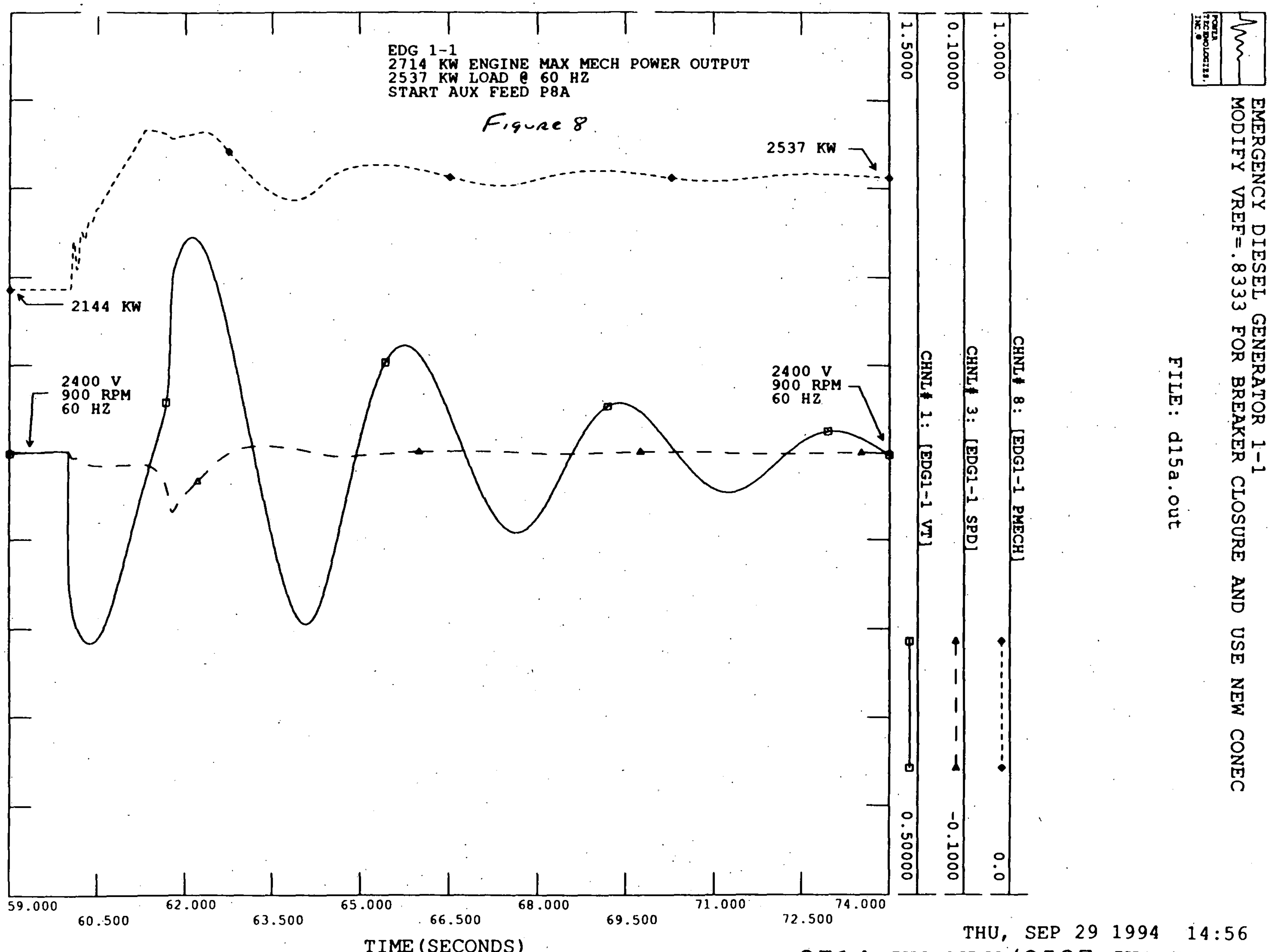

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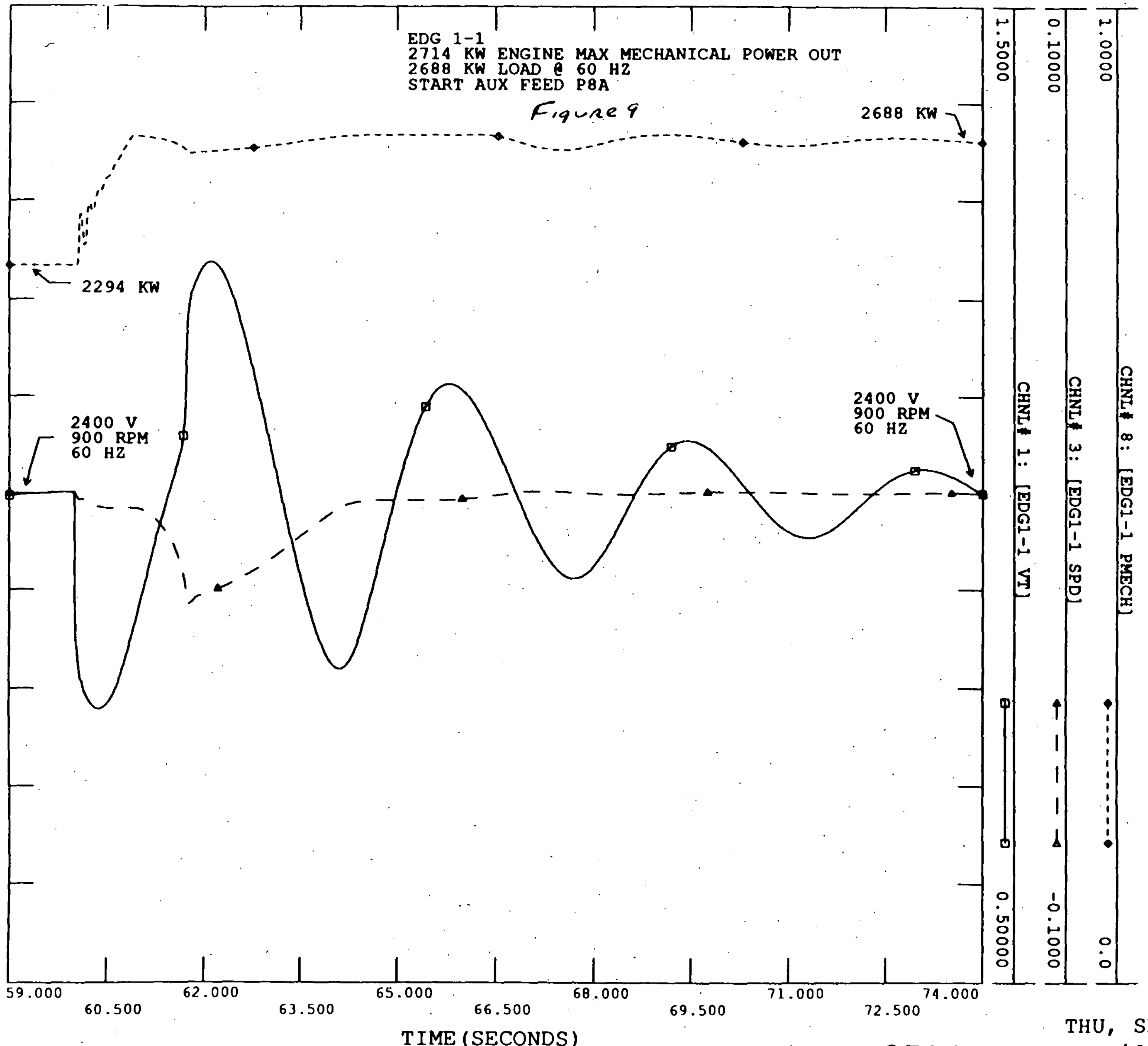

THU, SEP 29 1994 11:23

2714 KW MAX/2688 KW LOAD

ATTACHMENT A

MODELING OF EMERGENCY DIESEL GENERATORS IN AN 800 MEGAWATT NUCLEAR POWER PLANT

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Jackson, Michigan

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Power Technologies, Inc.
Schenectady, New York

Abstract - Computer models have been developed of emergency diesel generators and their associated emergency core cooling system induction motors during sequencing and results compared with field tests. Models required to perform studies of emergency diesel generators in a nuclear plant are presented. Field measurements indicating different response of two seemingly identical generator excitation systems are discussed. Results of 480 volt ac contactor dropout testing are provided for determining voltage limits in the 480 volt system during motor starting transients.

Keywords - Diesel Generators, Induction Motors.

INTRODUCTION

Design requirements of nuclear plants include backup power supplies provided by emergency diesel generators (EDGS). These generators provide the sole source of power to large emergency core cooling system (ECCS) loads during a loss-of-coolant accident (LOCA) coincident with a loss of off-site power via the utility transmission network.

Digital computer software and hardware technology make it possible for a utility to develop and maintain accurate models of these critical power supplies to assess their adequacy due to electrical modifications and load additions over the life of the plant. The models also make it possible to simulate LOCA scenarios and verify the capability of the EDGS to provide a safe and reliable source of power to critical loads during an accident.

This paper summarizes the efforts of one utility to develop and maintain computer models of the EDGS and their associated ECCS loads in an 800 megawatt nuclear power plant. The models are compared to field test data from routine testing of the EDGS following a refueling outage. Additional discussion is provided concerning voltage limits in 480 volt systems through field testing of ac contactors. Finally, differences in response of two supposedly identical EDG excitation control systems are presented.

THE NEED FOR MODELING OF EMERGENCY DIESEL GENERATOR SYSTEMS

The need for developing and maintaining accurate models of EDGS and their associated systems in nuclear power plants can be summarized as follows:

1. To verify that all ECCS induction motors will start and accelerate during a LOCA when fed from the EDGS, which are weaker power supplies than the off-site power supply via the utility transmission network.

2. To verify that ECCS motors already running and loaded to LOCA conditions will continue to operate (e.g., not slow down and possibly trip) during remaining motor starting transients.

3. To verify that 480 volt ac contactors will have adequate voltage to pickup when required and will not drop out during motor starting transients.

4. To assess whether electrical modifications and load additions to the original EDGS and associated ECCS systems will exceed diesel generator capabilities.

5. To verify that ECCS induction motor sequencing steps do not "overlap", resulting in excessive motor starting transients and potential tripping of critical loads required during a LOCA.

6. To provide simulations of the EDG and associated ECCS system loads during postulated LOCA conditions that cannot be duplicated through field tests.

92 SM 561-1 EC A paper recommended and approved by the IEEE Electric Machinery Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1992 Summer Meeting, Seattle, WA, July 12-16, 1992. Manuscript submitted October 7, 1990; made available for printing April 16, 1992.

EMERGENCY DIESEL GENERATOR SYSTEMS

Two independent EDG systems, each capable of supplying power to ECCS motors for safely shutting down the reactor following a LOCA, are provided for the 800 megawatt nuclear plant presented in this paper. The EDGS and associated ECCS induction motors used in the studies are summarized in Figures 1 and 2. Each generator is rated 2400 volts, 3.125 MVA, and uses automatic sequencers to start the ECCS induction motor loads. The table provided in each figure summarizes the starting times of the ECCS induction motor loads during field tests associated with required EDG testing as part of a recent plant refueling outage. As can be seen, ECCS motor loads such as containment spray are not started during routine EDG testing. Such loads are included, however, in the final computer simulations representative of LOCA conditions.

INDUCTION MOTOR MODELS

The electrical and mechanical characteristics of the ECCS induction motors for each EDG system summarized in Figures 1 and 2 are presented in Table I. Manufacturers' speed versus torque and current curves, as well as motor and load inertias, were available. These motor starting characteristics are critical when developing the models of the overall ECCS systems fed by the EDGS.

Figure 3 summarizes the model chosen by the authors to represent the induction motors summarized in Table I and Figures 1 and 2. It is a double-cage representation used successfully to represent deep-bar rotor effects in squirrel-cage induction motors during starting [1,2].

The model parameters were determined through trial and error by using the manufacturers' data and a software package to interactively select parameters until the model reasonably duplicated the motor torque, current and power factor during starting. Table II summarizes the equivalent circuit parameters found for the ECCS induction motors using this method. Figures 4 and 5 present a comparison of the manufacturers' data and model results for the 400 horsepower LPSI and HPSI motors. As can be seen in the figures, the double cage induction motor model duplicates the manufacturers' data quite closely. Similar results were obtained for the remaining ECCS induction motor models used in the studies.

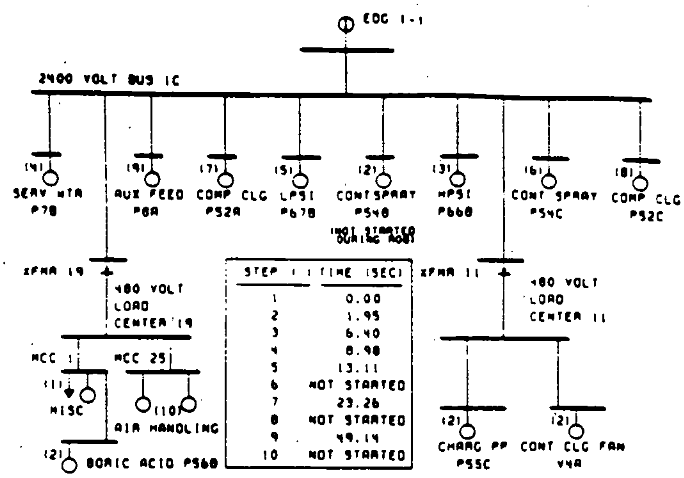


Figure 1. EDG 1-1 System

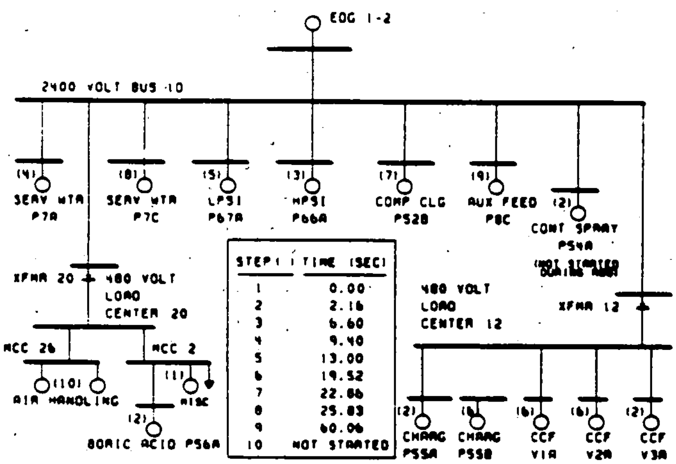


Figure 2. EDG 1-2 System

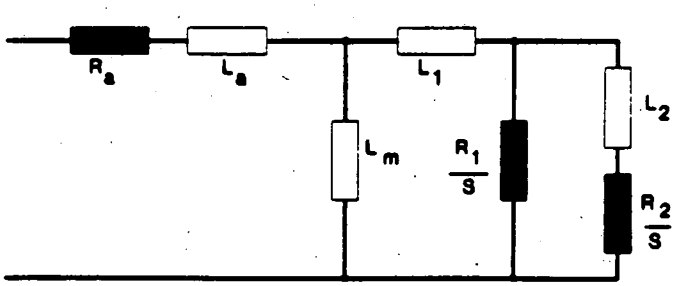


Figure 3. Double Cage Induction Motor Model

Table I
Summary of Induction Motor Characteristics

Motor	Horse power	Sync rpm	KVA	H(sec)
EDG 1-1 Misc	118	1800	118	0.5
EDG 1-2 Misc	205	1800	205	0.5
Boric Acid	30	3600	29.5	1.0
Charging Pumps	75	1800	72.4	0.256
Charging Pump P55A	100	1800	99.1	0.44
Cont Cooling	75	1800	69.3	1.16
Cont Spray	250	3600	219	1.18
HPSI	400	3600	343	1.18
LPSI	400	1800	367	0.426
Service Water	350	1200	330	0.73
Component Clg	300	1800	267	0.385
Auxiliary Feed P8A	450	3600	402	0.696
Auxiliary Feed P8C	400	3600	343	1.18
Air Handling V95, 96	25	1800	20	0.5
Air Handling V26A, B	20	1800	21	0.5

Table II
Summary of Induction Motor Double Cage Equivalent Circuit Parameters (per unit on motor base)

Motor	RA	LA	LM	R1	L1	R2	L2
EDG 1-1 Misc	0.02	0.015	2.7	0.02	0.15	0.015	0.05
EDG 1-2 Misc	0.02	0.015	2.7	0.02	0.15	0.015	0.05
Boric Acid	0.01	0.035	2.7	0.16	0.08	0.009	0.10
Charg Pumps	0.005	0.02	2.7	0.30	0.007	0.011	0.015
Charg Pp P55A	0.02	0.025	2.7	0.15	0.04	0.015	0.13
Cont Cooling	0.008	0.04	2.7	0.18	0.05	0.011	0.14
Cont Spray	0.015	0.068	3.1	0.06	0.035	0.007	0.04
HPSI	0.013	0.05	3.0	0.1	0.09	0.018	0.065
LPSI	0.015	0.055	3.0	0.065	0.09	0.02	0.12
Service Water	0.02	0.029	3.0	0.06	0.092	0.014	0.08
Component Clg	0.02	0.05	3.7	0.06	0.08	0.012	0.08
Aux Feed P8A	0.008	0.08	3.6	0.03	0.07	0.015	0.08
Aux Feed P8C	0.015	0.068	3.1	0.06	0.035	0.007	0.04
Air Hd V 95,96	0.02	0.015	2.7	0.02	0.15	0.015	0.05
Air Hd V26A,B	0.02	0.015	2.7	0.02	0.15	0.015	0.05

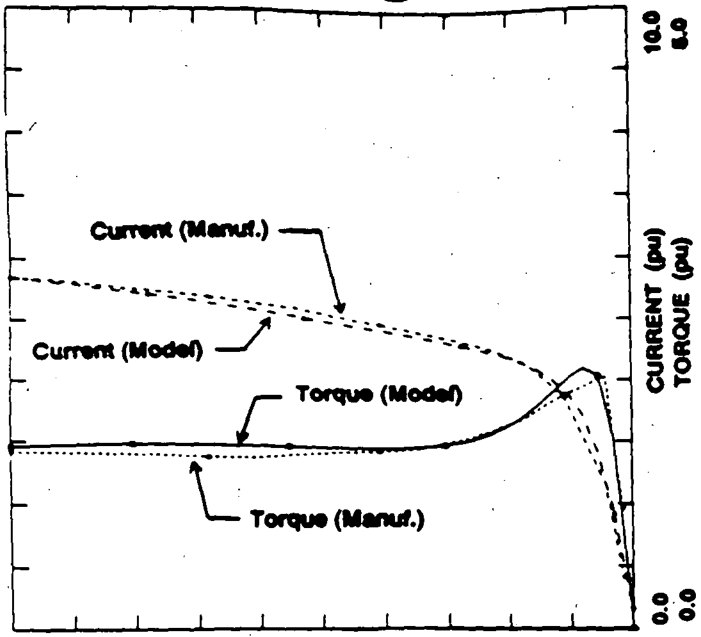


Figure 4. Manufacturer Versus Double Cage Motor Model for LPSI Motor

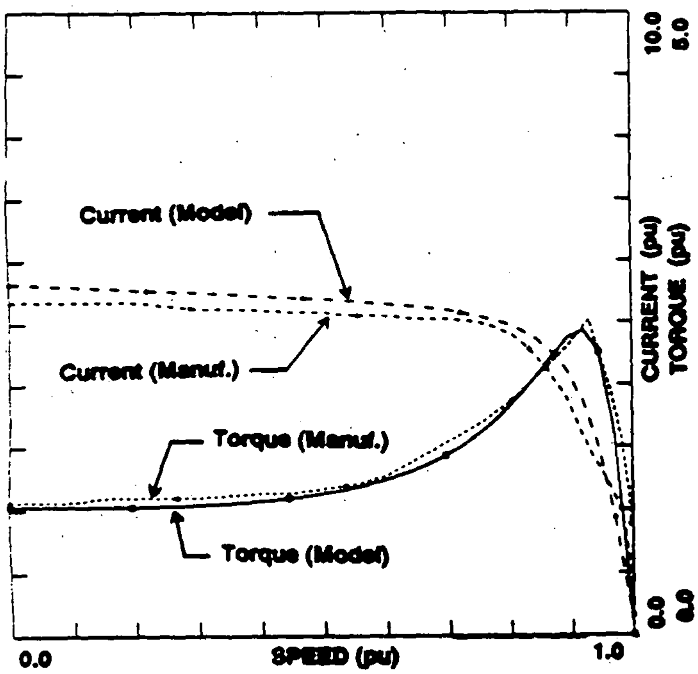


Figure 5. Manufacturer Versus Double Cage Motor Model for HPSI Motor

GENERATOR MODEL

The generators are modeled using a salient pole representation and include the effects of the amortisseur windings. Figure 6 summarizes the block diagram of the model. Generator equivalent circuit and saturation data were obtained from the manufacturer and are presented in Table III. A minor reduction of the subtransient and transient reactances provided a better fit between the model and field measurements of the motor starting transients. The reduction of these parameters may indicate additional machine saturation during the large motor starts not represented in the original machine data.

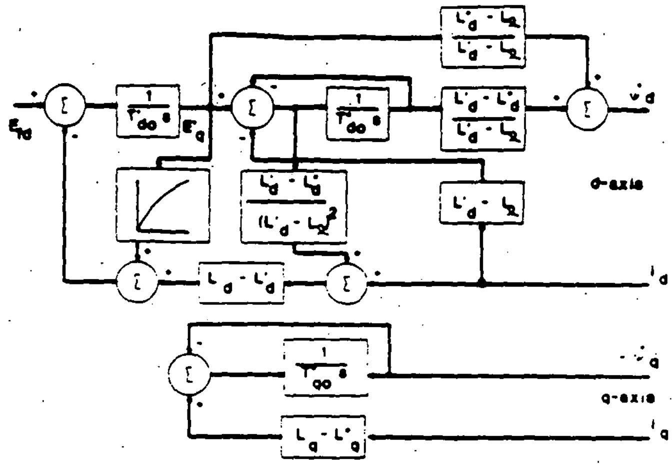


Figure 6. Electromagnetic Model of Salient Pole Generator

Table III
Summary of Generator Parameters

Inductances (per unit)	Machine Constants (sec)	Saturation Data
Ld= 1.56 Lq= 1.06	Tdo'= 3.7	S(1.0)= 0.1724
Ld'=.296 Lq"= 0.177	Tdo"= 0.05	S(1.2)= 0.6034
Ld"= 0.177	Tqo"= 0.05	
L1= 0.088	H= 1.0716	

Note: Ld" and Lq" adjusted to 0.15 and Ld' to 0.26 based on field tests. All parameters in per-unit on machine base of 3.125 MVA, 2400 volts.

EXCITATION SYSTEM MODEL

A static excitation system (similar to the IEEE type ST2 model [3]), having both generator current and voltage as inputs is used for the excitation control system for each EDG. No manufacturer's data, however, was available to develop such a model. A control system block diagram of the excitation system could have been developed by the manufacturer by removing the excitation system and performing bench tests. This option did not meet plant approval. A suitable excitation control system model, however, had to be found which would approximate the generator terminal voltage response during the motor starting transients.

Figure 7 summarizes the excitation control system chosen by the authors, one which has been used successfully by others [4]. The time constants and exciter gain were adjusted until a reasonable match was obtained between the model and field tests for generator terminal voltage response during motor starting conditions for each EDG. (The motor starting conditions provided the response of the EDG with both voltage and current feedback.) Table IV summarizes the final values used in the studies.

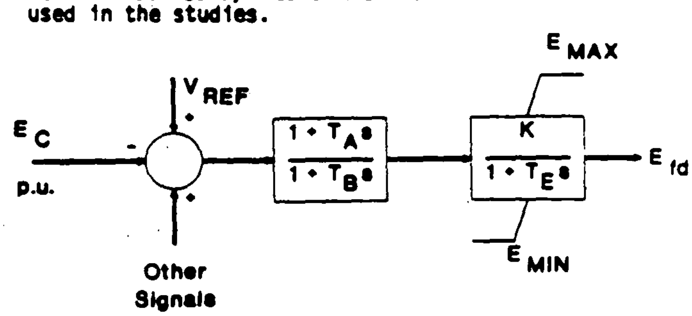


Figure 7. Excitation System Model

Table IV
Summary of Excitation System Parameters

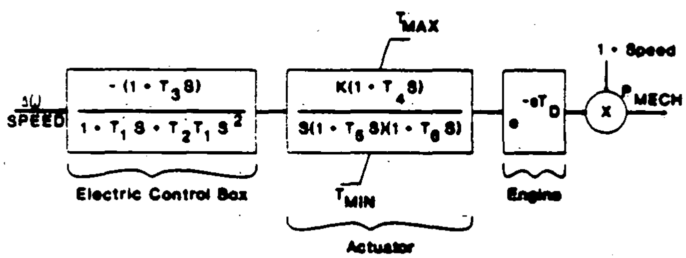
Generator	TA (sec)	TB (sec)	K	TE (sec)	EFDmax (pu)	EFDmin (pu)
EDG 1-1	3.0	6.0	77.5	2.0	6.0	0.0
EDG 1-2	3.0	6.0	77.5	1.0	6.0	0.0

Determining the time constants and gains in Figure 7 (through trial and error) to match response of the generator during motor starting was time consuming. While the model matched the motor starting transients, additional voltage oscillations were found in the model following the motor starts that were not evident in the field measurements.

It is of the authors' opinion that further investigation is needed in the area of developing field testing methods for excitation systems which use both current and voltage as feedback. Such field testing would enable the engineer to determine model parameters for a more complete and accurate excitation system representation for EDGS such as the IEEE type ST2 model. It would also avoid removal of the excitation system for bench tests which is usually unacceptable to plant operations.

GOVERNOR MODEL

The governor model chosen by the authors was also used successfully in reference [4]. Figure 8 summarizes the control system and associated parameters used in the studies. The gains and time constants used in the governor model were adjusted until a reasonable match was obtained between the model and the results from field measurements of generator speed during motor starting.



$T_1 = .01$ $K = 40$
$T_2 = .02$ $T_D = .024$
$T_3 = .2$ $T_{max} = 1.1$
$T_4 = .25$ $T_{min} = 0$
$T_5 = .009$
$T_6 = .0384$

Figure 8. Governor Model

RESULTS OF FIELD MEASUREMENTS VERSUS COMPUTER SIMULATIONS DURING MOTOR SEQUENCING

Computer simulations of the ECCS motor sequencing on each EDG, as summarized in Figures 1 and 2, were completed and compared to field measurements of EDG terminal voltage and changes in speed. Figures 9 through 12 summarize the generator terminal voltage response of EDG 1-1 while starting the HPSI, Service Water, LPSI, Component Cooling Water and Auxiliary Feedwater motors. As can be seen in the figures, the model is quite close to field test measurements during the motor starting transients and is somewhat conservative in terms of initial voltage drop and recovery time above 1.0 per-unit operating voltage. Table V summarizes the motor acceleration times measured during the field tests and from the computer simulations. Reductions in several motor inertias were required to obtain acceleration times near those measured in the field. However, the original motor manufacturer's inertia constants, which generally result in accelerating times longer than those from field tests and thus give conservative results, are used in the final studies for each EDG when representing LOCA conditions.

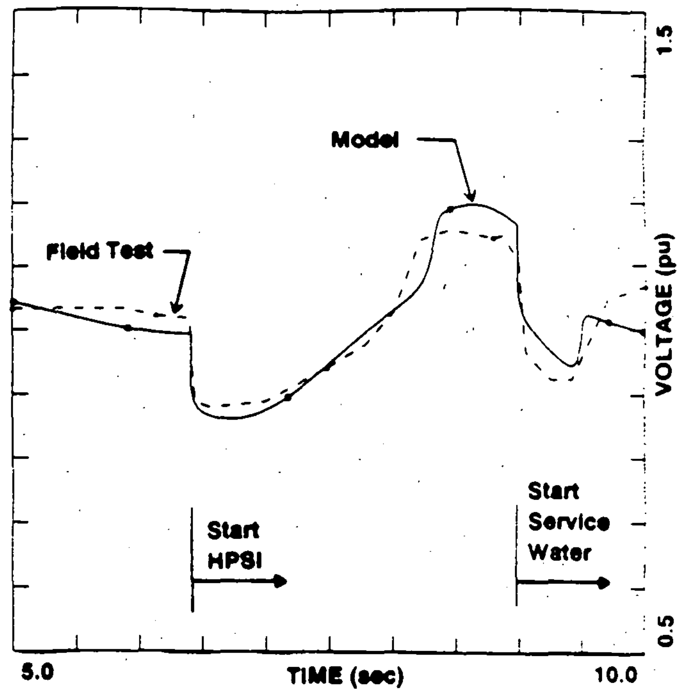


Figure 9. EDG 1-1 Terminal Voltage Response During HPSI and Service Water Motor Startup

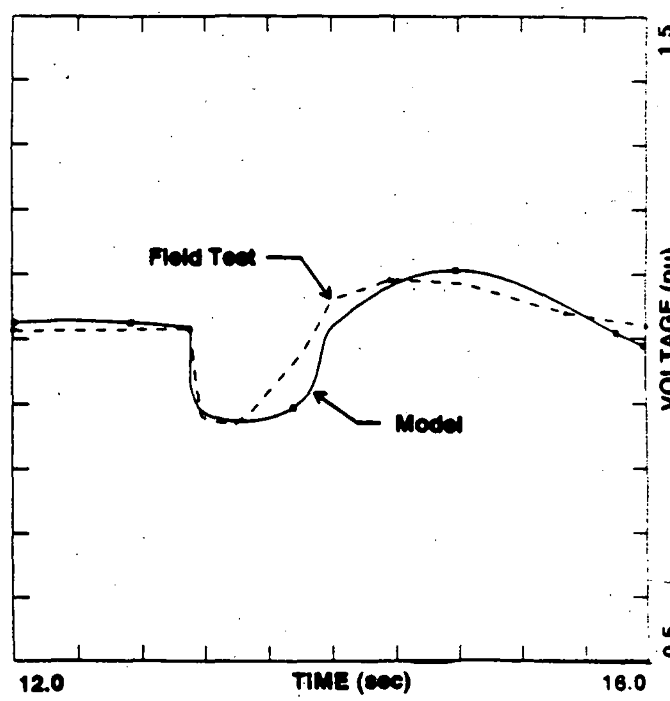


Figure 10. EDG 1-1 Terminal Voltage Response During LPSI Motor Startup

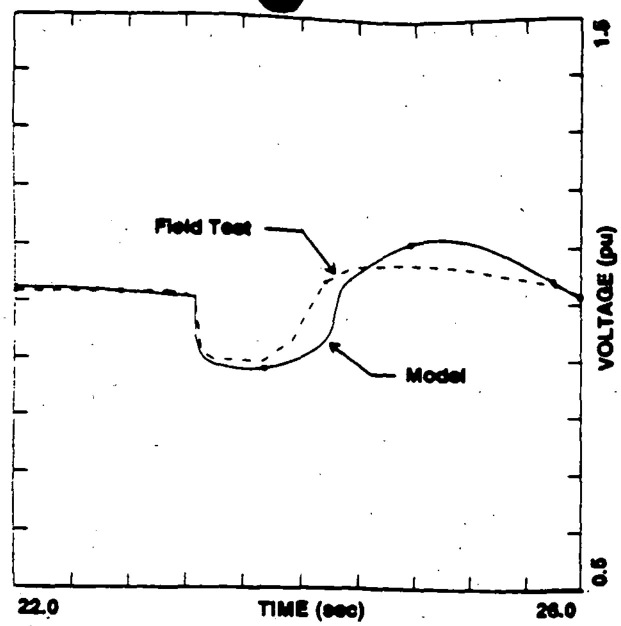


Figure 11. EDG 1-1 Terminal Voltage Response During CCW Motor Startup

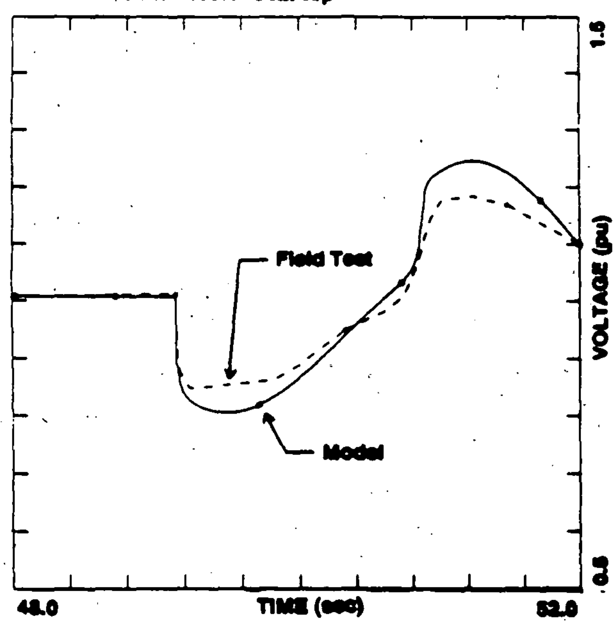


Figure 12. EDG 1-1 Terminal Voltage Response During Auxiliary Feedwater Motor Startup

Figures 13 through 15 summarize the speed fluctuations found in the actual field measurements and through computer simulations during the starting of the LPSI, Component Cooling Water, and Auxiliary Feedwater Pumps on EDG 1-1. As can be seen in these figures, the computer model matches the field measurements reasonably well and is slightly conservative. The speed fluctuations are very minimal (less than 1 percent) indicating the EDG governor essentially maintains system base frequency during the motor starting transients.

Figures 16 and 17 summarize the generator terminal voltage response of EDG 1-2 while starting the HPSI, Service Water, and Auxiliary Feedwater pumps. As can be seen in the Figures, the model is quite close to field test measurements during the motor starting transients and, similar to EDG 1-1, is somewhat conservative in terms of initial voltage drop and recovery time above 1 per-unit operating voltage. Table V summarizes the motor acceleration times measured during the field tests versus the simulations.

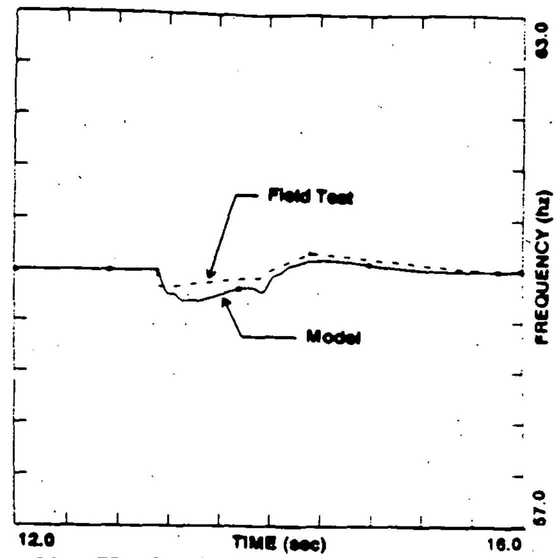


Figure 13. EDG 1-1 Speed Fluctuations During LPSI Motor Startup

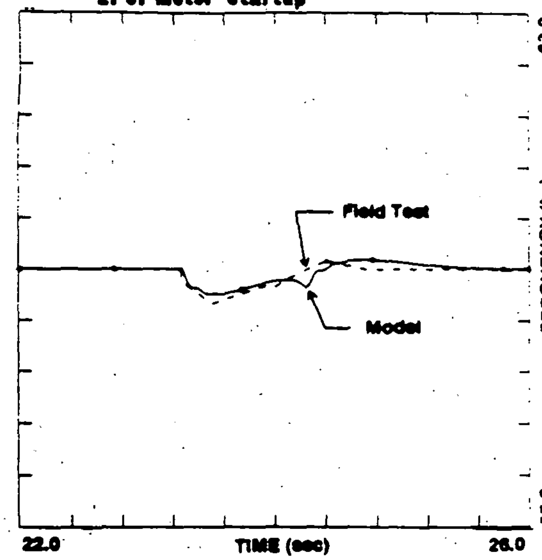


Figure 14. EDG 1-1 Speed Fluctuations During CCW Motor Startup

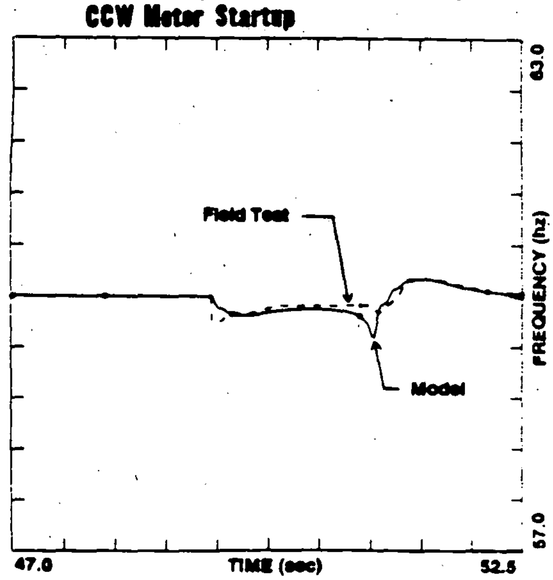


Figure 15. EDG 1-1 Speed Fluctuations During Auxiliary Feedwater Motor Startup

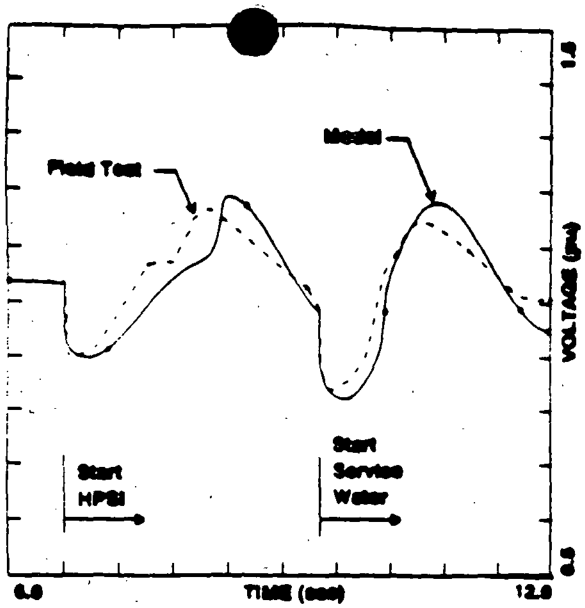


Figure 16. EDG 1-2 Terminal Voltage Response During HPSI and Service Water Motor Startup

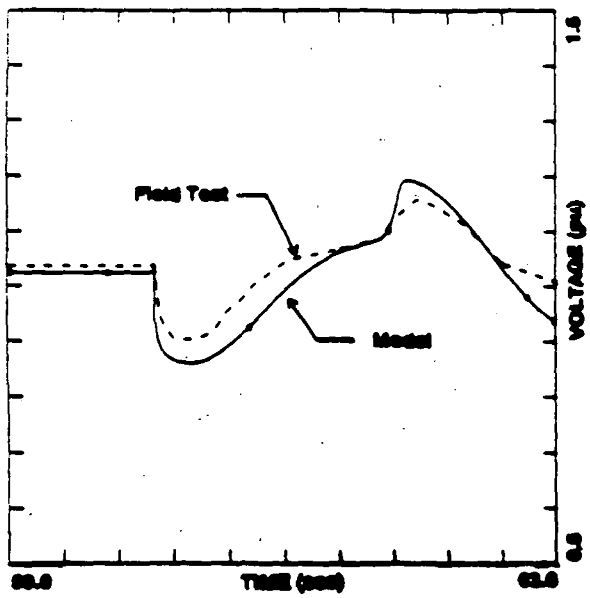


Figure 17. EDG 1-2 Terminal Voltage Response During Auxiliary Feedwater Motor Startup

Table V
Summary of Motor Acceleration Times During Sequencing

Motor	Inertia H (sec) original	Inertia H (sec) revised	Acceleration time (sec) field	Acceleration time (sec) model
HPSI P66B	1.18	[illegible]	1.77	[illegible]
Serv Water P7B	0.73	0.313	0.4	0.53
LPSI P67B	0.426	[illegible]	[illegible]	[illegible]
Comp Clg P52A	[illegible]	0.417	[illegible]	[illegible]
Aux Feed [illegible]	no change		1.7	1.73
HPSI P66A	1.18	[illegible]	1.4	1.73
Serv Wtr P7A	0.73	0.313	0.7	0.73
Comp Clg P52B	[illegible]	0.417	0.4	0.67
Serv Wtr P7C	0.73	0.313	0.7	[illegible]
Aux Feed [illegible]	1.18	[illegible]	1.8	1.77

EXCITATION SYSTEM RESPONSE

The excitation systems used by the two EDGS are identical in vintage, size and field settings. No changes have been made since original installation. Field testing revealed, however, a much slower generator terminal voltage response on EDG 1-1 than EDG 1-2 when starting similar induction motor loads. This difference in response can be seen by examining Figures 18 and 19, which compare field measurements of terminal voltage of each EDG when starting the 400 hp HPSI and 400 hp LPSI motors. No explanation could be found as to why the responses were different. Field adjustments of the voltage regulator on EDG 1-1 did not improve the response. This is offered as a caution to others who may assume the response of the excitation systems on identical EDGs is the same after testing only one EDG. The excitation system on each EDG must be tested for response to determine its characteristics for performing motor starting studies.

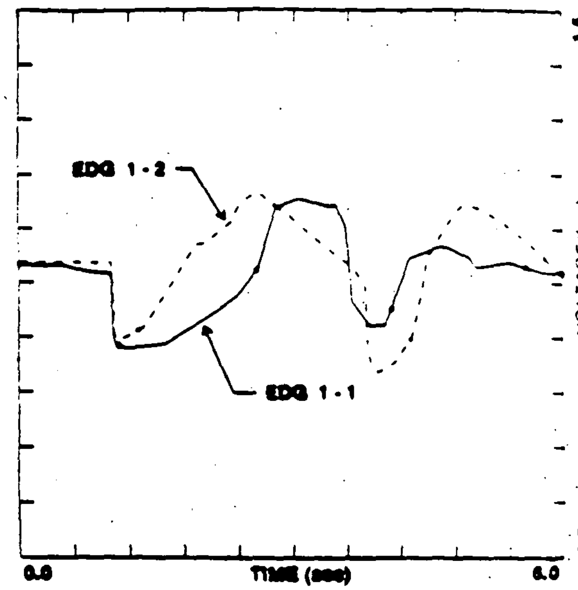


Figure 18. EDG 1-1 Versus EDG 1-2 Terminal Voltage Responses During HPSI Motor Startup

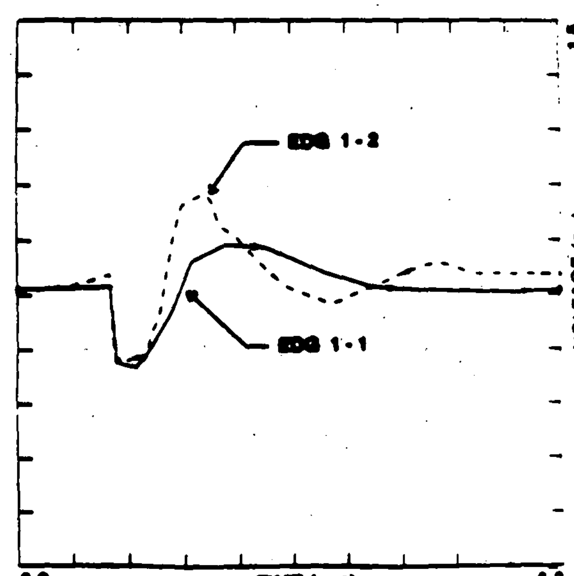


Figure 19. EDG 1-1 Versus EDG 1-2 Terminal Voltage Response During LPSI Motor Startup

LIMITS IMPOSED BY 480 VOLT SYSTEMS

In order to determine limits imposed by the 480 volt systems, field testing of ac contactors was performed to determine pickup and dropout voltages. Table VI summarizes the results of field tests performed on all contactors fed by 480 volt Motor Control Centers 1 and 2. As can be seen in the Table, the highest ac contactor dropout voltage was 0.625 per unit (480 volt base).

Table VI
Results of ac Contactor Field Tests on 480 Volt Motor Control Centers 1 and 2

Contactor Size	Minimum Pickup Volts (per unit)	Maximum Dropout Volts (per unit)
1	.725	.425
1	.692	.375
1	.692	.400
1	.692	.367
1	.692	.400
1	.692	.450
1	.725	.383
1	.725	.367
1	.708	.383
1	.708	.383
1	.650	.358
1	.717	.358
1	.700	.358
2	.808	.567
2	.733	.625
2	.775	.567
2	.725	.525
3	.750	.525
3	.675	.508

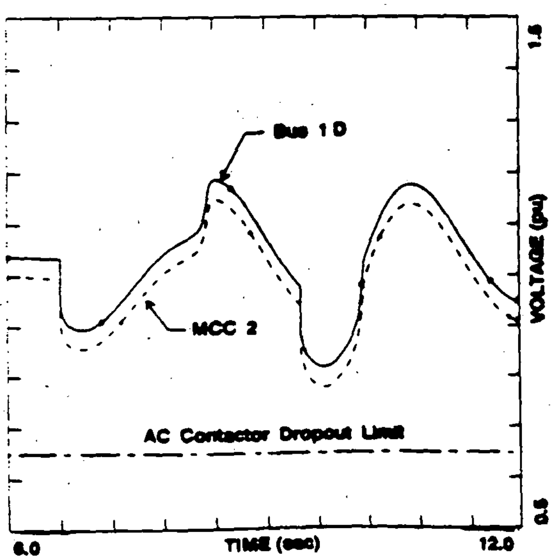


Figure 20. 480 Volt Minimum Voltage Versus AC Contactor Dropout Voltage

Based on these results, an ac contactor dropout voltage of 0.65 per unit (for conservatism) was assumed as the limit in the studies. Figure 20 summarizes the lowest voltage transient seen by 480 volt motor control center 2 fed by EDG 1-2 during the starting of the HPSI and Service Water Motors. As can be seen in the figure, the minimum voltage is 0.78 per unit, which is well above the contactor dropout limit of 0.65 per unit.

CONCLUSIONS

Models of EDGS and their ECCS induction motor loads during sequencing have been developed for an 800 megawatt nuclear plant. The models were developed using digital computer software and hardware. Field tests and corresponding simulations using the models indicate a close correlation during motor sequencing. Additional testing of ac contactors in 480 volt systems to establish contactor pickup and dropout voltages have been presented to provide limits when performing EDG sequencing studies.

Field tests have been presented which indicate the response on two seemingly identical EDG excitation systems can be different. To avoid potential problems, separate field testing is recommended when developing models of multiple EDGS.

Additional work is needed in the area of excitation control system field testing for systems employing both generator terminal voltage and current feedback. Such testing methods could be used to develop more accurate control system models representative of static excitation systems.

REFERENCES

[1] B.J. Chalmers, A.S. Mulki, "Design Synthesis Double-Cage Induction Motors," Proc IEE, Vol. 117, No. 7, July 1970.

[2] S.S. Waters, R.D. Willoughby, "Modeling Induction Motors for System Studies," IEEE Transactions on Industry Applications, Vol. IA-19, No. 5, September/October, 1983.

[3] IEEE Committee Report, "Excitation System Models for Power System Stability Studies," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 2, February 1981.

[4] L.N. Hannett, F.P. de Mello, G.H. Tylinski, W.H. Becker, "Validation of Nuclear Plant Auxiliary Power Supply by Test," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No. 9, September, 1982.

BIOGRAPHIES

Kenneth E. Yeager received the BSEE from Michigan Technological University in 1976. He was employed by Goodyear Atomic Corporation, Piketon, Ohio from 1976 to 1978. He then joined Consumers Power Company and is currently responsible for the design and analysis of nuclear and fossil power plant auxiliary systems. Mr. Yeager is a member of IEEE and Registered Professional Engineer in the State of Michigan.

Johnny R. Willis received the B.S.E. and M.S.E degrees from the University of Alabama in Birmingham in 1972 and 1978, and E.E. degree from the University of Michigan in 1985. He was employed by Rust Engineering, Birmingham, AL from 1974 to 1979 and Consumers Power Company from 1982 to 1987. He then joined Power Technologies, Inc. as a Senior Engineer where he conducts studies related to power system dynamics. Mr. Willis is a member of IEEE and a Registered Professional Engineer in Alabama and New York.

Discussion

W. G. Bloethe, N. I. Deeb and **S. S. Shah** (Sargent & Lundy, Chicago, IL): The authors are to be congratulated on their timely paper. While the NRC has not yet taken an official position on the subject, the question of the dynamic performance of the emergency diesel generators has been raised during some Electrical Distribution System Functional Inspections (EDSFI's). Therefore, other stations may be required to perform an analysis similar to that described in the paper.

We would appreciate the authors' comments on the following concerns which arise from our experience in performing such studies:

1. The authors state that their induction motor models are based on the manufacturer's data. However, a recent paper[1] indicates that the performance of the motors in the field can be considerably different from that indicated by the manufacturer's data. Could the authors comment on the significance of comparing the actual performance of the motors with the manufacturer's data used in the modeling? The authors also indicate that the effective moment of inertia for the motors differ from the values given by the manufacturers. We agree with the authors' use of the more conservative values given by the manufacturers. Nevertheless, we would be interested in any comments that the authors may have on what might cause the manufacturers' moments of inertia to vary from the values observed in the field tests.
2. The authors also stated that the induction machine parameters were selected so that the model reasonably duplicates the motor torque, current, and power factor during starting. However, the authors indicated previously that only the manufacturers' speed versus torque and speed versus current curves as well as the motor and load moment of inertia were available for the study. The results of the motor modeling shown in Figures 4 and 5 for the LPSI and HPSI pump motors show the speed versus torque and speed versus current characteristics only. Our own experience in induction motor modeling has shown the difficulty of matching all three characteristics of a motor, i.e., speed versus torque, speed versus current, and speed versus power factor. The authors did not reflect the speed versus power factor characteristics of their motor models in their paper. We would appreciate the authors comments on the significance of matching the motor speed versus power factor characteristics. If speed versus power factor information is available, can the authors provide a comparison of the speed versus power factor characteristics of the LPSI and HPSI pump motor models with the actual motor characteristics?
3. Numerical techniques have been used to assist in the matching of the motor model parameters to the motor characteristics. Have the authors used any such techniques to reduce the amount of trial and error required to model an induction motor?
4. The authors state that the generator excitation system used both a potential and a current power supply. Could the authors provide additional information on the excitation systems? We have successfully used the IEEE type ST2 (former type 3) model for representing the excitation system of an emergency diesel generator with both potential and current power supplies. The effect of the current power supply is most important during the initial recovery from the voltage dip. This may explain why the initial recovery given by the authors' model tends to be slower than that shown in the test data. The addition of the current power supply to the model may allow the voltage regulator loop of the excitation system model to be revised to reduce or eliminate the oscillatory behavior during the latter part of the recovery described by the authors.
5. We agree with the authors that additional work is needed in modeling and determining the model parameters for emergency diesel generator excitation systems. In addition, we feel that there is room for improving the modeling of governor systems for the same reasons given by the authors. Also, when we have had modeling information from the governor manufacturer, the form of the model did not match the standard models given by the IEEE committee.
6. Obtaining adequate test data in a power plant environment is not a simple task. Could the authors describe their testing program and the methods used to acquire the test data? What techniques were used to minimize the effects of noise during data collection?

[1] Hassan, I. D.; Weronick, R.; Bucci, R. M.; and Busch, W. "Evaluating the Transient Performance of Standby Diesel-Generator Units by Simulation." *IEEE Transactions on Energy Conversion*, September, 1992, Vol. 7, No. 3, pp. 470–477.

Manuscript received August 7, 1992.

I. D. Hassan, R. Weronick, and R. M. Bucci (Ebasco Services Incorporated, New York, New York): The authors present a dynamic simulation which appears to correlate with field tests. However, some additional information would be helpful to us and, we believe, other interested readers, to compare the authors' approach with the approach described in [1].

Could the authors comment on the type of software that was used and its accessibility to nuclear utilities? Has the software been verified in accordance with nuclear quality assurance standards?

In [1] it is stated that the EMTP program was used for the diesel generator simulations, and the appropriate modules were verified for nuclear applications. The EMTP program has wide availability and accessibility to potential users (various versions are available through EPRI and EMTP user groups). Also, the user can model virtually any electromechanical device represented in a transfer function form by use of the appropriate EMTP modules. We have found that commercially marketed dynamic programs of the kind typically used for transient stability analysis generally have fixed control system models. These require recompiling (which may require the intervention of the software developer) to develop customized control system arrangements that closely match the performance of in service voltage regulators and engine governors. Could the authors comment on the relative ease in applying their software to develop customized models?

Also, it would be helpful if the simulated EDGs' terminal voltage response during the load application in Step 2 is included in the paper.

[1] I.D. Hassan, R. Weronick, R.M. Bucci and W. Busch. "Evaluating the Transient Performance of Standby Diesel-Generator Units by Simulation", IEEE Paper 92 WM 078-6 EC.

Manuscript received August 14, 1992.

K.E. Yeager, J.R. Willis: The authors appreciate the efforts and comments of the discussers. We feel that by sharing experiences in this area, all contributors can benefit. We first address the points raised by Messrs. Bloethe, Deeb and Shah:

1) Although the manufacturer's data has been used to develop the motor models, experiences with motor starting studies at other plants have indicated that manufacturer data is usually accurate in terms of locked rotor current and power factor. Actual acceleration times, however, are more difficult to match, indicating inaccuracies in (1) the manufacturer's motor speed-torque characteristics, (2) motor and/or pump inertias, or (3) the pump speed-torque characteristics (flow configurations due to valving of piping systems during testing).

It may improve motor modeling accuracy to record actual motor performance when started from the normal power supply. This would provide data which could be compared to motor starting simulations of each individual motor and would guide adjustments of the motor model prior to using it in diesel sequencing studies. Unfortunately, performing additional individual induction motor starting tests and measurements in an operating nuclear plant can be a formidable task. In addition, setting up pump conditions which represent actual LOCA flow conditions during motor starting may not be possible.

The authors chose to limit the testing configurations, measurements, and engineering analysis to sequencing conditions via the emergency diesel generators and used the results to adjust the motor inertias to match motor acceleration times. It is believed that the changes to the Plant system due to various valving configurations, etc., affected the acceleration times of the motors during testing (the motors were started unloaded or at some other pump condition). Adjustments in the inertias were made instead of pump speed-torque characteristics only as a matter of choice. Use of worst case inertias and pump speed-torque conditions during LOCA sequencing studies assures conservative results.

2) Locked rotor power factors were available from the manufacturer for a few of the motors. If not, a value of .25 was assumed. During the development of the motor models, adjustments in the motor stator equivalent circuit parameters were made for each motor until a relatively accurate match was obtained between the given or assumed (.25) locked rotor power factor. Once the locked rotor power factor was matched, the general shape of the speed - power factor curve was dependent on the equivalent circuit of the motor and its response during starting. The authors experience indicates that this technique will provide an adequate model of motor power factor for motor starting studies.

3) The authors have noted technical publications for applying numerical method to aid to matching induction motor characteristics, and have contributed to this effort [A]. For this study, however, trial and error techniques were used.

4) The authors plan to improve the excitation system model using an IEEE type ST2 (former type 3).

5) No comment.

6 Due to long data gathering time (approximately 1 minute) oscillographs have provided a dependable source of acquiring test data during diesel sequencing and have been used as a backup to digital recording instruments. We have had problems with noise on several digital recorders. However, PTI has been successful using its PC-based Dynamic System Monitor for recording transient data for the main generator at power plants for later use in model derivation. This instrument should also be applicable to diesel sequencing measurements as well.

Next we address the points raised by Messrs. Hassan, Weronick and Bucci.

The software used for the study was the PSS/E program, which is commercially available to nuclear utilities. For several studies, the software with accompanying model data has been verified with nuclear quality assurance procedures by comparison of simulated response versus field measurements, as was the case in the discussers' referenced work.

With regard to developing customized dynamic models for the PSS/E program, the software design requires the user to develop computer code which can be linked into the main program. While this is more involved and requires a higher level of program familiarity of the user than model building from transfer functions, it is also more flexible. Each method has its strengths and weaknesses.

The simulated terminal voltage response of the EDGs during Step 2 load application is shown in Figure 21.

[A] B.K. Johnson, J.R. Willis, "Tailoring Induction Motor Analytical Models to Fit Known Motor Performance Characteristics and Satisfy Particular Study Needs," IEEE Transactions on Power Systems, Vol. 6, No. 3, August 1991, pp. 959-965.

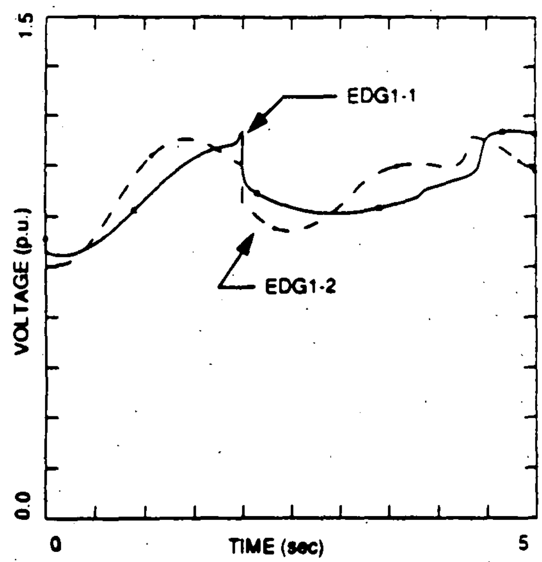


Figure 21. Step 2 Diesel Generator Voltages.

Manuscript received September 22, 1992.

ATTACHMENT 5

Consumers Power Company
Palisades Plant
Docket 50-255

QUALITATIVE EVALUATION
SAFETY SIGNIFICANCE OF REDUCED PUMP FLOW

NOVEMBER 22, 1994

4 Pages

QUALITATIVE EVALUATION
SAFETY SIGNIFICANCE OF REDUCED PUMP FLOW

A peak D/G load of 2573 KW is automatically sequenced onto the D/G following a DBA LOCA. An evaluation by KEYeager has shown that D/G 1-1 would not have been able to support the operation of these sequenced equipment at normal motor speeds of 60 hertz between July 1994 and September 1994. Had this automatic sequencing been required during the time in question it would have resulted in a 4% reduction in pump and fan speeds for the D/G loads over the first 30 minutes of the event. This speed reduction would have increased to 9% between 30 and 32 minutes when D/G loading is increased to 2688KW due to the addition of several manual loads. After 32 minutes the D/G loading is reduced and normal pump operation would have been restored for the duration of the event.

Based on the pump affinity law, a pumps' flow will vary one for one with its' speed. Therefore any percentage reduction in pump speed will equate to a similar reduction in flow. A fan will behave in a similar manner.

The DBA sequenced loads that would have operated with a reduction in flow had EDG 1-1 been required for a DBA event prior to August 1994 are :

P-54B & P-54C	CONTAINMENT SPRAY PUMPS
P-55C*	CHARGING PUMP
P-56B*	BORIC ACID PUMP
P-66B	HPSI PUMP
V-4A**	CONTAINMENT AIR COOLER FAN
P-7B	SERVICE WATER PUMP
P-67B	LPSI PUMP
P-52A & P-52C	COMPONENT COOLING WATER PUMPS
P-8A	AUX FEEDWATER PUMP
V-95***	CONTROL ROOM VENTILATION FAN

* The Charging and Boric Acid pumps do not provide any mitigating effects in the first 32 minutes of the DBA LOCA event.

** The containment air cooler associated with this fan is not required to operate for any safety related purpose and cooling water is automatically isolated from the cooler on an SIS.

*** The control room ventilation fan maintains a positive pressure in the control room envelope and following an accident helps reduce iodine isotopes entering the C.R. by drawing entering air through charcoal filters. A reduction in the speed of V-95 would have a positive effect on its required function following and accident. One of the main sources of iodine to the control room is unfiltered air inleakage through the isolation dampers. Reducing the fan speed will reduce the pressure drop across these dampers thus reducing the amount of unfiltered air that enters the control room.

The limiting Chapter 14 events that would have been impacted by the reduced equipment speeds are the LOCA fuel analysis, and the LOCA containment analysis. These are the only events that would require the D/G to support the maximum expected DBA loads, and they have the least amount of margin to peak clad temperature, containment pressure, and containment temperature safety limits. Equipment operating during other Chapter 14 events, where the load may have exceeded 2438 KW, would have experienced similar but less severe reductions in speed. Since all other events have less restrictive load profiles and more margin available to safety limits, the consequences of reduced pump and fan speeds will be bounded by the evaluation of their impact on the LBLOCA analyses.

The following discussion summarizes the results of the present analyses and the safety limits that need to be protected. It also provides a discussion of the conservatisms in the analyses that would serve to mitigate any detrimental effects of reduced flows, and a qualitative evaluation of their impact. The 9% flow reduction between 30 and 32 minutes will have little or no impact on this evaluation due to its short duration and the fact that peak temperatures and pressures occur much earlier in the event.

LBLOCA FUEL ANALYSIS

EMF-91-177 Supplement 1, calculated a Peak Clad Temperature (PCT) of 2095 °F. This PCT occured 63.53 seconds after the initiation of the LBLOCA. The Standard Review Plan (SRP) safety limit is 2200 °F.

There are several conservatisms associated with this analysis that could have mitigated any increase in PCT. PCT is driven by three major factors, the blowdown rate of the PCS, the magnitude and duration of Safety Injection Tank (SIT) flow rate, and the magnitude and timing of LPSI pump flow. The PCS blowdown rate has the greatest impact on PCT, therefore the LBLOCA Fuel analysis minimizes containment pressure to maximize the blowdown of the primary system. The analysis accomplishes this by assuming that all containment heat removal equipment is operating at time zero of the accident. The reduced speed scenario being evaluated here is only a credible event when EDG 1-2 is not available, which would reduce the available containment heat removal equipment for the reduced speed scenario by more than 50% from what was assumed in the LBLOCA analysis. Additionally it would cause a slight reduction in the capability of the equipment that is available. This would result in a PCT lower than the 2095 value calculated in EMF-91-177. The PCT analysis did conservatively use a LPSI & HPSI pump allignment representative of the failure of a D/G, so the injection pump flow paths used in the analysis are consistent with the expected available flow paths associated with the reduced speed scenario being evaluated.

The predicted PCT occurs at 63.53 seconds, just prior to the SITs emptying at 63.7 seconds. A reduction in LPSI and HPSI flows will not be significant since the flow from the SITs' is more than adequate to keep the downcomer full and PCT is reached prior to the end of SIT flow. After PCT occurs the LPSI pumps will be pumping against a depressurized system and only need to remove decay heat. Special test T-339 verified that the measured LPSI flow capability was significantly higher than that assumed in the analysis, especially at lower system pressures.

There is also conservatism built into the other pump flows used in the analysis (HPSI, AFW, and Cont. spray). These flows were all calculated using a degraded pump head flow curve. The degradation was based on pump performance at the required action range for the quarterly ISI tech spec surveilence test. The analysis flow rates also accounted for the maximum allowable instrument uncertainty in the measurement loop used for the ISI test. Additionally the HPSI and AFW pump flows have very little impact on the results of the analysis, and SW and CCW pumps are not included in the analysis for this event.

A 4% reduction in flow applied to the LPSI pump performance used in the present analysis may have caused the PCT to exceed 2095 °F by delaying the time to PCT beyond the SIT injection phase; however, the PCT would not have approached the SRP linit of 2200°F. This assesment is supported by an evaluation of the impact of reduced LPSI flow performed by our fuel vendor in

1986. The evaluation was done for the analysis of record at the time and concluded that a 30% reduction in LPSI flow only increased the PCT by 10 degrees. This general trend can be applied to the present LBLOCA analysis and further supports the argument that a 4% decrease in flow would not cause a considerable increase in PCT, and would not eliminate the entire 105 degrees of margin between the calculated value of 2095 and the limit of 2200.

Considering the discussion above and the inherent conservatisms in the Siemens Power Corporation LBLOCA methodology the safety significance of reduced flows for the LBLOCA fuel analysis would have been minimal.

LOCA CONTAINMENT

The calculated peak pressure for the LOCA containment analysis is 53.46 psig, the SRP limit is 55 psig. The rapid blowdown of the PCS for this event results in mass and energy releases to containment ending just prior to the calculated containment building peak pressure at 13.5 seconds. It is the termination of the energy input along with the heat removal capability of the passive heat sinks that maintain the peak pressure below its design limit. Since this is prior to any loads being sequenced on the D/G a reduction in pump or fan speed will not have any impact on the calculated peak pressure.

The SRP also requires the pressure at 24 hrs to be reduced to 27.5 psig,(less than half the design pressure). The Analysis calculates the pressure at 24 hours to be 12.9 psig. The event will be under control by the time 24 hrs is reached. The pumps will have been returned to normal speed for over 23 hours. The reduction in speeds for the first 32 minutes would result in slightly higher Containment atmosphere temperatures than predicted by the analysis. The higher temperatures will tend to cause the heat removal equipment to operate more efficiently, and by 24 hours should have brought the containment temperature and pressure back to the values predicted by the analysis.

The temperature profile also must stay below the allowable EEQ envelope determined in A-PAL-93-074. As discussed above a 4% reduction in the Containment Cooling flow rates assumed in the present LOCA analysis would cause the temperature profile to increase slightly in the first 32 minutes. This increase is expected to be less than 5°F, which is the minimum margin between the EEQ profile and the calculated profile. This minimum margin occurs between 3 hours and 24 hours. As discussed above the temperature profile for a reduced speed scenario will begin to migrate back toward the predicted analysis profile after the pump flows are returned to normal at 32 minutes. Even if the atmosphere did exceed the EEQ envelope by a few degrees it would not result in any equipment failure.

There are several conservatisms in the analysis that would very likely keep the temperature profile below the EEQ limit. The pump flows used in the analysis (LPSI, HPSI, SW, CCW, Cont. spray) have the same conservatisms as discussed in the LBLOCA fuel evaluation above. The water source for the containment sprays is an outdoor tank vented to the atmosphere with a normal capacity of 250,000 gallons of water. This tank was conservatively assumed to be at an equilibrium temperature of 100 F.

The Service Water system is the ultimate heat sink at Palisades. It takes suction from Lake Michigan. The Service Water was assumed to be a constant 85 F throughout the analysis. Historical data has shown that the lake only exceeds 80 degrees periodically and for short durations, and it has not exceeded 82 degrees over the reviewed operating history (1980 to present). Based on past sensitvity calculations on the impact of source temperature it is judged that the reduction in flow would be offset by the actual source temperatures that would have actually been present. Considering the discussion above the safety significance for the LOCA containment event would have been minimal.