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TITLE

100-K AREA ELECTRICAL POWER SYSTEM,
LOAD AND VOLTAGE STUDY
FOR
PROJECT CG-775

AUTHOR

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ELECTRICAL POWER SYSTEM LOAD AND VOLTAGE STUDY FOR
PROJECT CG-775

1.0 INTRODUCTION

- 1.1 The proposed increased water capacity for 100-K plants will greatly increase the electrical load to be supplied by the existing area power distribution systems. To determine the effects of the increased loading on the power system a study was requested by Reactor Modification Design Unit.

Two inter-related conditions, system loading and voltage variations, were considered as basic problems for the study.

The load study for this report has been conducted considering the following factors:

1. Loads supplied from the 5 KV system not requiring emergency power backup should be connected to a non-emergency bus.
2. Transformer capacity on the 5 KV system should be adequate so that with the loss of any one transformer, the system can continue to operate on the remaining power supply.
3. The rating of the present bus is 8650 KVA and must not be exceeded.

The voltage study for this report has been conducted considering the following factors:

1. That the BPA transmission line voltage at Midway bus can be assumed to vary between 241 and 230 KV.
2. That the 13.8 KV direct connected loads will be all on or all off at one time.
3. That power factor correction should be considered for voltage regulation on the 13.8 KV system.
4. That for purposes of determining maximum voltage variations, 5 KV transformer loads should be assumed as the maximum fan-cooled rating.

2.0 PURPOSE

The purpose of this study will be to determine the following:

1. A load analysis will be made to determine if the capacity of the existing system is adequate.

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2. The amount of voltage regulation on the 13.8 KV system will be determined with recommendations for correction if required.
3. The amount of voltage regulation on the 5 KV system will be determined with recommendations for correction if required.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 SYSTEM LOADING

A. 13.8 KV System

The capacity of the existing 13.8 KV system is adequate to carry the increased loads proposed for Project CG-775.

B. 5 KV System

The capacity of the existing 5 KV system is inadequate to supply the increased loads proposed for Project CG-775. An expanded power system is proposed and shown as Figure 1 of the appendix.

3.2 VOLTAGE REGULATION

A. 13.8 KV System

Voltage regulation on the 13.8 KV system will be 19%. This amount of regulation is within operating limits considering the fact that the high lift pumping load is stopped and started as a unit.

B. 5 KV System

Voltage regulation on the 5 KV system bus will be 25%. This amount of voltage regulation is excessive for the utilization equipment operated on the electrical system supplied by the 5 KV bus. Voltage regulators must be added to all transformers supplying the 5 KV system. It is recommended that the voltage correction factor be 10% above and 10% below a midpoint setting.

4.0 DISCUSSION

4.1 ANALYSIS OF POWER SYSTEM PROPOSED FOR PROJECT CG-775

A. 5 KV Area Loads

The normal power loads for the six 5 KV buses are tabulated based on the recommended power system as shown in Figure 1. These loads include the additions for K area projects CG-791 and CG-839. It should be noted that the tabulations are for east area where certain loads appear which are not present in the west area.

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Bus M

	<u>KW</u>	<u>KVAR</u>
3 - 600 HP Raw Water Pumps	1 458	786
2 - 1650 HP Raw Water Pumps	2 600	1 470
1 - 250 HP Hot Water Pump	200	108
	<u>4 258</u>	<u>2 364</u>

KVA = 4 880

Bus A

	<u>KW</u>	<u>KVAR</u>
1 - 1650 HP Raw Water Pump	1 300	735
1 - 1500 HP Primary Pump	1 132	672
1 - 300 HP Back Wash Pump	243	131
*1 - 1706 KER Existing Service	460	196
* 1706 Anticipated load increase	460	196
	<u>3 595</u>	<u>1 930</u>

KVA = 4 080

Bus B-E

	<u>KW</u>	<u>KVAR</u>
2 - 1500 HP Primary Pumps	2 264	1 344
2 - 300 HP Service Water Pumps	486	262
**165 Building Station Service	350	170
**105 Building Station Service	300	148
**183 Building Station Service	100	50
**105 Building Project CGI-791	175	20
1706 KER Project CGI-839	693	369
	<u>4 268</u>	<u>2 363</u>

KVA = 4 880

Bus C-F

	<u>KW</u>	<u>KVAR</u>
2 - 1500 HP Primary Pumps	2 264	1 344
2 - 300 HP Service Water Pumps	486	262
**165 Building Station Service	350	170
**105 Building Station Service	300	148
**183 Building Station Service	100	50
**105 Building Project CGI-839	155	40
	<u>3 655</u>	<u>2 014</u>

KVA = 4 160

* This load on east area only.

** These loads are transferable at the Building 480 volt bus between buses B-E and C-F. Loads are represented here as the normal load equally split between buses.

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<u>Bus D</u>	<u>KW</u>	<u>KVAR</u>
1 - 1650 HP Raw Water Pump	1 300	735
1 - 1500 HP Primary Pump	1 132	672
1 - 300 HP Back Wash Pump	243	131
1 - 1706 KER Existing Service	460	196
1706 KER Anticipated load increase	460	196
*1700 Area Service	3 795	1 980

KVA = 4 270

<u>Bus L</u>	<u>KW</u>	<u>KVAR</u>
3 - 600 HP Raw Water Pumps	1 458	786
2 - 1650 HP Raw Water Pumps	2 600	1 470
1 - 250 HP Hot Water Pump	200	108
Fence Lighting	50	-
	4 308	2 364

KVA = 4 910

B. 5 KV Emergency Loads

The loads tabulated for buses B-E and C-F represent the total emergency load on each generator except that one primary pump will be dropped from each set of emergency buses upon loss of BPA. The amount of emergency load that the generator can carry after a BPA failure should not exceed the rating of the machine, which is 4350 KW and 5000 KVA at 0.87 power factor.

C. Maximum Loading on 5 KV System

The nominal rating of the power transformers supplying the 5 KV system is 5,000 KVA without fans and 6250 KVA with fans. This rating is based on the transformer operating at rated secondary voltage of 4.16 KV. When the power system is operating at minimum voltage, there is a derating factor to be applied to the transformers. The transformer derating factor is based on a number of conditions. First the ratio of the load losses to the no load losses has a bearing on the problem. The load losses vary directly as the square of the load current, and the no load losses vary inversely as the applied voltage. The maximum temperature of the transformer is based on these losses and the maximum hot spot temperature limitation for a given KVA and the measured top transformer oil temperature. It is difficult to determine the true derating factor without actual temperature measurements of the transformer when operating under rated load. Considering all of the factors related to the transformer temperature rise, we have assumed a 92% derating factor and at minimum voltage conditions the maximum transformer capacity will be 5750 KVA with fans, which we consider to be a conservative rating for our operating conditions.

* This load can be fed from either KW or KE.

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Normal operation of the 5 KV system is with all bus tie breakers open and each transformer supplying its own bus load. Assuming the loss of any one transformer, two transformers and one generator can be operated in parallel, and the 5 KV system remain split. The division of load will be as follows:

Load demand on one half of 5 KV system	13,770 KVA
Load that can be carried by two 5 KV transformers at minimum voltage conditions	<u>11,500 KVA</u>
Load to be picked up by steam driven generator	2,270 KVA

The load to be supplied by the generator is approximately 2,000 KW. Under normal operating conditions the generator supplies 1,000 KW of load. Therefore, for the abnormal condition of loss of one 5 KV power transformer, the generator operating in parallel with two transformers will supply the additional load at twice its normal KW output.

D. Total Load on 13.8 KV System

The maximum load on the 13.8 KV System is based on the use of six pump operation. However, during periods of five pump operation, each pump operates at a higher horsepower range. The following tabulation of loads does not allow for normal generator contribution which is approximately 1000 KW and 2500 KVAR for each machine. These tabulations are made for the loading on the east area 5 KV system, which is larger than the west area because of the 1706 KE building loads.

The motor loadings shown for the secondary pump are based on test data taken during the test operation of a prototype unit and covered in document ¹HW-60659.

<u>Load</u>	<u>KW</u>	<u>KVAR</u>
Bus B-E	4 268	2 363
Bus C-F	3 655	2 010
Bus M	4 258	2 364
Bus L	4 308	2 364
Bus A	3 595	1 930
Bus D	<u>3 795</u>	<u>1 980</u>
Total 5 KV load	23 879	12 961

Five pump operation - each pump operating at 10,700 HP

5 - Secondary Pump Motors	42 900	24 400
5 KV System load	<u>23 879</u>	<u>12 981</u>
Total area load	66 779	37 361

KVA = 76 500 at 0.873 P.F.

¹HW-60659 - Report of Preliminary Testing Project CG-775
Prototype Testing of Process Pumping Units by
M. H. Schack, et al. June 15, 1959

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Six pump operation - each pump operating at 10,000 HP

6 - Secondary Pump Motors	48 600	27 600
5 KV System load	<u>23 879</u>	<u>12 961</u>
Total area load	72 479	40 561

KVA = 83 000 at 0.873 P.F.

E. Maximum Loading on 13.8 KV System

The present 13.8 KV system in each K area is supplied by two 30/40/50 MVA transformers which are operated in parallel to divide the load between the two transformers.

The total capacity of the two transformers is based on the limitations, if any, resulting from high ambient air temperatures and low voltage on the 230 KV primary power system.

As stated previously, the derating factors for a given transformer are based on the load losses, the no load losses, and their ratio to each other with consideration for hot spot temperature limitations.

The K area power transformers were designed with a 13% impedance. This is much higher than in a normal transformer design. The effect of the higher impedance is to require a higher primary voltage to produce rated secondary voltage. Under ASA standards the transformer must be capable of delivering rated KVA at 80% power factor at 5% above rated output voltage. This standard gives an indication of the extent of overvoltage the transformer will withstand on the primary without exceeding rated temperature. At the rated overvoltage condition the no load losses would be approximately 50% above the no load losses at normal rated voltage. With a ratio of two for the load losses to the no load losses, some indication is given to the effect of a drop in voltage on the total transformer losses. For a decrease in primary voltage, the no load losses decrease at a greater rate than the load losses increase. Our load forecasts indicate a power factor of 0.873 and a minimum primary voltage of 105% of rated tap voltage. These operating conditions are favorable to much lower transformer losses than allowable under ASA standards. For these reasons, we do not feel that a derating factor need be applied to the 100 MVA rating of the two area power transformers for reasons of applied voltage on the primary terminals.

The second derating factor to be considered is the condition for high ambient air temperature for which ASA standards state that for each degree centigrade above 30°C averaged over a 24 hour period, the transformer rated capacity is derated one per cent. Records indicate that there have been a few such high temperature periods here at HAPO.

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Applying this derating factor for conditions reflected by past temperature records will reduce the transformer capacity by 3%. To apply this factor on a yearly basis for future planning seems reasonable. However, on an operating basis, this factor may not need to be applied if means of external cooling are provided for the few days requiring the additional cooling.

The loads predicted for project CG-775 are 83% of transformer rating, and therefore if the transformer were to be derated for high ambient temperature, the transformer rating would still exceed this load.

4.2 CALCULATION OF VOLTAGE REGULATION

Values of voltage regulation on the 230 KV and 13.8 KV bus are taken from report ¹HW-63895. These values are based on Bonneville Power Administration Midway bus voltages of 230 and 241 KV, a swing of 11 KV. For normal HAPO load conditions the bus voltages at K area substations will vary as follows:

Base KVA = 100,000
Base KV = 220
Base Amps = 262

230 KV Bus Voltages

Minimum - with K area at maximum load	1.02 p.u.
Maximum - with K area at minimum load	1.09 p.u.

13.8 KV Bus Voltage

Minimum - with K area at maximum load	.905 p.u.
Maximum - with K area at minimum load	1.08 p.u.

The calculations for power factor corrections and its effect on voltage regulation for the 10,000 HP motors was made by the graphical method. The voltage regulation problem solution for the 5 KV system was also made by the graphical method. The results of this type of solution are as accurate as slide rule calculations, and the information is readily understandable since the resulting components of the solution are shown in magnitude and direction.

All voltage values are given in per unit values. The use of per unit values avoids the confusion of converting to various voltage levels when considering the three separate system voltages.

The corresponding operating voltage at any system voltage level can be obtained by multiplying the per unit voltage by the base voltage and dividing by the correct transformation ratio.

¹HW-63895 - Load Flow Study HAPO 230 KV System by R. F. Haynes, Feb. 8, 1960.

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The units used for graphical scale is indicated for each reactor diagram. The sending voltage, i.e., voltage impressed on the high voltage terminals of the transformer, is represented by E_s . The receiving end voltage, i.e., voltage on the low voltage terminals of the transformer, is represented by E_r . Load current is represented by I_L and lags the receiving end voltage by the power factor angle.

4.3 VOLTAGE REGULATION ON 13.8 KV SYSTEM

The voltage regulation on the 13.8 KV system is a result of two factors. The first is the swing of the BPA transmission system voltage. This is about 5%. BPA has stated that they intend to hold the voltage on the midway substation bus between the limits of 230 and 241 KV. The second factor is the voltage drop through the 230/13.8 KV substation transformers. Due to the large amount of impedance in these transformers this voltage drop will be approximately 12%. The over-all effect of these two variations will change the voltage on the 13.8 bus by 19.5%.

This is a rather wide variation in voltage conditions, and its effect on the system operation must be considered on the basis of the utilizing equipment.

The cost of voltage regulators if applied to the 13.8 KV system would be excessive. As long as the minimum voltage conditions for maximum loading on the 10,000 HP motors can be met without excessive no load conditions, it is acceptable to let the voltage swing on the 13.8 bus. The voltage will rise above the 13.2 KV motor 10% rating during reactor shutdown periods. Since these motors are not connected to the line during the reactor shutdown period, and are started up in a relatively short period, the effect of the overvoltage on the motors can be neglected.

During periods of maximum voltage conditions, the primary winding on the 5000 KVA transformers will be operating at 11% above rated voltage. Under these conditions the load on the transformers is light and the only adverse effect is the voltage stress is 1% above the normal over-voltage rating. However, these periods of operation will be short.

Power Factor Correction on 10,000 HP Motors

As a means of improving the voltage regulation on the 13.8 KV system, a study was made of the feasibility of correcting the power factor on the 10,000 HP motors. Power factor correction could be accomplished by adding static condensers to the terminals of the motors and switching these condensers as a unit with the motor. However, there are restrictions on the amount of reactive current that may be applied to a motor. Normally the capacitive current should not exceed the motor excitation current. The reason for this is to prevent high transient voltage conditions within the motor windings during switching operations, and to limit the generation of fault current by the motor during system faults. For the 10,000 HP high lift motors the maximum amount of capacitors that could be added per

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motor would be limited to 2350 KVAR. Based on this value of capacitance, the power factor on the 13.8 KV system could be corrected from 0.873 to 0.935. This amounts to 18.7% reactive correction. Voltage regulation as a result of transformer impedance drop would be changed from 12.5% to 7.6% for a net gain in regulation of 4.9%.

The improvement in voltage regulation does not justify the cost of power factor correction measures.

During the test operation of the prototype pump unit No. 1, it was found that the 10,000 horsepower motors would generate as long as there was a source of field excitation. The use of static condensers on any part of the 13.8 KV system would provide the source of excitation for the 10,000 HP motors, causing a period of generation following a BPA outage. Any amount of generation removes power from the flywheel and in turn reduces the amount of water that can be pumped by the flywheel following a BPA outage.

5.0 VOLTAGE REGULATION ON 5 KV POWER SYSTEM

The voltage drop through the transformers supplying the 5 KV system will be approximately 4.5%. However, the compounding effect of the voltage swing on the 230 KV system, the voltage drop through the 230/13.8 KV transformers and the voltage drop through the 13.8/4.16 KV transformers produces a voltage regulation of 25.3% on the 5 KV bus. This variation is excessive and will cause equipment malfunction and probable damage.

Normally induction motors can tolerate a $\pm 10\%$ variation in voltage. However, the low lift primary pumps after being rewound to 1500 horsepower rating can tolerate no more than 5% overvoltage. In the latter case, overvoltage will cause excessive motor heating and could limit the operation of these motors during high ambient temperature conditions.

The steam driven generators are limited to no more than $\pm 5\%$ voltage variation.

To correct for the voltage variations, it is necessary to add voltage regulators to the existing transformers and include load ratio taps on new transformers to be added to the system.

Ten per cent voltage regulation above and below will be sufficient to correct for the anticipated voltage variations.

Voltage regulators to be added to the existing system must be on the low voltage side of the transformer and not applied on the 13.8 KV system. This is necessary because the fault currents on the 13.8 KV system are beyond the capacity that these regulators are built to withstand.

The voltage regulators can be satisfactorily operated in parallel. Where the regulator will be required to operate in parallel with the emergency generator, the transformer voltage regulator should be set to control the bus voltage.

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6.0 SELECTION OF TRANSFORMER TAPS

The voltage units used in this report have been stated in the per unit values. This was done to avoid the confusion of actual transformation ratios. On the basis of these per unit values and the actual minimum voltage requirements, the taps for transformer operation can be selected.

On the 13.8 KV system it is desirable that the voltage at the terminals of the 10,000 HP motors does not fall below 12.8 KV in order that the motor may supply the pumping load without drawing excessive load current. On the basis of the minimum voltage on the 13.8 KV bus being 0.905 per unit, tap No. 4 with a ratio of 214.5/13.8 KV, should be selected for operation on the two 50 MVA power transformers. During periods of plant shutdown and maximum voltage on the BPA system, this transformation ratio will give a voltage of 15.3 KV on the 13.8 bus.

On the 5 KV system it is desirable that the voltage on the secondary terminals of the 13.8/4.16 KV transformer be selected to allow the regulator the maximum use of its 10% above and 10% below control. On the basis of the primary voltage varying between 15.3 KV and 12.8 KV the use of tap No. 3 with a ratio of 13.8/4.16 KV will permit the secondary voltage to vary from 4.6 KV to 3.67 KV. The 10% control on these two voltage limits will result in 4.14 KV and 4.03 KV respectively. At this tap setting when the primary voltage is 15.3 KV, the transformer winding is operating at 11% overvoltage. For this reason a lower ratio tap setting cannot be used.

7.0 LOAD LIMITS FOR 10,000 HP MOTORS UNDER VARYING VOLTAGE CONDITIONS

There are two separate operating conditions for the water plant which affect the individual motor loading. These conditions are six pump operation where each motor is operated at 10,200 HP and five pump operation where each motor is operated at 10,800 HP.

The estimated total temperature of the motor windings is 95°C by RTD when the motor is operating at 11,000 HP output, 71°F cooling water, and 12.5 KV terminal voltage. For the above loading conditions the cooler outlet temperature can be expected to be about 35°C. This allows 5°C rise for maintenance of the cooler to the 40°C basis of machine and cooler rating.

No difficulty should be encountered with the starting of a motor on a 15% overvoltage.

The voltage regulation on the 13.8 KV bus was calculated on the basis of six pump operation. In consideration of limits for operation, we have used the loading per motor on the basis of 10,800 horsepower and set the voltage limits based on the maximum system load when six pumps are operated. Actually the minimum voltage condition will be slightly higher for the 10,800 HP motor operating condition and we have neglected this for reasons of arriving at a conservative solution.

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The operation of these motors above the 10,000 horsepower rating and up to 11,500 horsepower is within the service factor allowance provided that rated voltage is maintained on the terminals of the motor. However, there will be periods of operation at 10,800 horsepower per motor when the terminal voltage is below rated value. Assuming the use of tap #4 on the main 50 MVA transformer, the minimum voltage at the motor terminals when under operation would be 12.8 KV. To determine the feasibility of operation under these conditions, a formal inquiry was made to the motor manufacturer as to the limits of safe operation. The letter of reply from General Electric Company as to the limits of operation on the 10,000 HP wound rotor motors is shown as Appendix D of this report.

The thermal rating of the 10,000 HP motors is 60°C rise by thermometer. Allowing 40°C maximum ambient air the total temperature by thermometer is 100°C and 105°C by RTD. This motor operates in a closed air duct system with a water cooled heat exchanger in the system rated for a maximum of 70°F water temperature.

The cooling system is designed for entrance air to the cooler of 100°C and discharge air from the cooler of 40°C when the water temperature to the cooler is 70°F.

The estimated maximum temperature of the motor when operating at 11,000 horsepower output and using 71°F cooling water, is not to exceed 95°C by RTD. Allowing 5°C for RTD measurements above thermometer measurements, the total air temperature to the cooler would not be over 90°C. These calculations were made by Mr. J. E. Tillma of the Large Motor and Generator Department, General Electric Company. His calculations were based on test data on the 10,000 HP motor taken during the May 1959 test of prototype unit No. 1 in East area.

The General Electric Company has assured us that we will not have any real temperature problems for the limits described and as long as the water cooler for the motor is maintained in a high serviceable condition. They have recommended that we do not operate the motor over 100°C by RTD, which is allowing 5°C of safety factor. They also recommend a minimum voltage above 13,000 volts at the motor terminals, as a factor to reduce motor losses. However, we have indicated that during the night period the voltage will at times drop to 12.8 KV and rise by 5% during the day. Any improvement in the minimum voltage condition by the BPA system would raise the bus voltage to the recommended operating level.

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APPENDIX A

Power Factor Correction Calculations

Condition:

Base KVA = 100,000
KV = 220
AMPS = 262

E_g = sending end voltage assumed to be 232,000 volts

E_{R1} = receiving end voltage before power factor correction

E_{R2} = receiving end voltage after power factor correction

I_{L1} = load current of one K Area 13.8 KV bus before power factor correction

I_{L2} = load current of one K Area 13.8 KV bus after power factor correction

I_C = charging current for capacitors on three 10,000 HP motors

Graphical Scale = 60

Voltage 50 units = 1 p.u.
Current 40 units = 1 p.u.

Maximum reactive KVAR per motor that can be added 2350 KVAR

For 3 motors $3 \times 2350 = 7,050$ KVAR

% Reactive = $\frac{7,050}{36,200}$ KVAR = 19.5%

For each three motors on a 13.8 KV bus the KW total load including 5 KV bus loads is 36,200 KW.

Present power factor is .873

For 19.5% reactive the power factor can be corrected to .935.

Reactive current through capacitors would be

$$I_C = \frac{7,050}{3 \times 220} = 18.5 \text{ amps @ 220 KV}$$

$$I_C \text{ p.u.} = \frac{18.5}{262} = .0706 \text{ p.u. amp charging}$$

then: $I_C = .0706 \times 40 = 2.83$ units of charging current

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APPENDIX A (continued)

Assumed. I_L per 13.8 bus at assumed E_{R1} .940

$$I_{L1} = \frac{41,500 \text{ KVA}}{3 \times E_R} = \frac{41,500}{3 \times .940 \times 220}$$

$$I_{L1} = 116 \text{ amps @ base 220 KV}$$

$$I_{L1} \text{ p.u.} = \frac{116}{262} = .443 \text{ p.u.}$$

$$I_{L1} = .443 \times 40 = 17.7 \text{ units}$$

$$\text{In phase} = 17.7 \times .87 = 15.5 \text{ units}$$

$$\text{Out phase} = 17.7 \times .49 = 8.7 \text{ units}$$

$$\begin{aligned} I_L X \text{ drop} &= .443 \text{ currents} \times .463 \text{ reactance} = .205 \text{ p.u.} \\ &= 50 \times .205 = 10.25 \text{ units drop} \end{aligned}$$

$$E_S = 1.055 \text{ p.u.} = 53 \text{ units}$$

Load current after power factor correction from vector diagram

$$I_{L2} = 16.5 \text{ units} = .413 \text{ p.u. at .935 P.F.}$$

$$\begin{aligned} I_{L2} X &= .413 \text{ current} \times .463 \text{ reactance} = .192 \text{ p.u.} \\ &= .192 \times 50 \times 9.4 \text{ units volts drop} \end{aligned}$$

$$E_S = 1.055 \text{ p.u.}$$

$$\begin{aligned} E_{R1} &= 47 \text{ units} \\ \frac{47}{50} &= .94 \text{ p.u.} \end{aligned}$$

$$E_{R2} = \frac{49}{50} = .98 \text{ p.u.}$$

% change in voltage

$$\frac{.98 - .94}{.94} = \frac{.04}{.94} = 4.25\%$$

Regulation without power factor correction

$$\frac{1.055 - .94}{.94} = \frac{.115}{.94} = 12.5\%$$

Regulation with power factor correction

$$\frac{1.055 - .98}{.98} = \frac{.075}{.98} = 7.63\%$$

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APPENDIX A

Power Factor Correction
 $E_s = 232 \text{ KV}$

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APPENDIX B

5 KV Regulation

Condition: BPA Voltage 241 KV

Base KVA = 100,000
KV = 220
Amps = 262

Maximum load is assumed to be the rating of the transformer with fans - 6250 KVA

$$\text{Load amp } I_L = \frac{.0625}{.93} = .0672 \text{ p.u.}$$

$$\text{Assumed } E_R = .93 \text{ p.u.}$$

Graphical Scale = 60

Voltage 50 units = 1 p.u.
Current 200 units = 1 p.u.

$$\begin{aligned} E_S &= .972 \text{ p.u.} \\ &= .972 \times 50 = 48.4 \text{ units} \end{aligned}$$

$$I_L = .0672 \times 200 = 13.4 \text{ units}$$

$$\begin{aligned} I_L \text{ in phase} &= 13.4 \times .871 = 11.7 \text{ units} \\ I_L \text{ out phase} &= 13.4 \times .491 = 6.6 \text{ units} \end{aligned}$$

Transformer Reactance = 1.10 p.u.
Transformer Resistance = .108 p.u.

$$\begin{aligned} I_L X &= .0672 \times 1.10 \times 50 = 3.70 \text{ units} \\ I_L R &= .0672 \times .108 \times 50 = .363 \text{ units} \end{aligned}$$

Reading from Vector diagram

$$E_S = .972 \text{ p.u.}$$

$$\begin{aligned} E_R &= 46.6 \text{ units} \\ &= \frac{46.6}{50} = .932 \text{ p.u.} \end{aligned}$$

$$\% \text{ Regulation} = \frac{.972 - .932}{.932} \times 100 = 4.3\%$$

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APPENDIX B

5 KV Regulation
 $E_s - 237.4$ KV

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APPENDIX C

5 KV Regulation

Condition: BPA Voltage 230 KV

Base KVA = 100,000

KV = 220

Amps = 262

Maximum load is assumed to be the rating of the transformer with fans - 6250 KVA

$$\text{Load Amp } I_L = \frac{.0625}{.86} = .0726 \text{ p.u.}$$

$$\text{Assumed } E_R = .86 \text{ p.u.}$$

Graphical Scale = 60

Voltage 50 units = 1 p.u.

Current 200 units = 1 p.u.

$$E_S = .905 \text{ p.u.}$$

$$= .905 \times 50 = 45.2 \text{ units}$$

$$I_L = .0726 \times 200 = 14.5 \text{ units}$$

$$I_L \text{ in phase} = 14.5 \times .871 = 12.7 \text{ units}$$

$$I_L \text{ out phase} = 14.5 \times .491 = 7.15 \text{ units}$$

Transformer Reactance = 1.10 p.u.

Transformer Resistance = .108 p.u.

$$I_L X = .0726 \times 1.10 \times 50 = 4.0 \text{ units}$$

$$I_L R = .0726 \times .108 \times 50 = .392 \text{ units}$$

Reading from Vector Diagram

$$E_S = .905 \text{ p.u.}$$

$$E_R = 43.1 \text{ units}$$

$$= \frac{43.1}{50} = .863 \text{ p.u.}$$

$$\% \text{ Regulation} = \frac{.905 - .863}{.863} \times 100 = 4.8\%$$

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APPENDIX C

5 KV Regulation
 $E_s - 225.2$ KV

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APPENDIX D

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Subject:

Copies:

HANFORD ATOMIC PRODUCTS OPERATION
10,000 H.P. PUMP DRIVE FOR 100-K AREA
ORIGINAL REQUISITION PAS-4070 (1953)

Mr. J. R. Eliason - Seattle Office

Schenectady, February 19, 1960

Mr. N. H. Meyers
Pasco, Washington, Office

The following comments are in regard to the November 23 request of Mr. W. R. Thorson, HAPO, concerning operation of the 10,000 horsepower wound rotor motors at less than rated voltage.

The tabulation below gives estimated temperature rises for various values of motor terminal voltage at outputs of 10,220 horsepower and 11,000 horsepower. These temperature rises were arrived at by calculating adjustments to the rises obtained during the load test conducted at Hanford on May 4, 1959. Stator winding R.T.D. No. 3 and test core T.C. No. 8 gave the highest readings during the load test and were used as a basis for the temperature rise estimates given below.

The load test was taken at 14,500 volts, a substantial overvoltage, and motor temperature data taken was rather limited. Any errors that might be present in the load test data used will, of course, reflect in the temperature rise estimates.

Motor Voltage K V	10220 H.P. Output		11000 H.P. Output	
	Estimated Temperature Rise, °C RTD	Core	Estimated Temperature Rise, °C RTD	Core
14.5	57 (Test)	39 (Test)	59.2	39.6
14.0	54.6	36.6	56.9	37.2
13.5	52.3	34.3	54.7	34.9
13.2	51.4	33.3	53.9	34.0
13.0	50.9	32.6	53.4	33.3
12.5	49.6	30.9	52.3	31.6

The values show to one-tenth of a degree are not intended to imply this degree of accuracy, but rather to more clearly represent the change from one value of voltage to the next. The temperature rises are rises above air temperature from the coolers.

Data from the May 4 load test indicate a cooling water temperature of 14°C (57.2°F) and air temperature from the coolers of 26°C. If cooling water temperature increases to 21.6°C (71°F) and all other factors such as load, water flow, and

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cooler condition remain fixed, the air from the coolers would be 33.6° C. At increased load of 11,000 horsepower and 21.6° C cooling water, the air from the cooler could be expected to be about 35° C.

From these figures the total temperatures can be estimated. Values in the range of 75° C to 95° C will be obtained for the stator RTD total temperature for the range of voltages and the loads shown in the table.

The air temperature from the cooler obtained during the load test indicates that the cooler is performing well and is probably quite clean. If fouling develops in the cooler tubes their performance will be reduced and higher air temperatures will result. This factor could well increase the air temperature from the coolers by 5° C and raise the inlet temperature to the 40° C basis of the machine and cooler rating. Additional winding temperature will, of course, result.

The figures shown would indicate an advantage for the lower voltage operation. For a given motor output, as the voltage is decreased the division of losses changes so as to increase the loss in the winding and decrease the loss in the punchings. This has the effect of increasing the difference between the RTD temperature and the actual winding copper temperature. My estimates indicate that actual minimum copper temperature for loads between 10,000 horsepower and 11,000 horsepower occurs between 13,000 volts and 13,500 volts. In the interest of lowest insulation temperature it would be well to keep the voltage above 13,000 volts.

The operation at Hanford demands the utmost in machine reliability, operation is essentially on a continuous basis and long machine life is expected. To achieve these goals, conservative machine operation is important. Operation of the motors with RTD temperature indication in excess of 100° C would be considered outside of this range. Temperatures in excess of 100° C should not be viewed with alarm but rather as temperatures that cause shortening of the insulation life. The "Ten Degree Rule" is generally accepted and states that insulation life is reduced by one half for each 10° C increase in winding temperature. RTD temperature indication in excess of 120° C should be viewed as definitely hazardous and immediate steps should be taken so that such a condition does not exist for more than a few hours.

Fred Mollerus was in Schenectady last week and advised that calculation indicated that voltage at these motors would go as low as 12,400 volts. This condition would exist only when maintenance work was in progress on one of the transmission lines. The low voltage condition will last for a maximum period of 8 hours and occur perhaps 3 or 4 times a year. For the remainder of the time I understand the voltage will be at least 13,000 volts.

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I do not foresee any real temperature problems with these motors for the conditions described. Care must be exercised, of course, so that abnormal conditions do not develop that would cause excessive temperature. Since the proposed loading is a substantial increase over loads carried in the past, this point will be of greater importance.

Mr. Thorson's letter also requested comments on starting these motors at 15% overvoltage. The period during which this overvoltage exists apparently lasts for only a few minutes. Under these conditions, no difficulty should be encountered with the overvoltage starting.

/s/ J. E. Tillma

J. E. Tillma, LARGE MOTOR & GENERATOR ENGINEERING
Bldg. 41 - 320 - Ext. 53647

JET/jmh

NOTES:
 1. EQUIPMENT SHOWN BY PHANTOM LINES IS EXISTING. EQUIPMENT SHOWN BY HEAVY SOLID LINES IS NEW.

FIGURE N^o 1

REVISED TO AGREE WITH NEW DESIGN REQUIREMENTS		DATE 2/18/60	BY S.N.B.	FOR	DATE
DESCRIPTION		REV BY	DATE	APP'D BY	FOR DATE
CLASSIFICATION		CLASSIFIED BY Phil Turner DATE 7/18/60			
NONE		DATE 7/18/60			
DWG. NO. SK-I-22457		REV. NO. 3		REV. NO. 1	
SCALE: NONE		APPROVALS			
DRAWN BY DATE 3-6-59		BY	FOR	DATE	
CHECKED BY DATE					
ISSUED BY DATE 2/18/60					
DES. ENG. NATHAN UNIT C280					
INST. NO. 7105					
PROJECT NO. CG-775					
U. S. ATOMIC ENERGY COMMISSION HANFORD ATOMIC PRODUCTS OPERATION GENERAL ELECTRIC					
ELECTRICAL ONE LINE DIAGRAM 100KE & KW PROPOSED INCREASED WATER CAPACITY					
DWG. NO. SK-I-22457		UNIT NO. 7201		REV. NO. 3	

John 1 - Paul
 2-17-60

DATE

FILMED

9 / 13 / 94

END