Form 01077 (R7-89)

FORM 101.1	REVISION 13

CERTIFICATION OF ENGINEERING CALCULATION

STATION AND UNIT NUMBER Keowee Unit 1 & 2

TITLE OF CALCULATION Analysis of Keowee Voltage Regulator Settings

CALCULATION NUMBER KC-Unit 1 & 2-2023

ORIGINALLY CONSISTING OF:

PAGES 1 THROUGH 27

TOTAL ATTACHMENTS 12 TOTAL MICROFICHE ATTACHMENTS 0

TOTAL VOLUMES 1 TYPE 1 CALCULATIONS/ANALYSIS YES ☐ No ☑

TYPE 1 REVIEW FREQUENCY N/A

THESE ENGINEERING CALCULATIONS COVER QA CONDITION 1 ITEMS. IN ACCORDANCE WITH ESTABLISHED PROCEDURES, THE QUALITY HAS BEEN ASSURED AND I CERTIFY THAT THE ABOVE CALCULATION HAS BEEN ORIGINATED, CHECKED OR APPROVED AS NOTED BELOW:

ORIGINATED BY C.E. Schaeffer [signature] DATE 6/ 4/95

CHECKED BY G.P. Edens [signature] DATE 6/ 4/95

APPROVED BY [signature] DATE 6/5/95

ISSUED TO TECHNICAL SERVICES DIVISION ________ DATE ________

REVIEWED BY TECHNICAL SERVICES DIVISION ________ DATE ________

MICROFICHE ATTACHMENT LIST: YES ☐ No ☑ SEE FORM 101.4

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Form 101.2 Revision 0

2S164 (12-82)

Calculation No. KC-2023

REVISION DOCUMENTATION SHEET	
REVISION NO.	REVISION DESCRIPTION

CALCULATION/ANALYSIS INFORMATION SHEET

CALCULATION/ANALYSIS NO. KC-Unit 1 & 2-2023
ORIGINATOR: CE Schaeffer [signature] DATE: 06/04/95
CHECKER: G.P. Edens [signature] DATE: 06/04/95

A. PROBLEM: This calculation is being performed to analyze Keowee Voltage Regulator operation, and document the bases for equipment settings. A lack of a formal document for these settings has been identified as a cause of mis-calibration of unit parameters important to safety. Reference PIP 4-093-0793.

B. RELATION TO QA CONDITION: 1

C. DESIGN METHODS: Due to the unique application of the regulator in a QA-1 generator, a study and documentation of this nature for the WTA has not been done before. Regulator system operation will be analyzed for both Power Generation and Emergency Power modes of operation. Keowee Emergency Power system Design Bases are applicable for the regulator, which determines generator output voltage. Using available information, a logical basis will be identified for all regulator system settings.

D. APPLICABLE CODES AND STANDARDS (NAME, NUMBER, DATE, REVISION): IEEE-421 Series.

E. OTHER DESIGN CRITERIA: Keowee Emergency Power Design Basis Document, OSS-0254.00-00-2005.

F. RELATED SAR CRITERIA (PSAR OR FSAR, PAGE, AMENDMENT): FSAR Section 8.3, Onsite Power Systems.

K. REFERENCES : Most devices are covered in regulator manufacturers IB KM-312-0089. Specific references are identified as each device is covered.

1.0 Conclusions

1.1 To minimize transient voltage dips during emergency operation, the reactive current compensator should be set to 0%, removing unnecessary reactive droop compensation. The Reactive Line Drop compensator should be set to compensate for 80% of the MSU transformer impedance.

1.2 Analysis ran to analyze failure scenarios indicate that adequate, but minimal, safety margin exists between the operating and minimum required voltage needed to ensure operation of safety loads. The current MSU tap setting lowers the voltage supplied to the ONS emergency loads by 5%. The MSU tap should be changed to tap 3, and the allowed emergency system source voltage band (currently specified as 13.5 to 14.1KV) can then be changed to the normal band of 13.8KV ±5%. A change to the CT4 transformer tap setting should also be considered to increase the voltage supplied to the ONS systems. These tap changes will provide additional margin. In addition, with the current MSU tap setting the unit voltage must be high to synchronize at normal grid operating voltages. This may unnecessarily limit the ability to supply VARs to the grid due to generator voltage limitations.

1.3 The order of calibration is critical for certain modules. The damping module should be calibrated after all other system gains are adjusted. The Voltage and Base Adjuster preset positions must be set after calibration of the Voltage Error Detector and Firing Circuit Input Modules to ensure proper generator voltage during emergency operation. These preset positions should be calibrated to provide nominal output voltage.

1.4 The overexcitation settings currently do not protect the field winding, and should be changed as discussed in section 6.6.

2.0 Keowee Ratings

Reference Attachment 3 (Pg 1) & Attachment 2

Voltage	-	13.8KV
Total Power	-	87.5MVA (=1p.u.)
Current	-	3661A
Rated Temp Rise		60°

Rated KW - .9pu or 78.75 MW (at .9 pf)
Rated KVAR - .55 pu or 48.125MVAR (at 0 pf)
Power Factor - 0.95 pf

Field Winding Ratings [at rated MVA & pf, Reference Attachments 1 & 3 (Pg 2)]:

Current - 1140A
Voltage - 186VDC
Field resistance 0.1283Ω @ 25°C

Main Stepup Transformer Ratings [Reference Attachment 4]

Voltage- Rated for 13.2KV, with allowed levels overexcitation given by curves in Attachment 7. High side rating is determined by the selected tap setting. Current rating is 218.5KV.

Impedance - 13.2 to 230KV impedance 14.37% at 102.5 MVA.

3.0 Assumptions/Bases for Equipment Settings

3.1 Assumptions

For analysis in section 6.15, it will be assumed that exciter output voltage (and thus field current) will remain constant as generator voltage decreases. Although the decreased output voltage applied to the exciter bridge would tend to cause the exciter output voltage to decrease, the firing circuit bias signal also varies with terminal voltage, and will provide an earlier firing of the exciter SCR's. This would tend to provide higher SCR bridge output voltage as terminal voltage decreases. A representative of Westinghouse was contacted to determine which effect would be dominant, and his response in located in attachment 10. This assumption is conservative between rated voltage and 70% of rated voltage, and the expected minimum terminal voltage is 82.1% (11.33KV÷13.8KV), reference attachment 6, page 2.

3.2 Basis for Keowee MSU Tap Setting

Conventional Generator-MSU design is to have the MSU voltage rating at 95% of the generator rating. With this design, the generator should be operated between 95 & 105% of rated (with the high voltage limited by the V/Hz limiter), and thus the transformer operated at between 100 & 110% of its rating as grid voltage swings between its normal extremes. At normal frequency, the MSU transformer is designed to be able to supply rated load with secondary voltage not in excess of 105%. The tap setting should ideally be selected so the highest expected grid voltage is slightly less than 105% of rated secondary voltage at that tap, to allow for unlimited load on the transformer.

Currently set on tap 5, the rated secondary voltage on the MSU is 218.5KV. Thus the maximum allowed secondary voltage (without limiting load) would be 229.4KV. Since the grid voltage is normally above this value, the MSU is operated in an overexcited condition. The affect of this operation was discussed with the manufacturer (John Perry of G.E., see attachment 9), who reviewed the gas analysis records to evaluate the potential for adverse effects on the MSU. It was his opinion that the gas analysis results were consistent with an overexcitation condition, although he saw no reason to believe the transformer was subject to catastrophic damage. He concurred that the tap setting could be changed to eliminate the overexcitation condition. Changing the tap setting to tap 3 would change the rated secondary voltage to 230KV, and allow operating with voltages up to 241.5KV (1.05*230KV) without limitations. The maximum grid voltage observed recently has been about 237KV.

Since Keowee also supplies emergency power to ONS, there is also a consideration of adequate voltage to ONS loads. The impact of the tap is evaluated in calculations documenting the adequacy of overhead path, which should be reanalyzed before the tap change recommended here is made. Changing the CT4, 1X & 2X transformer tap settings should also be considered.

3.3 Maximum Exciter Output Voltage

Field excitation voltage is controllable from 2% to 93% of the maximum converter output voltage, which is calculated by the formula 1.35*AC Supply Voltage = 1.35*240 = 324VDC. However, multiple failures would be required for the excitation level to reach 324VDC; The failure of the control signal in the high direction and a failure of the upper limiting signal in the pulse generators <u>BOTH</u> firing circuit trains. The maximum bridge output assuming a single failure of the control signal high would be limited to .93*324 = 301VDC (reference KM-312-89 tab 15).

3.4 Keowee Output Voltage Band

The Keowee units are rated at 13.8KV. Due to emergency power system voltage adequacy concerns, the operating band for the generator voltage is specified as 13.5 to 14.49KV (98% to 105% of nominal).

3.4.1 Basis for Minimum Keowee Output Voltage

OSC-2444 assumes a 13.8KV generator bus voltage, but analyzes a 13.2KV generator bus voltage to allow for the expected transient voltage dip. The dynamic Keowee-Oconee Overhead analysis (OSC-5701) assumed generator terminal voltage of 13.8KV. Discussions with Nuclear G.O. were held to determine what voltage should be considered the minimum acceptable voltage. There is some question if any voltage below 13.8KV is acceptable. PIP 0-O95-0639 was written to address this concern. Preliminary calculations made on the dynamic model indicate 13.5KV on the generator output is adequate to ensure operation of emergency loads. These calculations will be formalized, and put into OSC-5701.

3.4.2 Basis For Maximum Keowee Output Voltage

The maximum output voltage on the generator will be based on the lowest of following limits; Generator overexcitation, MSU transformer overexcitation, and 4KV safety system maximum voltage. This maximum should allow for delivering rated MVAR to the grid.

The 4KV continuous operating voltage limit will be based on maintaining system voltage less than 4400VAC (110% of the 4000V motor voltage rating). There is only one transformer (CT4) between the Keowee output and the 4KV safety bus for the underground path, and two (Keowee MSU and CT1, 2, or 3) for the overhead. In addition, the overhead path load would either be the same or higher if other units LOOP loads are operating on the overhead. Both of these factors would cause less voltage drop through the underground path, and thus higher 4KV safety system voltage for the same generator output voltage. The LOCA running loads are 6.2MW + 3.82MVAR = 7.33MVA, reference OSC-2444. Subtracting 30% to allow for load variation leaves roughly 5MVA continuous load, which is less than minimum shutdown loads analyzed in OSC-2059 & 2060. The CT4 voltage regulation (impedance) is 16.68% on a 12MVA base, reference OSC-2444 rev 4, thus is 6.95% for 5MVA. The impedance of the underground cable is neglected for extra conservatism. At no load, a 4KV system voltage of 4400V is equivalent to 13.9KV on the Keowee output bus. At 5MVA, generator voltage would have to be approximately 6.95% higher than 13.9KV to compensate for the CT4 transformer losses. Thus the overexcitation limitations on the generator (105% of 13.8KV=14.5KV) will be more restrictive than the safety system maximum voltage.

The current Keowee MSU overexcitation limits are 229.4KV (1.05*218.5) at full load (102.5MVA), and 240.35KV (218.5KV*1.1) on the secondary at no load. These are more conservative than limits would be at the proposed tap. At no load, the transformer primary voltage is limited to about 14.52KV (1.1*13.2). Using an approximate MSU impedance of 14%, the MSU "primary side reference voltage" load will above 119%. Thus the generator limit of 105% will be limiting at all power levels, and the maximum generator voltage is limited to 14.49KV. Current practice is to limit voltage to 14.1KV during emergency operation.

3.5 Design Emergency Loading Power Level for Analysis

From the perspective of adequate voltage to ONS loads, the worst case load during an ONS design basis event is 10.766MW & 49.53MVAR (case 5, three unit blackout starting load, reference OSC-2444) would be loaded onto the overhead unit. However, the LOCA Design Basis Event imposes design requirements on the Keowee Emergency Power system, and there are no requirements imposed by the LOOP DBE, reference FSAR chapter 8. With a Single Failure of the underground unit's voltage regulator to switch into automatic, the overhead path would remain available, and LOOP loads would go there on a LOCA/LOOP. The LOCA unit would go to the underground, and the worst case load on that underground unit will be one unit's LOCA start loads, which are 7.42MW & 30.81MVAR (case 1 in OSC-2444).

3.6 Design Unit Loading Sequence

The units are designed to accept load during an emergency start while at normal speed and voltage, or while accelerating to normal speed if shutdown. For the load while accelerating scenario, the underground path will be loaded either in roughly 11 seconds (1 second load shed timer + 10 second standby breaker close time delay, reference OSS-0254.00-00-2000), or when voltage reaches a level where the synch relays on the SK & S breakers will pickup if longer than 11 seconds. On a failure of the underground, LOCA loads would be loaded on the overhead path after an additional time delay. During an emergency start. the regulator is transferred into automatic by a voltage buildup relay, which picks up a latching relay (90XIC), which then picks up several other control relays. Block loading will cause a voltage dip (which may cause the 53 relay to drop). Since the 90XIC relay is only reset by the field breaker tripping, once it is latched the transfer to automatic will occur no matter what happens to the 53 relay. Thus, the unit should not be loaded during start up before 90XIC picks up to ensure V/Hz control is present as described in FSAR section 8.3.1.1.1.

4.0 System Operation

The Keowee Generators are designed to be used for two functions: 1) The ONS emergency power source, where the units will function as an isolated generator, and 2) A source commercial power where they will be connected to the grid. When connected to the grid, terminal voltage and frequency will be controlled by the grid under all load conditions. When acting as an isolated source, the generator speed governor and voltage regulator are the only controls on emergency power system voltage and frequency.

KEOWEE
TYPE WTA REGULATOR AND STATIC EXCITER

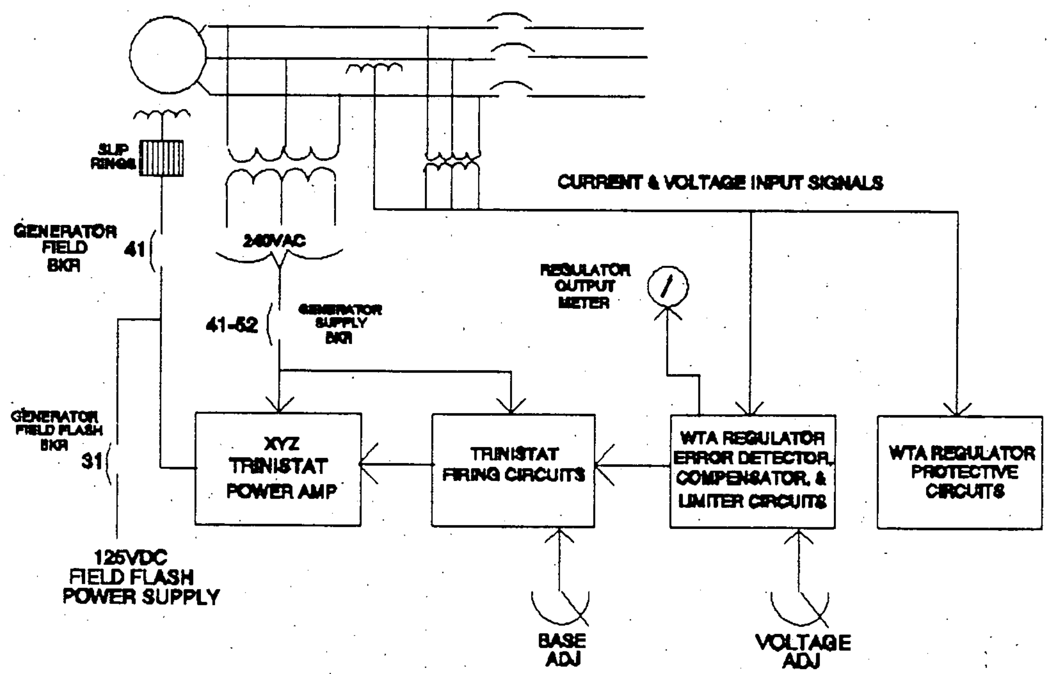


Figure 1

The Keowee generator field current at rated voltage & no load (approximately 675A) is called the base level of excitation. Assuming the unit is isolated from the grid (as it would be when serving as an emergency power source) and excitation current is constant, generator output voltage would vary with changes in unit load. Depending on the type of load, voltage may increase (with increased capacitive loads), or decrease (with increased real or inductive load). With the generator isolated the regulator will function to control generator output voltage as load varies from 0 to maximum (emergency loads starting) to some intermediate level (emergency loads operating). To maintain generator voltage over the full range of possible load variations, the automatic voltage regulator will monitor terminal voltage, and change field excitation current as necessary to maintain constant voltage. The field current must increase to 900A at rated load & 1pf, and approximately 1025A at rated load & .95 pf. (ref. Attachment 3 pg. 3).

If the generator is connected to the grid, terminal voltage will be determined largely by grid voltage, and the voltage regulator will be used to control reactive load. The reactive load will be manually controlled by use of the voltage adjuster in automatic, or the base adjuster in manual. To pickup reactive load on the generator, the operator must raise the output voltage above the grid voltage.

The WTA regulator/exciter has two modes of operation, automatic and manual. In automatic mode with the generator isolated, the WTA regulator Voltage Error Detector senses generator voltage and compares it to a reference signal (as determined by the Voltage Adjuster), and provides an error signal to the Signal Mixer. For the model WTA regulator, generator voltage cannot be restored to exactly the no load level because an error signal is necessary to maintain the field current above the base excitation level. With proper calibration, the regulator should maintain steady state generator voltage within ±½% of no-load unless current compensation is used.

The regulator is provided with current compensation circuits, which can be used to modify the sensed voltage signal, and provide a linear droop or rise in steady state terminal voltage with increased load. Droop is necessary for systems where multiple units are paralleled at their output terminals without an appreciable impedance between them, to ensure each unit will respond appropriately to load transients. At Keowee, the main stepup transformer provides the necessary impedance, and reactive droop is not required (see section 6.8). A rising characteristic may be desirable to compensate for voltage drops in the system. This characteristic can be provided with the use of Line Drop Compensation.

The Signal Mixer receives the voltage error signal, which is compared to several limiter signals to ensure the unit is controlled within safe limits. The Signal Mixer inputs are from the Voltage Error Detector & Minimum Excitation Limiter through the positive auctioneering inputs, and from the V/Hz & Maximum Excitation limiters through the negative auctioneering inputs. Assuming operation in the normal range, the error signal is inverted and sent to the firing circuit, which adds the control signal to base (0 to -10VDC) and bias (5VDC at rated output voltage) signals. The combined signal is used to control the amplifier SCR firing angle.

Excitation power is supplied by a 13.8KV/240VAC transformer through the Generator Supply breaker. The level of excitation is controlled by varying the firing angles of three SCRs in the positive legs of a three phase bridge rectifier. Each SCR can be controlled to fire from 10° to 170°, when the voltage across it (V_{app} in figure 1) is in the positive half cycle. Earlier SCR firing allows more energy to pass to the field, increasing the generator excitation current. Once fired, the SCR remains on until V_{app} drops to 0.

The SCR control signal is produced by combining a DC Base, DC Bias, & a 10VAC peak-to-peak signal (which leads V_{app} by 90°) with the DC voltage error signal in the pulse generator. The combined signal (Vcomb) crossing 0 from positive to negative initiates the generation of the pulse turning on the SCR (see figure 2).

Pulse Generator

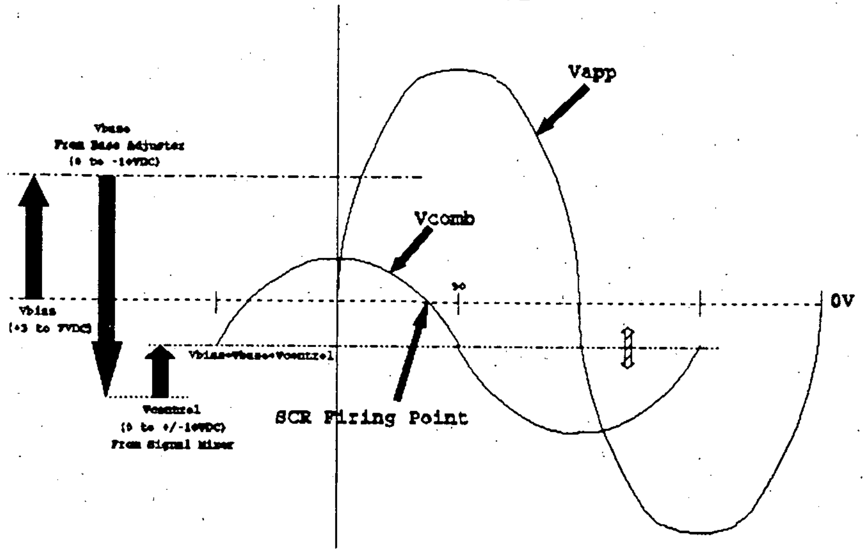


Figure 2

With the regulator in manual, the error signal from the signal mixer is removed from the firing circuit, and the bias & base adjuster signals determine the level of excitation. Operator action may be required to maintain voltage as the unit is loaded, as the excitation level will remain constant in manual except for some correction provided by the bias signal which varies between 3 & 7VDC with generator terminal voltage.

5.0 MVAR Capability Concerns

Attachment 12 is a IEEE Transaction which discusses suggested testing to determine the reactive power capability of existing generators. To summarize this paper as it applies to the voltage regulator, overly conservative setting of protective devices and poor selection of transformer tap settings may unnecessarily restrict the MVAR capacity of the generator. A program implemented in Colorado to optimize these settings freed 500 MVAR of unused capability on the system, which was equivalent to between 5 & 45 million dollars worth of VAR compensation capacitors. A recent request was made to test the MVAR capability of the ONS units this summer indicates Duke may move in the same direction. This calc will strive to achieve the balance of protecting Keowee equipment without undue conservatism which might impact unit capacity.

6.0 Regulator Settings

The WTA Regulator/Exciter has the following controls:

6.1 Regulator Control Switches and Relays

The WTA voltage regulator is provided with three operating states; Off, Test, and On. The regulator can be controlled locally or remotely (as determined by switch 143T), using control switches 190 at Keowee or 290 in the unit 1 & 2 control room. With the regulator off or in test, excitation will be controlled manually as discussed above. Moving the control switch from Off to Test energizes the close (latch) coils of relays 90X1A & 90X1B, which energizes the regulator circuits. Moving from Test to On energizes the close coils of relays 90XA & 90XB, which connects the output of the regulator to the firing circuit, and allows automatic voltage control. The off position energizes the trip (unlatch) coils of the 90XA, 90XB, 90X1A, & 90X1B relays, which disconnects the regulator from the firing circuit and deenergizes the regulator circuits. Going from On to Test will energize the trip (unlatch) coils of the 90XA & 90XB which will disconnect the regulator from the firing circuit (transfers control to manual).

During startup, field current is initially determined by the field flash voltage. As generator voltage builds up, the exciter output voltage will increase, and take control of the field once it exceeds voltage from the battery. For automatic startup, the 53 voltage buildup relay energizes the close coil of the 90X1C relay, which energizes the close coil of relays 90X1A & 90X1B (equivalent to placing regulator in test) and timer 90X1A/TD. The 90X1A/TD will time out in a few seconds and energize relays 90XA & 90XB, switching the regulator to automatic. The time delay is provided to allow for the regulator circuits to become energized before switching to automatic. According to Gene Forte of Westinghouse, this time is normally around 5 seconds, with the current 2.5 second setting at Keowee the lowest he has seen. To minimize the time to get the regulator switched to automatic, this will be specified at 2.5 second.

6.2 Firing Circuit Drawer

The Firing Circuit drawer consists of one Input, Overvoltage, Power Supply, Phase Shifter, & Transformer module, and three Pulse Generator modules.

The transformer module converts a 3-ph, 240V input into 45 & 120VAC outputs shifted 0, 60, 120, ···, 300° lagging behind the input X-Y voltage. There are no adjustable controls associated with this module (ref. KM-312-35).

The Phase Shifter module takes 120V signals from the 60, 180, & 300° transformer module outputs, shifts them 90° lagging, reduces and filters it to produce a pure 10V peak to peak sine wave with 30, 150, & 270° phase angles. These signals provide the basic sine waves which are shifted in the pulse generators to produce the proper SCR firing angles. While the manufacturers instructions say this module is preset at the factory, current practice is to adjust the R1, R2, & R5 pots as necessary to achieve a 10V peak to peak signal on each of the outputs (ref. KM-312-34).

Each pulse generator (PG) sums the following signals to determine the proper SCR firing angle: A 10VAC p-p signal from the phase shifter, a 3-7VDC bias signal which varies with generator output voltage (this variation provides a small amount of voltage correction when in manual control), a 0-10VDC signal from the Base Adjuster, and the 0 to ±10VDC control signal from the Signal Mixer. This module also receives 120V & 45V rms signals which are combined to determine the minimum and maximum firing angles. While this module does not have adjustable controls, each pulse generator should periodically be tested separately. Firing circuit problems can be hidden by the redundancy of the other firing circuit components, and separate testing is the only sure way to find problems, which primarily occur in the pulse generators (ref. KM-312-32).

The power supply converts 90VAC from the 240/90VAC transformer to a ±15VDC output. This module does not have adjustable controls. (ref. KM-312-24).

The firing circuit Input Module is equipped with the Low Adjust pot (R7) which sets generator voltage with the Base Adjuster in the minimum position, the High Adjust pot (R4) which sets generator voltage with the Base Adjuster in the maximum position, the bias pot (R13) which controls the bias voltage supplied to the pulse generator, and the overvoltage pot (R15). The generator voltage adjustments typically are set to allow control of output voltage from 85% to 115% of nominal. Thus with the regulator in manual, R7 should be set with the base adjuster in the minimum position to provide 85%, and R4 should be set with the base adjuster in the maximum position to provide 115% of nominal on the generator bus. Care should be taken to minimize the time above 110% to ensure the V/Hz trip will not occur.

The pulse generator bias voltage will vary with generator output voltage. The R13 bias pot should be set so that 5V is provided to the pulse generator when generator voltage is nominal.

The overvoltage detector protects the machine from transient overvoltage excursions. It monitors machine terminal voltage, and is designed to cause the power amp SCRs to "phase back" to reduce output voltage. Once voltage is reduced below the pickup value, the phase back signal is removed, and control from the firing circuit is restored. The module will be set to provide protection at 120% of nominal.

6.3 Volts/Hz Limiter and Protective Relays

An excessive V/Hz ratio may cause damage to the generator or unit transformers. A rapid thermal degradation of winding insulation can be caused by the stray flux heating present during abnormal combinations of voltage and frequency. These concerns are discussed in Attachment 7, and section 4.5.4 of IEEE C37.102. The potential problem with overexcitation when connected to the grid due to the MSU tap setting is addressed in section 3.2 above.

The WTA regulator is equipped with a V/Hz limiter and protective relay. The limiter will generate a signal to prevent voltage error detector control of unit voltage above a limit derived from unit frequency. The limiter output signal varies with machine voltage and frequency, and is compared with the Voltage Error Detector output in the Signal Mixer through a negative auctioneering circuit. The auctioneering causes the most negative of the two signals to control the generator voltage. The protective trip has an associated time delay, and is designed to shutdown the unit if the limiter fails to maintain voltage as designed.

The V/Hz limiter and relay receives input from a 14.4KV/120VAC PT, and the limiter is currently set to limit at 1.05p.u. (121VAC @ 60Hz), on a 13.8KV base. The IEEE paper in Attachment 12 setting the V/Hz limiter at 1.08 of generator rated, which would correspond to 112.9% of the transformer base. This setting is recommended to maximize MVAR capability of the generator, but would not protect the MSU & CT4 secondaries from exceeding 110% overexcitation at no-load. The current setting of 1.05pu will be maintained based on the discussion in section 3.4.2 above, and protecting the MSU & CT4 transformers. If the suggested transformer tap change is performed, the overexcitation limit in terms of primary voltage would increase due to the higher secondary rating, and this limit could be raised to 1.08 as recommended by the IEEE paper.

Attachment 12 recommends setting the V/Hz protective trips at least 3% higher than the limiter. The setpoint should be high enough to assure that the relay will reset if picked up by a transient overvoltage condition, to preclude spurious trips due to transients. Problems were experienced in the past where a unit experienced a V/Hz trip and normal lockout, and the relay setpoints were raised to the current settings of 128.5V on unit 1 & 135V on unit 2 as read off the relay indicator.

The most limiting function will be the 110% no-load limit on the MSU, and the 105% limit on the generator. The V/Hz relays should be set as low as possible while ensuring they would reset after a transient above the limiter setpoint. This is desirable since it is likely that V/Hz protective trip will be moved to the 86E lockout relay where a misset V/Hz relay would cause a loss of a unit during emergency operation. The current setpoints correspond to 1.16p.u. on unit 1 & 1.22p.u. on unit 2 on the 13.2KV transformer base. The instruction leaflet for the SV relays indicated that these relays have a dropout to pickup ratio of 90 to 98% (ref. I.L. 41-766.1J), and thus the settings of

the SV V/Hz relay should be about 1.16pu (1.05 + 10% + the tolerances of the limiter and the SV relays). The SV relays have been identified as bad actors by the SQUG analysis. Thus, these relays will be replaced, and the settings of the new relays should be based on the reset tolerance of the relay.

The V/Hz/TD relays are currently set at 5 sec (U1) and 16 sec (U2). The firing circuit overvoltage module will prevent the unit from providing voltage in excess of 120%. From the overexcitation limit curve for the transformers in attachment 7, the transformers can withstand 120% voltage for 60 seconds. A setpoint of 30 seconds will protect the transformers, and ensure emergency safeguards loads are not exposed to voltage from 110% to 120% of rated for an extended period. It should be noted that multiple failures normally would be required to cause voltage to increase to this setpoint.

Reference Westinghouse I.L. 41-766.1J, KC-75 & 76.

6.4 Voltage Error Detector

The Voltage Error Detector module compares a signal corresponding to generator output voltage to a reference signal, and generates a signal which can vary between ±10VDC. If generator voltage is high as compared to the reference, the output signal will be a negative value.

The Voltage Error Detector has the following field adjustments: Voltage Adjuster Minimum Voltage (R5), Range (R8), & Gain (R14). In addition, internal controls are available to correct for output ripple (three phase balance pots).

Generator output voltage is normally controlled between 95 & 105%. Some control above 105% no load voltage is required to allow pickup of reactive load. Adjustments typically are set to allow control of output voltage from 90% to 110% of nominal.

For Keowee, the minimum voltage will be selected to be the minimum analyzed no load voltage to ensure emergency power system operation, and the R5 minimum adjustment should be set with the voltage adjuster in the minimum position to provide 13.5KV no load on the generator output. This will be low enough to allow control of voltage below the minimum expected bus voltage when paralleling with the grid, and keep the minimum voltage with a hypothetical single failure which drives the voltage adjuster to the lower limit above the minimum analyzed voltage with the MSU on tap 5. Since the current tap setting requires a higher primary voltage than normally would be required, the R8 voltage range adjust should be set with the voltage adjuster in the maximum position such that generator output voltage is 1.15 * nominal. This should allow sufficient margin to pickup rated MVAR on the machine. MVAR capability testing will show if this setting is adequate.

It will be necessary to defeat the V/Hz limiter to reach the upper limit, and care should be taken to minimize the time at 115% to less than the 6 minute limit per the overexcitation curves, to protect against excitation transformer and generator damage. The gain adjust would then be set as high as possible without causing unstable system operation, which would be indicated by voltage fluctuations during steady state.

The suggested transformer tap change would lower the generator voltage for normal and emergency operations, and the maximum and minimum voltage settings can be set closer to the normal 90 & 110%, with the minimum determined by new calculated emergency power system minimum voltage requirements.

6.5 Overcurrent Module

The overcurrent module detects current in the non-linear resistor bank. This bank protects the power amplifier components against damage from voltage spikes, which would be generated in the field winding by high negative sequence currents during transients and faults on the generator output terminals. The overcurrent protection is designed to detect catastrophic failures of the non-linear resistors and trip the unit. The accuracy of this module's settings are not important, as the duration of current during transient overvoltages is short compared to resistor short circuit. Westinghouse representatives recommend setting pickup and time delay pots to mid-position. Testing of this trip will become safety significant if the trip for this is moved to the 86E lockout.

6.6 Overexcitation Protection - Isolation Transducer, Maximum Excitation Limiter (MXL) & Overexcitation Protective Relays (76, 76T1 & 76T2)

This instrumentation protects the generator field winding from thermal damage due to overexcitation. The isolation transducer isolates control circuits in the WTA logic drawers from high generator field voltage, and amplifies the small field signal to a usable level. Its input is a signal representing the level of field excitation from a 1500A/100MV current shunt, and is used to control a magnetic amplifier. The output of the transducer is a 0 to ±10VDC signal. The Maximum Excitation (Inverse Time) Limiter receives its input from the isolation transducer. The overexcitation protective relay 76 receives it's input from parallel leads from the same field shunt, and provides overcurrent protection for the generator field in the event the MXL does not reduce field current.

Device 76 provides overcurrent protection for the generator field in the event the MXL does not reduce field current. The right hand contact energizes aux relay 76X, which drives the base adjuster to the rated load field setting (as determined by 70B adjuster limit switch S9 & S10) and picks up time delay relays 76T1 & 76T2. Relay 76T1 energizes relays 94RA & 94RB switching the system to manual control. Relay 76T2 energizes the unit lockout relay energizing excitation lockout relays 86EX1 & 86EX2.

The 86EX2 relay trips the 41 field breaker to protect the field, and the 86EX1 relay removes the 41 field breaker close permissive. This protection is not currently available during an emergency since the 86N LOR is overridden by an emergency start signal.

Settings

This discussion refers to the new IT modules to be installed by MM OE-6850 & 6851. The proper settings for the IT module will be determined by observing the output voltage with the application of a 0-100mV test signal at the field shunt leads (SH1 & SH2). The Gain (R20) potentiometer shown on Westinghouse Diagram 688C524-C should be adjusted such that a +5V (± 10%) should be observed at the output terminals when a signal equivalent to 1 p.u. field amps to is applied to the input. Field current at rated load is 1140A, which would correspond to 76mV at the shunt to calibrate the R20 pot.

The MXL pickup value is set to start timing at 1.05pu field amps, or 5.25V on the transducer output. It has an inverse time characteristic, and is currently calibrated to pickup in 180 seconds at 120% field current. The 76 relay is set to pick up at 1.10pu, or 83.6mV on the field shunt, and the current setting of 76T1 is 195 Sec, and 76T2 is 200 Sec.

The MXL & OXP settings were plotted on a graph (Attachment 5) with the generator thermal limit curve (from Attachment 1) and the maximum available converter output voltage of 325VDC or 175% of the rated field voltage (186VDC). These curves reveal the MXL does not protect the field at higher levels of overexcitation. The MXL time dial shifts the inverse time curve shown on attachment 5, page 2 of 2 to the left or right (the curve on att 5, page 1 of 2 would thus shift up or down), and should be set low enough to ensure the field winding is protected for all possible levels of overexcitation, but high enough to not interfere with generator forcing requirements. There are not any documented studies on forcing requirements, but System Planning Stability studies are typically run for approximately 20 seconds. To provide protection over the entire range of possible converter output voltage, it is recommended to set the MXL to pickup at 105% as before, and set timer to time out in 120 seconds at 120% (see Attachment 5 page 1). This setting completely protects the field winding, while providing over 50 seconds of forcing capability at full overvoltage. The lowering of the MXL time setting is not expected to impact the ability of the unit to supply rated MVARs, which is based on the field winding thermal capability.

Failures which would cause the exciter voltage to go extremely high would be detected by other protective devices (e.g. firing circuit overvoltage module, 60 loss of potential relay, & V/Hz). Thus, the 76T1 & 76T2 timers should be calibrated to protect the field winding during lower levels (prolonged periods) of overexcitation. It should coordinate with the rotor thermal limit curve and MXL module at lower levels of overexcitation. The 76 relay pickup should remain at 83.6mV. The 76T2 timer should be left to pick up at 200 seconds. Relay 76T1 time will be left to be 5 sec less than 76T2 (195 seconds). These settings coordinate well between 110 & 130% of rated field current. These settings meet the criteria delineated in EQ-4.02, and IEE C37.102.

References: KM-312-12, KM-312-68 (conn diagram), KEE-112-4, EQ-4.02 (Electrical Discipline Design Criteria Manual, section 5.2, Overexcitation Protection), IEEE C37.102, IEEE Guide for AC Generator Protection (section 4.2, Field Thermal Protection).

6.7 Loss of Potential Protection

The 60 Voltage Balance Relay protects the generator from high voltage transients caused by blown regulator PT fuses. This relay monitors and compares the regulator (intelligence) and metering PT's and trips the unit to manual if the voltage from the regulator PT is low compared to the meter PT. This relay is a GE type CFVB11A relay, which is factory set for pickup when regulator PT voltage is 80% of the meter PT voltage. This setting will detect a single blown PT fuse, and is adequate. Reference GEI-31030C, Voltage Balance Relay IB.

6.8 Current Compensator Settings

The voltage regulator is equipped with three current compensator modules, the Reactive Droop, Reactive Line Drop, and Resistive Line Drop Compensators. Each module takes a signal from the C to V transducers representing current out of the machine, and modifies the voltage sensed by the voltage error detector. Each compensator can be dialed to provide no impact on sensed voltage, or to provide as much as 10% compensation. The droop and line drop compensators modify the voltage signal in opposite ways, so both should not be used concurrently.

The Reactive Droop module is currently set at 4%, which means that at rated reactive load out of the machine (48.125 MVAR from Attachment 2, pg 1), generator voltage will be 4% less than the no load voltage. A test was recently conducted where a RCP was started on the unit. The MVAR measured during the start transient was 43 MVAR, and a droop of approximately 3.6% was recorded, vs. a predicted 3.57% (43/48.125*4%).

Conversations with Joe Hurley of Westinghouse have revealed that the 4% setting is a typical value used for reactive droop. Reactive droop is necessary in configurations where multiple generators are connected together at their output terminals with no appreciable impedance in between. This droop is used to ensure the units will share changes in system load appropriately, and is not necessary when a generator has its own stepup transformer. The impedance across the Keowee transformer primary windings is 30%, and thus reactive droop is not necessary. Reference Attachment 6, Conversation Record Sheet for phone calls to Joe Hurley.

In response to the issue of maximizing the MVAR capability of existing facilities, system planning has requested we implement line drop compensation. This feature will cause generator output voltage to increase as reactive load increases. With the existing MSU transformer tap setting, the generator normal output voltage is high (roughly 13.8KV when synched to a 230KV grid) with the machine unloaded. The generator voltage will be limited by the V/Hz limiter, defeating the effect of the line drop compensator. Even though it won't be completely effective, this feature can be implemented before the tap change is done.

System planning has requested the reactive line drop compensator be set to compensate for 60 to 80% of the MSU transformer impedance. The method suggested for computing this is to take .8 * the MSU reactance and convert it to the generator base. Thus, this module should be set to provide 14.68% * 0.8 * 87.5MVA / 102.5MVA ≈ 10%. Reference Attachment 4 for transformer impedances and MVA ratings.

6.9 XASV Automatic Generator Synchronizing System

The Keowee generator is designed to be automatically synchronized to the system grid during commercial operation across ACB 1 or 2, and the XASV Synchronizer provides a control signal to the Regulator Voltage Adjuster and governor speed adjuster motor. The synchronizer is not required and the input signals are disconnected during an emergency start, and the Synchronizer is considered non-QA. For completeness, the synchronizer settings will be covered.

Synchronism can be defined by characteristics of voltage magnitude and phase difference. Two sources are considered "Synchronized" when the voltage magnitudes are matched, and the phase angle between the two sources is zero. At the moment the breaker closes, the two sources should be synchronized to minimize the electrical transient when the systems are connected.

The XASV Synchronizer provides control signals to the generator voltage regulator to match voltage magnitude, and to the governor speed changer motor to control frequency such that the generator frequency is slightly higher than grid frequency. It is impractical to exactly match frequency, and slightly higher generator frequency is desirable to cause the generator to pick up load once the breaker closes.

The synchronizer measures the rate of change in synchronization across the breaker, and computes the proper advance angle before synchronization at which the breaker close signal should be provided considering the ACB closing time. This will allow the breaker contacts close when the phase angles of the two sources are matched.

The XASV Synchronizer has four modules to provide proper synchronization across the ACB's. The X & A modules set the acceptable conditions of Voltage, ΔVoltage, ΔFrequency, and maximum phase angle for breaker closure, while the S & V modules provide the controls necessary to meet those conditions.

X - Automatic Synchronizer - Measures the Δfrequency between the two sources and using the breaker closing time, computes the proper breaker close signal advance angle which will allow the ACB main contacts to make at the moment of synchronism. It then compares the computed angle to the set limit. If the computed angle is less than the limit, the module supplies a close pulse to the breaker at the computed angle. If the computed angle is greater than the set angle, the close pulse is delayed until the speed matcher adjusts frequency to reduce the computed advance angle below the set limit. The module is equipped with the following controls:

- The Breaker Closing Time pot and multiplier is set to correspond to ACB-1 & 2 operating times. Currently set at .15 sec (.15 * 1 on unit 1 and .075 * 2 on unit 2).

- Advance Angle control pot sets the maximum advance angle (and thus provides a maximum rate of change in synchronism limit), at which the breaker close pulse can be generated. Convention for manual synchronization of two sources is to adjust frequency such that the synchroscope rotates 1 revolution in about 6 seconds. This rate would correspond to a advance angle for the ACB's of 9°. The set limit for automatic synchronism is currently at 15° both units, which is considered acceptable.

A- Voltage Acceptor - Prevents breaker closure if either source's magnitude, or the difference between the two sources is outside of limits. This module is equipped with the following adjustable controls:

- Lower Voltage Limit - Prevents closure if either source voltage is below the limit. Currently set at 97V on unit 1 and 100V on unit 2. The 100V setting would correspond to a grid voltage of roughly 200KV, which is well below the expected minimum grid voltage. For consistency, the unit 1 setpoint will be changed to 100V.

- Upper Voltage Limit - Prevents closure if either source voltage is above the limit. Currently set at 119V on unit 1 and 120V on unit 2. The unit 1 setpoint corresponds to a grid voltage of 236.37KV which is very close to the normal operating grid voltage. This could cause problems if it becomes necessary to connect a unit the grid with high voltage. This setpoint will be changed to 125V on both units which would correspond to a grid voltage of 248KV.

- Voltage Difference Limit - Prevents closure if the difference in source voltages is above the limit. This limit must be greater than the limit of the voltage matcher. This limit is currently set at 2V.

S- Speed Matcher - Becomes operable when generator frequency is within 10% of bus frequency. Measures online bus frequency, and controls incoming generator speed by providing correction (raise or lower) pulses to the generator speed controls. Is equipped with a speed kicker which senses if frequencies are exactly equal, and provides a signal to increase generator frequency sightly above bus frequency. This module is equipped with the following adjustable controls:

- Raise Speed Pulse Time. Currently set at 0.3 sec on unit 1 and 0.2 sec on unit 2.
- Lower Speed Pulse Time. Currently set at 0.2 sec on both units.
- Raise Kicker Pulse Time. Currently set at 10 sec on both units.

The lower raise speed pulse on unit 2 may be responsible for sluggish governor motor response and during synchronism, which has caused the unit to "go in the hole" or reverse power when synched to the grid. Since the raise & lower pulses drive the same speed changer motor, the lower pulse on both units and the raise pulse on unit 2 will be changed to 0.3 sec.

V- Voltage Matcher - Senses difference between the generator and bus voltage and provides a generator voltage control signal to the regulator voltage adjuster when the difference is above the adjustable setpoint. The control signal uses a pulse-wait scheme. The module on unit 1 has an adjustable pulse time and a fixed 6 second wait scheme. The unit 2 module has been replaced, and has adjustable pulse wait time.

- Accuracy. Currently set at 1V on unit 1 and 1.5V on unit 2.
- Pulse Duration. Currently set at 1 sec on unit 1 and 0.75 sec on unit 2.
- Unit 2 Wait time is currently set for 3 sec.

The voltage matcher provides a voltage correction signals to the voltage adjusters in the regulator on each unit. The pulse wait scheme should coordinate with the adjuster speed, which is the same for both units. The accuracy should be set to allow control to within the Voltage Acceptor Voltage Difference Limit, which is set at 2V. For consistency, the unit 2 settings will be changed to match unit 1 (Accuracy at 1V, Pulse Duration at 1 sec, and wait time at 6 sec).

6.10 Fan Control Circuits

Both excitation cabinets containing power amplifiers (EC2 & 3) are equipped with main (88M1 & 2) and reserve (88R1 & 2) cooling fans. The fans are started when Relay 88SV is energized when the supply breaker is closed, which picks up relays 88TD and 88X. Relays 88RAX & 88MAX should both be deenergized, since the exhaust louvers are closed with the fans off. The 88X relay will immediately energize the Main fans, and the resulting air flow should open both main exhaust louvers, and pickup 88MAX which will prevent starting the reserve fans when 88TD times out. If either main exhaust louvre fails to open, 88MAX will not be energized, and when relay 88TD times out, the reserve fans will start. If both reserve fan exhaust louvers open, the 88RAX relay will pickup, dropping out the main fans.

Relay 88SV is a SV relay connected to a full wave bridge with 120VAC applied, and is set at 100VDC. The 88TD is currently set at 13 seconds, and will be specified as 15 ± 2Sec. Both settings are adequate. Reference KEE-112-3 & 212-3.

6.11 Voltage Buildup Relays

As discussed in section 3.6 above, the 90XIC relay should be latched before 11 seconds to ensure the automatic regulator is placed in service as designed. The 53 relay picks up the 90XIC latching relay once voltage reaches its setpoint. Tests indicate the 53 relay will flip flop between on & off as voltage builds up at the reduced frequencies. The 90XIC (Westinghouse MG-6 relay) requires 60msec to pickup per Attachment 8. Tests indicate the 53 relay contact will be closed for at least 60 msec by 9 seconds into the start sequence, thus this design is adequate.

According to KEE-113-B, the 53 relay should pickup when generator voltage reaches 20% of nominal voltage, which corresponds to 23VAC on the regulator PT secondary. However, the relays currently installed have a minimum pickup of 70VAC (60%). As discussed above, the current design is adequate. These setpoints will be added to the setpoint document, and the 20% setpoint should be deleted from the KEE.

The SV relays are to be replaced for SQUG concerns. The new 53 relay should be selected to allow pickup of the 90XIC earlier (before 8.5 sec), to allow for the 90XIA/TD time delay (2.5 sec) to expire before the unit is loaded. Assuming frequency increases linearly as the machine accelerates, the buildup relays must be able to sense this voltage with input frequency as low as 25Hz (8sec/18sec* 60Hz).

The field flash breaker has an automatic signal to trip during start up. The SV (to be called 53-31T) voltage buildup relay was installed as a field revision during installation testing, and is set at approximately 100VAC on the potential intelligence transformer. This relay trips the field flash breaker once generator voltage has reached a level where the generator can provide its own excitation power. The ability of the generator to supply its own excitation with reduced terminal voltage was discussed with Gene Forte of Westinghouse, who indicated that the unit should be capable of supplying its own excitation above 20% voltage. The new relay for this application should be set the same as the 53 relay, to trip the field flash power off, and allow the exciter output to control the field current.

If a problem exists where voltage fails to build up, the 31TD relay will trip the breaker to protect the DC system battery. KC-75 has a record of DC system current during a black start test. The field flash transient lasted approximately 10sec before the SV-2 relay tripped the 31 breaker. The DC voltage adequacy calculations KC-75 & 76 assume the flashing current is available for one minute. Currently set at 30 on unit 1 & 45 seconds on unit 2, the time delay should be set for 45sec. on both units.

6.12 Minimum Excitation Limiter

The MEL provides the lower limit for generator field excitation. This function is used for two purposes, (1) To ensure stator thermal operating limits are not exceeded when operating as a synchronous condenser, and (2) Maintain the unit characteristics above the Steady State Stability Limit (SSSL) curve to protect against unit instability. The MEL module is used to prevent machine excitation from decreasing below a variable level depending on the generator output power (MVAR & MW) characteristic.

The MEL would typically be set to maintain generator output above the SSSL curve (reference Eng Criteria Manual EQ-4.02), and coordinate with the 40G Loss of Field relay (see OSC-4300 Appendix F), which provides a protective trip of the unit before it enters a dangerous condition. At Keowee the generator capability curve is the limiting characteristic, and the MEL should be set to maintain the unit operation within capability limits. Figure 2 of EQ-4.02 specifies a minimum margin of 5% between the capability curve for units that are tested, and 10% for units that are not tested. The Keowee units will be calibrated periodically, thus the 5% margin will be used.

The Keowee Generator Capability Curve capability curve is defined by the stator and rotor thermal limits, and is a plot of complex power $S = P + jQ$ (attachment 2, pg 1). Normal operating condition for the Keowee generator is to be overexcited, with a lagging power factor and supplying MVARS to the system grid (synchronous condenser operation of Keowee is not currently allowed). The MEL will thus serve to prevent failures of the voltage error detector causing the limits to be challenged. The curve will be drawn to meet the criteria in EQ-4.02, and approximate the thermal limit curve as much as possible without imposing limits on normal overexcited operation.

The method for setting this relay is to first construct a curve for the desired setting. This curve is a circle whose center is somewhere on the positive Q axis, constructed to coordinate with the capability curve. These curves are shown on Attachment 2, page 1. The actual pot settings are determined by field adjustments to the module dials until the module output approximates the specified curve. In practice, the voltage (from the PT), current (from the CT) and phase angle for 3 points on the curve are calculated. These values are used as inputs to be injected into the regulator circuits. The MEL pots are adjusted as required until the module output becomes more positive than (and thus takes control due to the positive auctioneering diodes) the Voltage Error Detector Output with the same inputs applied.

The following data is derived from the MEL curve in attachment 2, pg 1, and should be used for this procedure.

Base MVA = 87.5
Voltage = 13.8KV*120VAC÷14.4KV = 115VAC
VA = sqrt(MW^2 + $MVAR^2$) * Base MVA
Current = 5A ÷ 5000A * VA ÷ sqrt 3 * 13.8KV
Phase Angle = $\tan^{-1}$ MVAR/MW

MW	MVAR	PT Sec. Voltage	CT Sec. Current	Leading Phase angle
.1pu	.78pu	115VAC	2.88A	82.69°
.5pu	.66pu	115VAC	3.03A	52.85°
1.0pu	0	115VAC	3.66A	0°

It may not be possible to exactly mimic the curve drawn. The .1pu & 1pu MW points should be approximated as accurately as possible, and any error should be taken at the .5MW point.

6.13 Damping Module

This module will affect the system dynamic response to changes in generator output voltage/load. The input from the Isolation Transducer (representing field current) is capacitively coupled to an op amplifier. The capacitive coupling causes the input to the op amp to be 0 unless field current is changing. The Damping module will provide a signal to the signal mixer which the opposes the detected change. This will minimize the time necessary for voltage to stabilize after a transient.

Control pots are available for Time Constant & Gain. The pots are currently set at 5. The optimum settings can be determined by recording the dynamic response with a chart recorder, and adjusting until the response matches the optimum response as indicated on drawing 801A094 of KM-312-0089. This should be performed after the error detector gain is adjusted during a calibration procedure.

6.14 Voltage Adjusters

The Base (70B) & Voltage (70V) Motor Operated Adjusters are motor driven potentiometers controlled by remote control switches.

The 70B base adjuster controls dual potentiometers which provide an operator interface with the redundant firing circuits, to allow manual adjustment of generator voltage or reactive load.

The 70V voltage adjuster has a single potentiometer which provides an operator interface with the voltage error detector, to allow manual adjustment of generator voltage or reactive load when the regulator is operating in automatic. The output of the voltage error detector acts through the signal mixer, and will boost or buck the base adjuster signal, depending on the relationship between the actual generator voltage and the voltage adjuster controlled reference signal. The 70V voltage adjuster is controlled during non-emergency automatic unit startup by the Synchronizer, and is also adjusted by the operator as necessary to control reactive load when connected to the grid. Thus, this adjuster can not be expected to be at the preset position if an emergency start signal is received when connected to the grid.

Both are equipped with 10 adjustable cam switches, S1 through S10. Switches S1 & S2 are limit switches which limit the range of potentiometer travel. They are factory set, and should not require adjustment.

Switches S3 & S4 are used to drive the adjusters to the preset position after the unit is shutdown. The base and voltage adjuster preset positions will determine the unloaded generator voltage during an emergency start where the unit was not previously running. The base adjuster preset position will determine the generator voltage during manual startup, or in the event of a voltage regulator failure.

The Keowee voltage band is discussed in section 3.4.1 above. According to conversations with the ESS regulator technicians, experience indicates that the accuracy of the preset position for the voltage and base adjusters is such that deviations more than 200VAC have not been experienced. This is less than 1.5% of 13.8KV. The accuracy of the test equipment used for calibration is well below 0.5% (.05V/110V). Thus, the preset positions should be set such that the generator voltage the unit is unloaded will be at least 2% above the minimum analyzed voltage to ensure emergency power system operation. A voltage of 13.77KV is 2% above the 13.5KV minimum analyzed voltage. Thus, the presets should be calibrated to provide a no load voltage of 13.8KV. These adjuster preset contacts should be set after calibration/changes of the voltage error detector to ensure generator output voltage will be at the desired value.

If the unit was automatically started, and is operating prior to an emergency start, the synchronizer has changed the voltage adjuster, and the position of the adjuster will affect the no load voltage of the unit during emergency operation. The base adjuster position is adjusted to control voltage manual unit operation. The adjuster positions in these cases may be different from the preset position, and probably will not correspond to the 14KV preset positions. A modification is recommended to place an emergency start contact in parallel with the 41/b contact in the 70V & 70B control circuits to drive the adjusters back to the preset positions.

Switch S5 & S7 pick up the high and low limit aux relays, which provides adjuster position indicating lights.

Switch S6 will energize a relay (70MVX & 70MBX) which provides a permissive interlock in the 4A & 4B Master Start solenoid circuit (ref. OEE-113). This permissive contact is bypassed by a ES signal, and will not impact the units ability to perform an emergency start. Contact S6 should be set to be closed when the adjuster is in the preset position as defined by switches S3 & S4.

Switch S8 on both adjusters, and switches S9 & S10 on the 70V voltage adjuster is not currently in use.

Switches S9 & S10 on the 70B base adjuster identifies the "adjuster rated load field position, where the base adjuster is driven by the OXP relay 76X. This position is not critical for emergency operation if the V/Hz protective trip is set as discussed in section 6.3 above, as this would only be a factor if a regulator failure caused an overexcitation condition on the generator. If this occurred during an emergency start, the overexcitation protection would cause the regulator to transfer to manual after driving the base adjuster to the 1p.u. position as defined by these switches. The V/Hz trip would ensure the unit would be tripped if excessive voltage (>110%) is being supplied to ONS. This analysis assumes and supports the move of the V/Hz trip signal to the 86E lockout relay. References KM-312-9, 13, KEE-112-4, KEE-112-5, OSC-5701, and KC-107.

6.15 Evaluation of Operation with the Regulator in Manual

The voltage regulator normally operates in automatic, and will act to restore generator voltage as it changes with varying load. Current voltage calculations which prove ONS voltage adequacy assume operation in automatic, which would not encompass the voltage dips expected with the regulator in manual. It will be assumed that operation in with the regulator in manual will cause the field voltage to be constant (see 3.1 above).

Generator no load voltage in manual will be determined by the base adjuster setting, which will be calibrated to provide nominal. With constant field current, the generator terminal voltage would decrease from the no load voltage as the unit is loaded. The worst case emergency load on the Keowee unit with the auto regulator failed and in manual would be one unit LOCA start loads of 7.42MW & 30.81MVAR. An analysis performed by Joe Hurley of Westinghouse assumed a constant impedance load of this magnitude, and revealed voltage out of the generator will decrease to 82.1% or 11.3KV while in manual under this load. This was well below any ONS emergency power system source voltage analyzed previously.

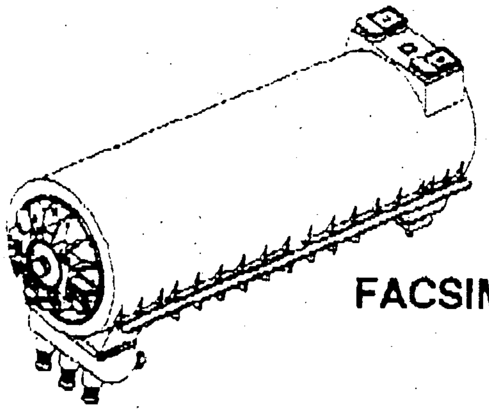
An analysis was performed and documented in OSC-5952 (case 3H & 3L) which used a dynamic model of the Keowee generator and emergency power path to assess the consequences of emergency operation with the regulator in manual. This analysis assumed constant field voltage at the no-load value as determine by the model, and showed that all ONS emergency loads would start and operate with the regulator in manual. Additional runs were made assuming a generator output voltage of 13.5KV to allow for expected tolerance of the no load voltage setting, and voltage was adequate, although marginally so. Thus, the Keowee generators will supply adequate voltage to ONS emergency loads with the regulator in either automatic or manual.

~~GS-5638~~

ATTACHMENT 1
Page 1 of 2

WESTINGHOUSE POWER GENERATION

THE QUADRANGLE
4400 ALAFAYA TRAIL
ORLANDO, FLORIDA 32826-2399



GENERATOR ENGINEERING
MAIL CODE - 00707-100
FAX NO. 407-281-3216 (WIN 439-3216)

FACSIMILE REQUEST FORM

To:
Name: Chris Schafer
Co./Dept: Duke Power
Location: Oconee Station
Dex Machine No: WIN ____
BELL (803) 885-4028
Verification Tele. #: WIN ____
BELL ____

From:
Name: JOE HURLEY
Dept: GENERATOR ENGINEERING
Tele #: WIN 439-2992
BELL (407) 281-2992

COMMENTS: I think that this is the curve you need. If not, please call me.

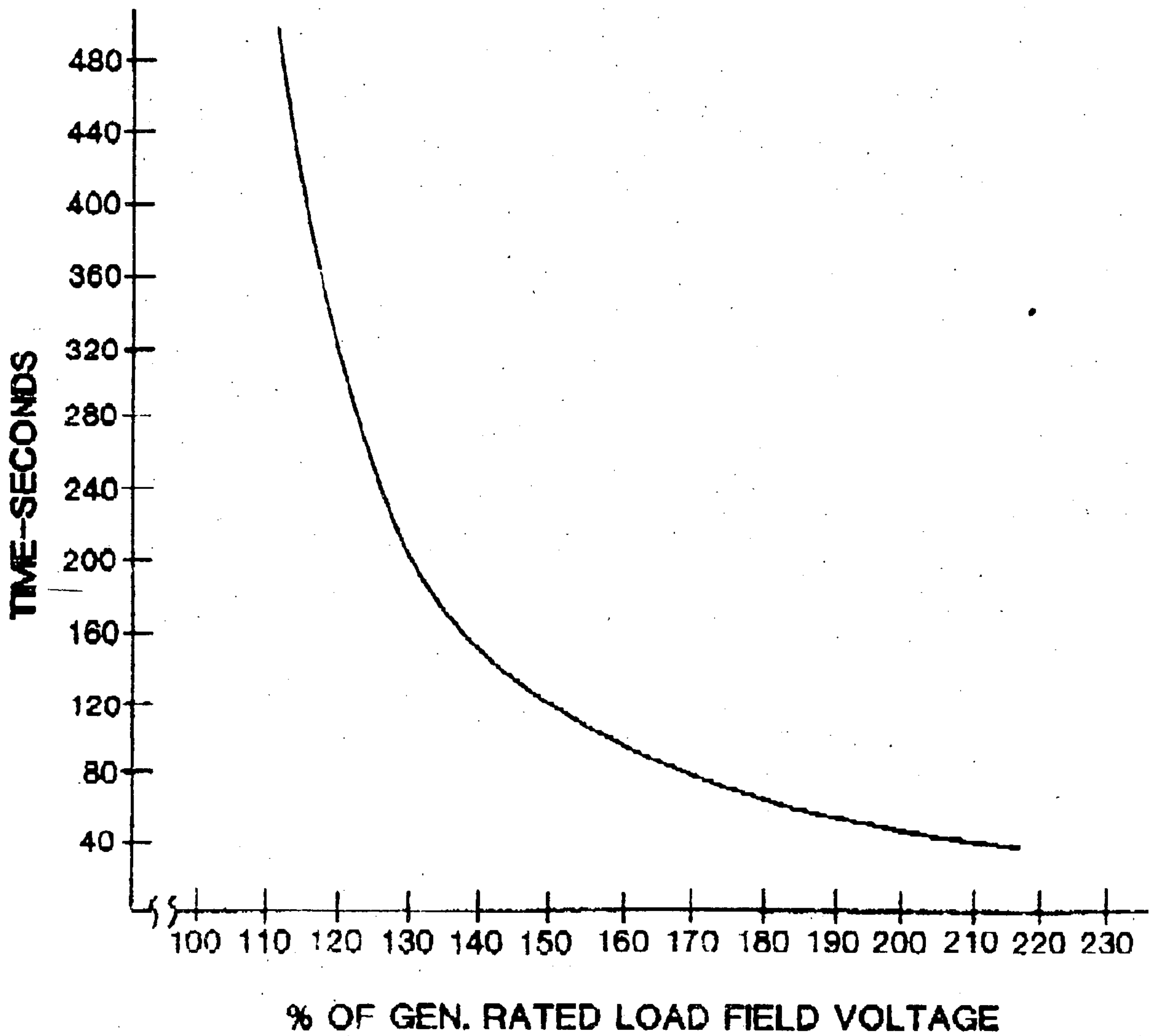
Joe Hurley 3/25/94

4/28/94 Called Joe for Rated Field Voltage = 186V CES

~~R = ... = 186V~~
Field R = .163Ω × 1140 A = 186V

No. of Pages Being Transmitted (including this cover sheet): 2

WESTINGHOUSE AIR COOLED HYDRO GENERATORS ROTOR SHORT TIME THERMAL CAPABILITY



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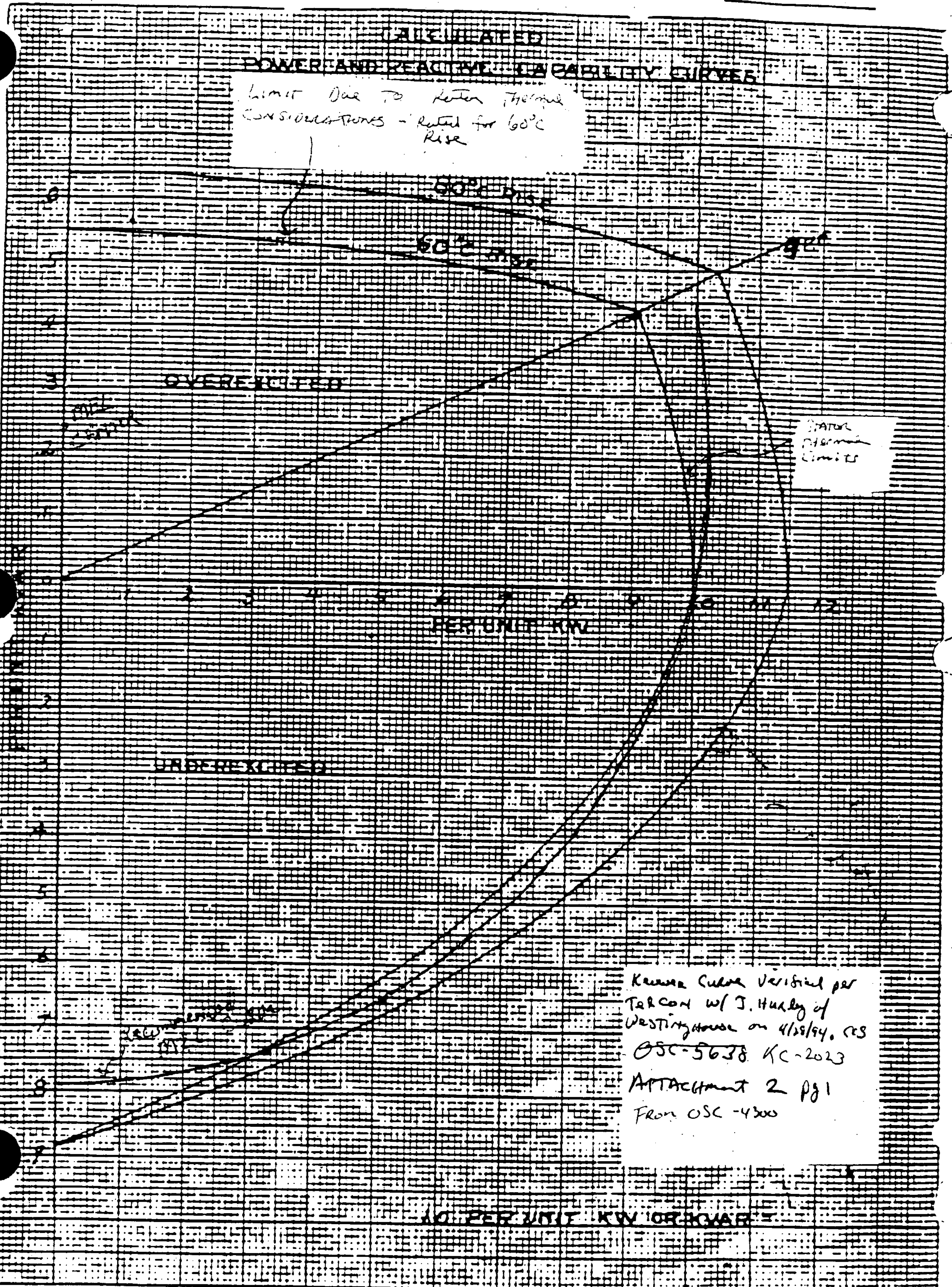

CALCULATED
POWER AND REACTIVE CAPABILITY CURVES
Limit Due To Rotor Thermal Considerations - Rated for 60°C Rise
80°C RISE
60°C RISE
OVEREXCITED
UNDEREXCITED
PER UNIT KW
Stator Thermal Limits
Kewaunee Curve Verified per Telcon w/ J. Hurley of Westinghouse on 4/28/94. RS
~~OSC-5638~~ KC-2023
ATTACHMENT 2 pg 1
From OSC-4300
1.0 PER UNIT KW OR KVAR

~~OSC-5633~~
ATTACHMENT 3
PAGE 1
KC-2023

WESTINGHOUSE INSTRUCTION BOOK

VERTICAL WATERWHEEL GENERATOR

DUKE POWER COMPANY
KEOWEE HYDRO PLANT

GENERATOR MASTER ORDER 74P0910
GENERAL ORDER CH-36800

INSTRUCTION BOOK NO. EP-1020-19V
JANUARY 1970

NAMEPLATE DATA

SERIAL NUMBER 74P0911
SERIAL NUMBER 74P0912
RATING ....87500 KVA
VOLTAGE 13800
AMPERES 3661

SPEED .... 8.
TEMPERATURE RISE ... 60°C
FREQUENCY .... 60 H
PHASE 3

APPROVED
DUKE POWER CO.
DATE: DEC 12 1969
T. EARL CARPENTER
CHIEF ENGINEER
By: ELECTRICAL DIVISION

WESTINGHOUSE ELECTRIC CORP.
LARGE ROTATING APPARATUS DIV.
EAST PITTSBURGH, PA.

Original Date
RECEIVED
OCT 2 4 1969
DUKE POWER COMPANY
DESIGN ENGINEERING

Insertion
DOCUMENT CONTROL DATE
AUG 0 1 1988
DESIGN ENGINEERING
DUKE POWER COMPANY

KM 300. --0034 001 CONTROL CO

KM-300-34-1
TAB 3

~~GSC-5638~~
ATTACHMENT 3
PAGE 2

CALCULATED PERFORMANCE & DATA

(A) Generator Losses in KW at Various Loads, Rated Power Factor

	% Load	115%	100%	75%	50%	25%
1.	Friction & Windage	600	600	600	600	600
2.	Core Loss	330	330	330	330	330
3.	Stray Load Loss	224	169	95	43	11
4.	Armature I^2R	290	219	123	55	14
5.	Field I^2R	237	205	165	130	98
6.	Excitation System	14	12	11	10	10
7.	Total Losses	1695	1535	1324	1168	1063

(B) Generator Losses in KW at Various Loads, 100% Power Factor

	% Load	115%	100%	75%	50%	25%
1.	Friction & Windage	600	600	600	600	600
2.	Core Loss	330	330	330	330	330
3.	Stray Load Loss	224	169	95	43	11
4.	Armature I^2R	290	219	123	55	14
5.	Field I^2R	145	128	112	97	84
6.	Excitation System	12	10	9	9	8
7.	Total Losses	1601	1456	1269	1133	1047

(C) Reactances and Resistances

.3

1. Direct axis, synchronous reactance = 94%
2. Quadrature axis, synchronous reactance = 49%
3. Direct axis transient reactance, unsaturated = 30%
4. Direct axis subtransient reactance, unsaturated = 23.5%
5. Quadrature axis, subtransient reactance, unsaturated = 28.5%
6. Negative sequence reactance = 26%
7. Zero sequence reactance = 10.5%
8. Resistance of stator winding, per phase, at 25°C = 0.0046 ohms
9. Resistance of field winding at 25°C = 0.132 ohms

(D) Generator Field Currents

1. At rated KVA, rated P.F. lagging = 1140 amps
2. At 115% KVA rated P.F. lagging = 1230 amps
3. At rated KVA, unit P.F. = 900 amps

(E) Net Weights

1. Complete generator = 1,130,700 lbs.
2. Rotor less shaft = 538,000 lbs.
3. Main shaft = 80,000 lbs.
4. Stator with coils, less coolers = 269,000 lbs.
5. Bearing bracket = 46,500 lbs.
6. Air Coolers = 3100 lbs. each
7. Miscellaneous parts = 178,000 lbs.
8. Excitation cubicles = not by LRA
9. Rotating parts = 618,000 lbs.
10. Heaviest assembly to be handled by crane during field assembly = Rotor + lift device = 546,470 lbs.
11. Heaviest assembly to be handled by crane during field erection = 546,470 lbs.

WESTINGHOUSE ELECTRIC CORPORATION

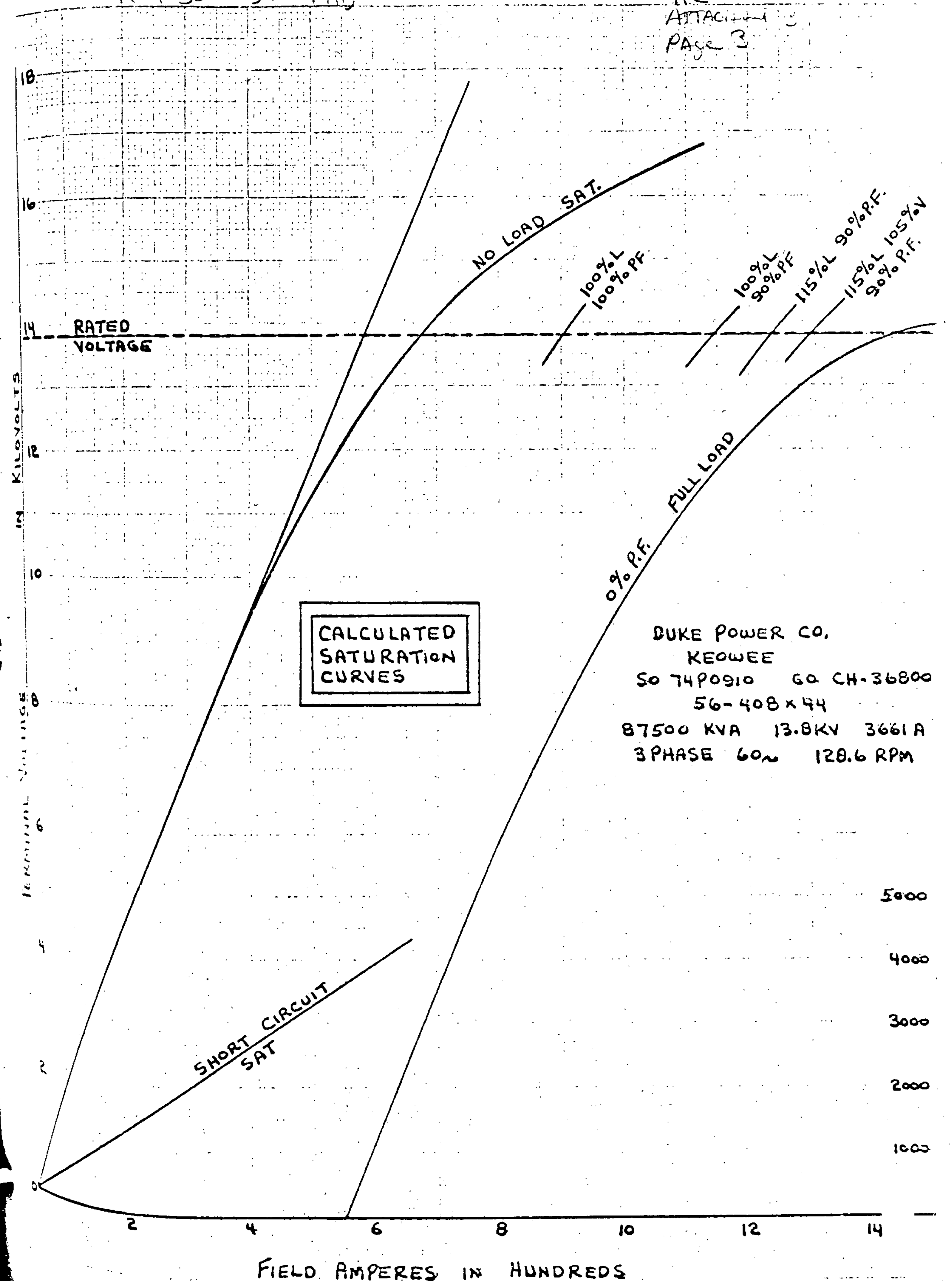
KM 300-34 TAB.

CURVE NO. 620538

KC-2023

ATTACHMENT 3

Page 3



E Bartels 8-21-69

620538 (1002)

KM 301-9 Kec[illegible]

File No.
Use Main Pwr. Transfer Name Plate
Mfr. General Electric Dwg. No. 253890
Transmittal Date 11-13-70 Copies 13

Sub		
Rec		
Rev A	TJA	11-9-70

RDD.

Final Disposition

Mfg

1 Folder

2 File

[redacted]

KEM-2

RECEIVED
NOV 2 1970
DUKE POWER COMPANY
KEOWEE 1 & 2

"Unit [illegible]"
For Reference [illegible]

Keowee
Main step-up

APPROVED

DUKE POWER COMPANY
By: J. Earl Carpenter Date NOV 10 1970

OSC-5636
UC-2023
ATTACHMENT 4 pg 1/42

PO 7240023   REQ 340 12587

(7) 280 HOLES
(4 HOLES LOCATED IN BLACK BAND AT TOP, 3 IN BOTTOM BAND)

2.750 — 2.750

GENERAL ELECTRIC

TRANSFORMER

NO. ~~M-P-2 DS96433~~   CLASS FOA   THREE-PHASE   60 CYCLES

VOLTAGE RATING 230000GR Y 132790 13200 13200
KVA RATING 205000 CONTINUOUS 55 C RISE FORCED OIL AND FORCED AIR COOLED
KVA RATING 230000 CONTINUOUS 65 C RISE FORCED OIL AND FORCED AIR COOLED

• : POLARITY MARK
C.T.'S A, B ARE FOR USE WITH INDICATING THERMAL RELAYS AND HOT WINDING TEMPERATURE INDICATORS.

"H" WINDING CONNECTIONS

LINES ON 1, 2, 3 — NEUTRAL ON 7

VOLTS	230000 KVA AMP	DIAL POS	TAP CHANGERS NO 1, 2, 3 CONNECT
241500	550	1	A TO B
235750	563	2	B TO C
230000	577	3	C TO D
224250	592	4	D TO E
218500	608	5	E TO F

"X" WINDING CONNECTION — LINES ON 4, 5, 6

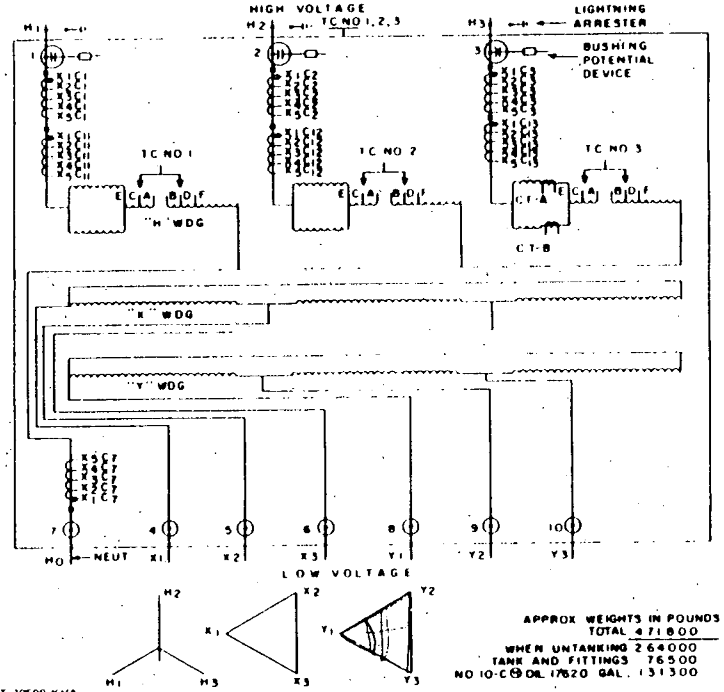
VOLTS	115000 KVA AMP
13200	5030

"Y" WINDING CONNECTION — LINES ON 8, 9, 10

VOLTS	115000 KVA AMP
13200	5030

BASIC INSULATION LEVELS

ITEM			IMPULSE LEVEL FULL WAVE KV
H1	H2	H3	900
X1	X2	X3	110
Y1	Y2	Y3	110
	H0		110



SUITABLE FOR OPERATION WITH THE NEUTRAL EITHER SOLIDLY GROUNDED OR GROUNDED THROUGH AN IMPEDANCE WHICH WILL LIMIT THE LOW FREQUENCY AND IMPULSE VOLTAGES FROM NEUTRAL TO GROUND TO VALUES CONSISTENT WITH THE INSULATION LEVELS SHOWN ON THIS NAMEPLATE.

TRANSFORMER OPERATING PRESSURE RANGE IS 0.6 PSI POSITIVE TO 0 PSI
TRANSFORMER TANK SUITABLE TO WITHSTAND 5 PSI PRESSURE AND FULL VACUUM WITH ALL TANK BRACING IN PLACE.
C.T.'S NO. 1, 2, 3, 7, 11, 12, 13 ARE 1200/5 AMP.
REFER TO C.T. OUTLET NP 224450 FOR CONNECTIONS AND RATIOS.

IMPEDANCE VOLTS 14.37 PER CENT 230000GR Y 13200 (X WDG.) VOLTS AT 102500 KVA
IMPEDANCE VOLTS 14.63 PER CENT 230000GR Y 13200 (Y WDG.) VOLTS AT 102500 KVA
IMPEDANCE VOLTS 30.06 PER CENT 13200 (X WDG.) 13200 (Y WDG.) VOLTS AT 102500 KVA
IMPEDANCE VOLTS 14.08 PER CENT 230000GR Y 13200 (X WDG.) 13200 (Y WDG.) VOLTS AT 20500 KVA

APPROX WEIGHTS IN POUNDS
TOTAL 471800
WHEN UNTANKING 264000
TANK AND FITTINGS 76500
NO 10-C OIL 17620 GAL. 131300

NP 253890

CAUTION! BEFORE INSTALLING OR OPERATING READ INSTRUCTIONS GEK-16423

ATMOSEAL OIL PRESERVATION SYSTEM

PITTSFIELD MASS   MADE IN U.S.A.

5.430 — 2.750 — 2.750
16.375
17.000

ETCHED STN STL C59F1E2, .020THK ETCHING FILLED WITH BLACK BAKING ENAMEL

AREA 204.000 SQ IN

NPF 105949 (2-57)
REV 2 (4-66)

REVISIONS   PRINTS TO

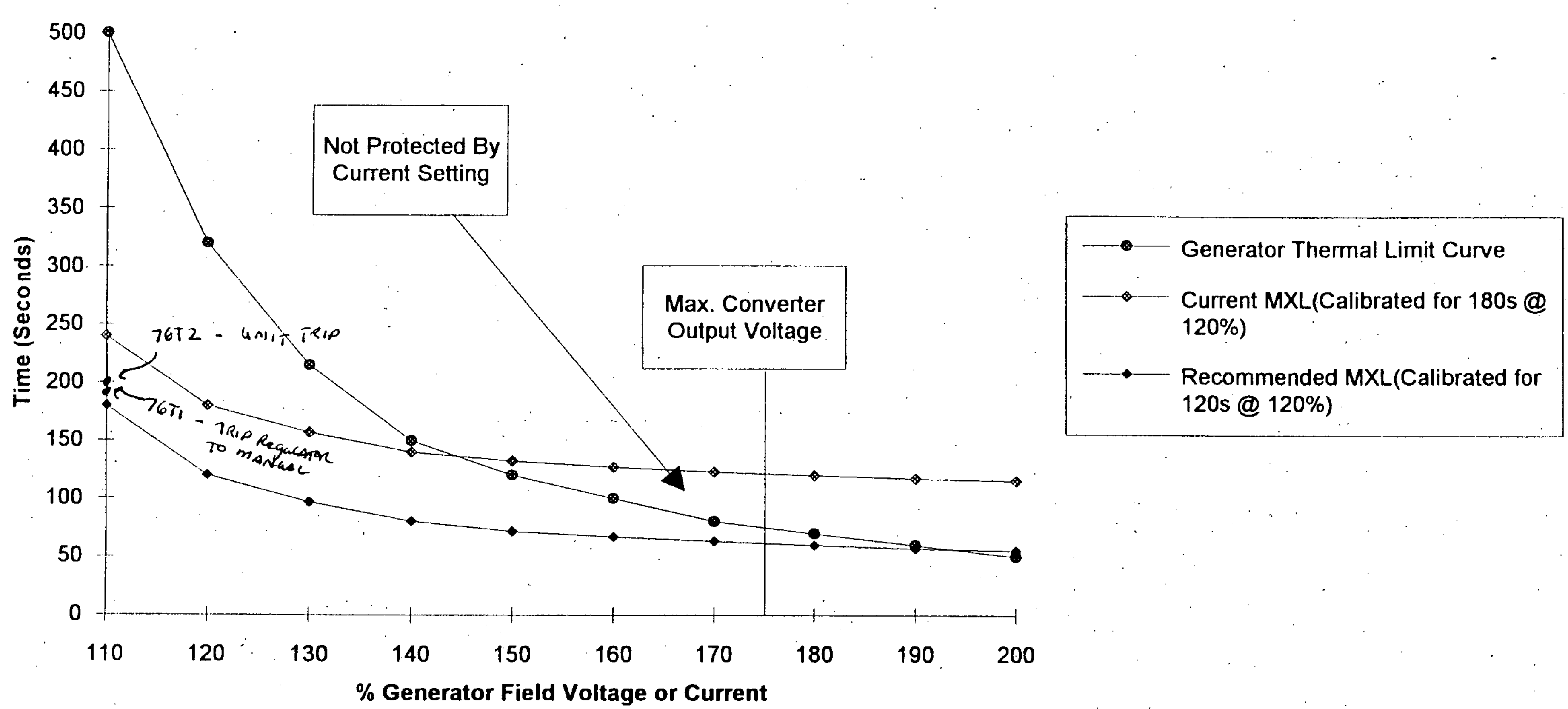
NP 253890

Uncontrolled Copy
For Reference Use Only

KC-2023
GSE-5632
Attachment 4 pg 2/2

ATTachment 5
Page 1 of 2

MXL COORDINATION WITH FIELD THERMAL CAPABILITY CURVE



KM - 312 - 0089
TAB 8
MXL Time Curve

~~OSC-5638~~
Attachment 5
Pg 2 of 2
KC-2023

4. With no inputs, output of A1 should be saturated at approximately +10 volts, A2 -10 volts, A3 -10 volts, A4 +10 volts.

5. Apply a signal to the input and observe that the output of A1 changes from positive to negative as the input exceeds the built in reference. (100% pickup point)

6. Check that A2 switches when the output of A1 is about -1 volt. (This corresponds to 10% over pickup.)

7. Check that A3 amplifier output starts to change from approximately -10 volts toward positive once A2 has switched. The rate that A3 changes voltage should increase as the input to A1 is increased.

8. When the output of A3 reverses polarity check that terminals 3 and 4 become positive and that the output of amplifier A4 switches negative.

9. Reduce the input signal to A1 and observe that 11 amplifiers reset when input signal drops to approximately 95% of pickup (+1/2 volt out of A1).

10. Replace with a new P-C module if above steps indicate a failure.

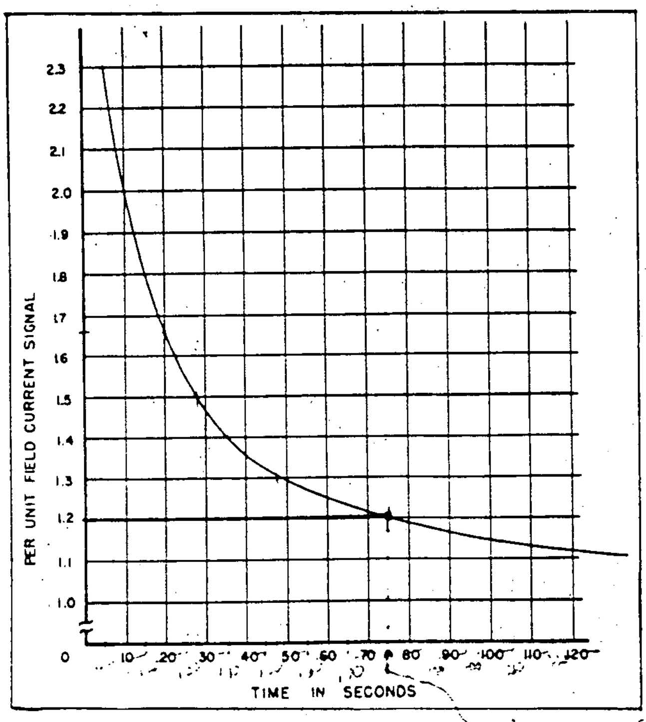


Fig. 1 *Inverse Timer Characteristic Curve*

If any of the foregoing checks indicate malfunction, replace the module with a new one and return the defective module to the factory for repairs. Contact your local Westinghouse District Office for return authorization.

CAUTION

Modification and/or repair of printed circuit boards requires careful handling by skilled personnel and often also requires special tools and test equipment; therefore, no attempt should be made to modify or repair printed circuit boards in the field.

Any attempt to make field modifications or repairs to the printed circuit board by the Purchaser will invalidate the warranty on this module.

SPARE PARTS

In order to minimize down time in event of a failure of this module, it is suggested that one spare module be kept on hand. When ordering spare printed circuit modules, be sure to refer to the style number that is printed on the face of the board.

DUKE POWER COMPANY
TELEPHONE CONVERSATION REPORT

PROJECT Keowee Voltage Regulator FILE NO. OSC-5638

SUBJECT Reactive Droop, Line Drop Compensation, and MEL Settings.

PERSON CALLED Joe Hurley, Westinghouse

DATE 5/18/94 and 6/8/94 TIME Various

PERSON CALLING Chris Schaeffer

SPECIFICATION NUMBER

SUBJECT DISCUSSED Use of Reactive Droop and Line Drop Compensation

RECOMMENDED RESOLUTION Reactive Droop is required when two generators are paralleled together at their terminals. The 4% Reactive Droop dialed in at Keowee is probably a typical value used when reactive droop is required. No other bases exists for the amount of droop used. If unit has its own stepup transformer, reactive droop is not necessary. Questioned if the split primary Keowee Stepup transformer would also permit operation without reactive droop. He agreed that the split primary is the same as if each unit had separate stepup transformers. The important characteristic is the impedance between the generator terminals. He agreed that reactive droop is not required for Keowee.

We then discussed the MEL settings and the generator capability curve. Several philosophies exist on setting the MEL. Typically, it is the responsibility of the operator to maintain the generator within thermal limits, and protective circuits are provided to prevent unit damage which an operator could not react fast enough to prevent. The key for the MEL is to coordinate with the Loss of Field relay, to attempt to allow continued operation without a unit trip. The MEL set inside the generator capability curve would be a conservative approach, although the current setting just outside the curve is typically how the unit is set elsewhere.

SIGNED C.E.Schaeffer

DUKE POWER COMPANY
TELEPHONE CONVERSATION REPORT

PROJECT Keowee Regulator Setting Calc FILE NO. OSC-5638

SUBJECT Keowee Excitation System Efficiency.

PERSON CALLED Joe Hurley, Westinghouse

DATE 10/16/94 TIME 4:30

PERSON CALLING Chris Schaeffer

SPECIFICATION NUMBER

SUBJECT DISCUSSED Effect of Manual Regulator Operation on Generator Output Voltage.

RECOMMENDED RESOLUTION Joe was called to get a feel for what generator voltage would be expected with the regulator in manual. He had a computer program he could use to determine voltage under loaded conditions with constant field current. He was asked to model a Keowee unit with several load levels. With a load of 7.42MW & 30.81MVAR (equivelent to 1 ONS unit LOCA start load), he determined terminal voltage would decrease to 11.33KV. With a load of 6.257MW & 3.82MVA (one ONS unit's LOCA running load), he determined that voltage would be 13.46KV.

SIGNED C.E.Schaeffer

Form 1021

KC-2023
~~OSC-5638~~
Attachment 6
Page 3 of 3

DUKE POWER COMPANY
TELEPHONE CONVERSATION REPORT

PROJECT Keowee Regulator Setting Calc FILE NO. OSC-5638

DATE 3/14/95 TIME 4:00

PERSON CALLING Chris Schaeffer

SPECIFICATION NUMBER

SUBJECT DISCUSSED Effect of decreased Generator Output Voltage when loaded on Field Current when in manual.

RECOMMENDED RESOLUTION Joe was called to what effect decreasing generator output voltage has on field current when in manual. When voltage decreases as the unit is loaded, the voltage supplied to the SCR bridge would decrease, and thus the bridge output voltage would decrease. However, the firing circuit Bias signal will vary with generator output voltage and provide compensation for the decreased voltage be causing the SCR's to fire earlier. The question is which effect would dominate. See Attachment 10 for Response

SIGNED C.E.Schaeffer

~~OSC-5638~~
ATTACHMENT ~~6~~ 7
Pg 1 of 8
KC-2023

Panafax Message

Panafax No. 803-885-4418 Req. No.:
Cover Sheet Plus 8 Pages Prop. No.:

To: Chris Shaffer - Duke

From: ELSIE SMITH
General Electric Company
One Coliseum Centre
2300 Yorkmont Road - Suite 600
Charlotte, NC 28217
Internal GE Phone No.: 8*582-7156 Panafax No.: 8*582-7171
External GE Phone No.: (704) 329-7156 Panafax No.: (704) 329-7171

COMMENTS: Please see attached information. Hopefully it will answer your question about volts per turn on transformers.

Date: 4/22/94 Time:

GET-3xxx
Supersedes GET-3344A

KC-2023
35C-5638

ATT 7
pg 3

OVEREXCITATION OF POWER TRANSFORMERS

OVEREXCITATION DEFINED

Overexcitation, as used herein, describes a condition of excessive flux in a power transformer. A common measure of the flux is the per unit excitation which is defined as the per unit voltage divided by the per unit frequency. The base quantities for voltage and frequency are the rated values.

Overexcitation exists when the limits specified by USA Standard C57.12.00 section 2.4 are exceeded. The Standard can be summarized as follows:

A transformer shall be capable of:

(a) Operating at 105 percent of rated secondary voltage while delivering rated output kva (≥ 0.80 pf lagging).

(b) Operating at 110 percent of rated secondary voltage at no load.

The limits apply to the rated secondary voltage or to the rated voltage and kva of any tap, only when operating at rated frequency. At other than rated frequency, the limits must be considered as applying to volts per hertz. Changed per [illegible]

CAUSES

Power system operating conditions may cause overexcitation of a power transformer and other connected apparatus. See Reference 1 listed at the end of this leaflet. Overexcitation can occur under circumstances such as the following:

1. *During regular operation* system operating practices might allow the transformer voltage (at rated frequency) to exceed the limits permitted by USA Standards. See Reference 2.

2. *During generator start-up and shutdown* overexcitation can be caused by reduced frequency operation, if the voltage is not reduced proportionately.

3. *When a malfunction occurs* in the controls of a generating station, a variation from the normal generator voltage and speed can produce damaging excitation levels.

4. *When various system regulators, breakers and relays misoperate, or when special tests are performed* on parts of the system, overexcitation can result.

5. *System emergency operation*, particularly during and after a major power disturbance, can cause an unbalance between generation and load which may result in underfrequency and/or overvoltage operation.

Underfrequency operation can occur for the system as a whole, or for any subdivided component part of the system that encompasses at least one generator, during a period when load exceeds generation.

Overvoltage operation may occur during load rejection or when a system is being pieced together after having been split apart by a disturbance. A transformer at the end of a long unloaded line or cable can be subjected to abnormally high voltage because of the voltage rise along the line produced by the flow of the capacitive line charging current.

EFFECTS

The major concern, relative to overexcitation of power transformers, is thermal degradation of insulation resulting from stray flux heating, rather than electrical breakdown of insulation due to overvoltage.

Excitation levels above those prescribed by the USA Standards may result in more flux than the core steel can contain; thus the core becomes saturated. The overflow flux strays into winding conductors, leads, and structural parts, where eddy currents produce losses and heating. If the heat so produced cannot be dissipated readily, permanent damage to adjacent insulating materials may result.

GENERAL ELECTRIC

~~OSC~~-5638
ATTACHMT 7
Pg 2 of 8
KC-2023

FAX TO: ELSIE SMITH USE CHARLOTTE 8*582-7171

FROM: JOHN PERRY LTSO PITTSFIELD 8*236-3999

DATE: APRIL 22, 1994

RE: DUKE POWER / OVEREXCITATION LIMITS

Attached is a copy of GET-3364B "Overexcitation of Power Transformers". The additional three sheets are up-to-date modifications to the standard GET-3364 which were never incorporated into the booklet. The booklet and addendum give "rule of thumb" limits for overexcitation under both no-load and load conditions. If greater details are required on the specific unit, a study will be required. Paul Bourassa can quote such a study if needed.

Best regards,

John Perry

FROM: J. H. (JOHN) PERRY
GENERAL ELECTRIC COMPANY
LARGE TRANSFORMER SUPPORT OPERATION
100 WOODLAWN AVENUE
PITTSFIELD, MASSACHUSETTS 01201
MAIL DROP B-14

PHONE: (413) 494-2512
8*236-2512

FAX: (413) 494-3999
8*236-3999

DSE-5638
ATT. 7
Pg 4 of 8
KC-2023

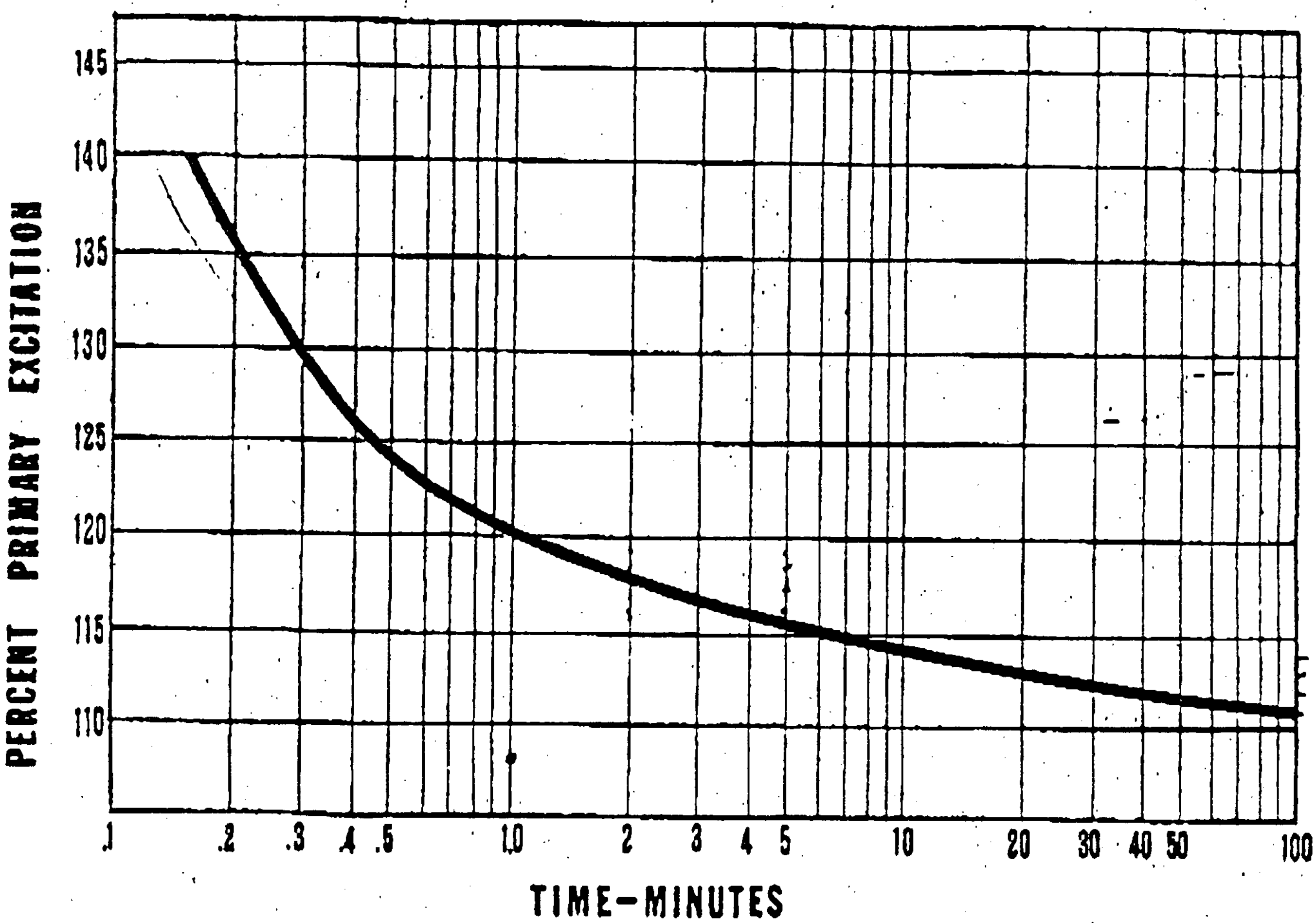


Fig. 1 General guide for permissible short-time overexcitation of power transformers. The "percent primary excitation" values above should be considered as the percent of rated volts per hertz applied to the primary winding at any load

Severe overexcitation can cause a transformer failure within a short time; however, less extreme overexcitation can occur without the operator being aware of its existence or consequences. Since the resulting thermal degradation of insulation is cumulative, the transformer may survive repeated instances of overexcitation which are moderate in degree before an electrical breakdown occurs. A failure may be separated from the initiating incident by months of normal service operation.

PERMISSIBLE LEVELS OF OVEREXCITATION

On a short-time basis, there is some capacity for excitation beyond the limits of the Standards since the heated parts have finite thermal time constants. Because the damage is a function of both magnitude and duration of overexcitation, Fig. 1 was developed to serve as a general guide for permissible short-time periods of overexcitation. The latitude for short-time overexcitation will be a function of each particular transformer design; therefore, any general guide such as Fig. 1 must be conservative.

For transformers with high impedance there is somewhat greater latitude for overexcitation than indicated in Fig. 1 and the curve may be adjusted accordingly. As indicated in the first section of this brochure, the transformer is designed to operate at 105 percent secondary voltage with rated 0.8 power factor lagging load. If the primary voltage (V_1) required for such operation is greater than 110 percent of rated, the ordinate scale of Fig. 1 may be multiplied by $V_1 \div 110$.

Operation anywhere *on or below* the curve of Fig. 1 will not cause significant loss of transformer insulation life.

For example, referring to Fig. 1, a transformer

could be operated at 120 percent excitation (1.2 times rated volts per hertz) for one minute without measurable damage. Then if the excitation was reduced to a level within the steady-state limits (specified by the Standards) for a period of several hours, the temperature of the heated parts would return to normal; thus allowing the short-time overexcitation experience to be repeated without measurable damage. Any reasonable number of repetitions (during emergency situations) would not be expected to affect the life of the transformer.

On the other hand, operation above the curve shown in Fig. 1, such as 120 percent excitation for two minutes, could cause the transformer to suffer permanent damage. Such damage is cumulative for repeated occurrences and could contribute eventually to a failure.

It is recommended that the transformer be inspected for possible damage anytime it is known to have been overexcited beyond the limits of Fig. 1.

DETECTION AND CORRECTION

Protective devices should be used to detect excitation beyond acceptable limits and to initiate corrective action. Some types of existing devices for overexcitation protection are discussed in detail in Reference 1.

In particular, it is recommended that separate volts per hertz detection be installed on all unit-connected generator-transformer combinations to sense and control overexcitation. Past relaying practices have not recognized the overexcitation problem. Since damage can occur in such a short time, protective devices are needed to recognize abnormal conditions quickly and to take action to prevent damage to the transformers.

REFERENCES

1. "Generating Station Protection and Operating Practices to Avoid Equipment Overexcitation," G. W. Alexander, W. J. McNutt, M. Temoshok, W. W. Walkley; Proceedings of The American Power Conference, 29th Annual Meeting, Vol. 29 1967.

2. USA Standard C57.12.00-1965 (or latest revision), "General Requirements for Distribution, Power and Regulating Transformers, and Shunt Reactors," Section 2.4.

3. "Influence of Design and Operating Practices on Excitation of Generator Step-up Transformers," G. W. Alexander, S. L. Corbin, W. J. McNutt; IEEE paper No. 31TP 66-83, presented at 1966 IEEE winter meeting.

4. "Effect of Frequency and Voltage Variations on Power System Equipment," M. Temoshok, D. D. Wilson; presented at Southeastern Electric Exchange meeting October 1967.

1.2 120%

KC-2023
~~GSC-5638~~

ATT 7
Pg 6 of 8

OVEREXCITATION DEFINED

Overexcitation, as used herein, describes a condition of excessive flux in a power transformer. A common measure of the flux is the per unit excitation, which is defined as the per unit voltage divided by the per unit frequency. The base quantities for voltage and frequency are the rated values.

Overexcitation exists when the limits specified in ANSI/IEEE Standard C57.12.00 section 4.1.6 are exceeded. The standard limits can be summarized as follows:

(1) Operation under load with secondary voltage and volts per Hertz not in excess of 105% of rated values, load power factor of 80% or higher, and frequency at least 95% of rated value.

(2) Operation at no load with neither the voltage nor volts per Hertz in excess of 110% of rated values.

The limits apply to any tap position.

CAUSES

(No change required)

EFFECTS

The major concern, relative to overexcitation of power transformers, is rapid thermal degradation of insulation from stray flux heating, which can produce free gas and lead to electrical breakdown of the insulation system. The increased dielectric stress from a moderate overvoltage is not, in itself, a primary cause for concern.

Excitation levels above those prescribed by the ANSI/IEEE Standards may result in more flux then the core steel can contain. The overflow flux strays into structural parts, windings, and leads, where it induces eddy currents which produce extra losses and heating. If the overexcitation event is extreme, the heat so produced cannot be dissipated rapidly and the consequent thermal degradation of insulation adjacent to the heated metallic part can produce free gas.

Although thermal degradation of insulation is permanent and deterioration of the mechanical strength of the affected parts is cumulative, that is not the major concern unless overexcitation beyond standard limits is repeated excessively. The dielectric strength of thermally degraded cellulose insulation is still very good as long as the insulation is totally impregnated with mineral oil. However, the presence of free gas within the solid or liquid insulation as an immediate consequence of an overexcitation event greatly reduces dielectric strength. Thus the principal concern is for dielectric failure of the transformer during or shortly after the overexcitation event while the free gas is still present.

PERMISSIBLE LEVELS OF OVEREXCITATION

On a short-time basis, there is some capacity for excitation beyond the limits of the Standards, since the heated parts have finite thermal time constants. Because the damage is a function of both magnitude and duration of overexcitation, Fig. 1 was developed to serve as a general guide for permissible short-time periods of overexcitation. To some degree the latitude for short-time overexcitation will be a function of each particular transformer design; therefore, any general guide must be conservative. Fig. 1 recognizes the fact that there was a major design change in General Electric large power transformers in the 1970-1972 period which somewhat reduced vulnerability to overexcitation, so two curves are presented, one for transformers built prior to 1972 and the other for those built in 1972 or later. Operation is not recommended at any point above the applicable curve in Fig. 1.

As an example of application of the curves, a pre-1972 transformer could be safely operated at no load and 120% excitation (1.2 times rated volts per Hertz) for one minute. A transformer built in 1972 or later could be safely operated for three minutes under the same circumstances. Any reasonable number of repetitions of these acceptable events would not be expected to affect the life of the transformer. However, in each case it is recommended that the prescribed time not be exceeded because of the risk of generation of free gas.

While the curves of Fig. 1 were prepared for no load conditions at variable frequency, they may be extended to load conditions at rated frequency in the following fashion:

(1) Determine a Primary Side Reference Voltage in percent of rated as the higher of either 110% or the Primary side voltage required to achieve 105% Secondary side voltage under full load, 0.8 power factor lagging.
(2) Multiply the ordinate value of Fig. 1 for any given permissible time duration by (Primary Side Reference Voltage-% /110%) to determine the adjusted permissible Primary side voltage under load.

This application can be illustrated by considering a transformer which has 7% regulation at full load, 0.8 power factor. The required Primary side voltage to achieve 105% Secondary side voltage at full load is 112%, which is greater than 110%, and this becomes the Primary Side Reference Voltage. For a pre-1972 transformer, the permissible excitation level at full load for one minute is then adjusted upward from 120% (Fig. 1) by a factor of (112/110) to an approximate value of 122%.

In the event of an overvoltage event in excess of the permissible levels shown in Fig. 1, free gas generated by overheated parts may exist for several days before it becomes dissolved in the oil. There is some risk of dielectric failure during this time period. After several days have passed, some measure of possible damage to insulation may be inferred from observation of changes in the dissolved gas content in the oil.

~~OSC-5638~~
KC-2023
ATT. 7
Pg 8 of 8

DETECTION AND CORRECTION

Protective devices should be used to detect excitation beyond acceptable limits and to initiate corrective action. Some types of existing devices for overexcitation protection are discussed in detail in Reference 1. In particular, it is recommended that separate volts per Hertz detection be installed on all generator-transformer combinations to sense and control overexcitation. Since damage can occur in a very short time, protective devices must recognize abnormal conditions quickly and take action to prevent damage to the transformer.

REFERENCES

(No change required)

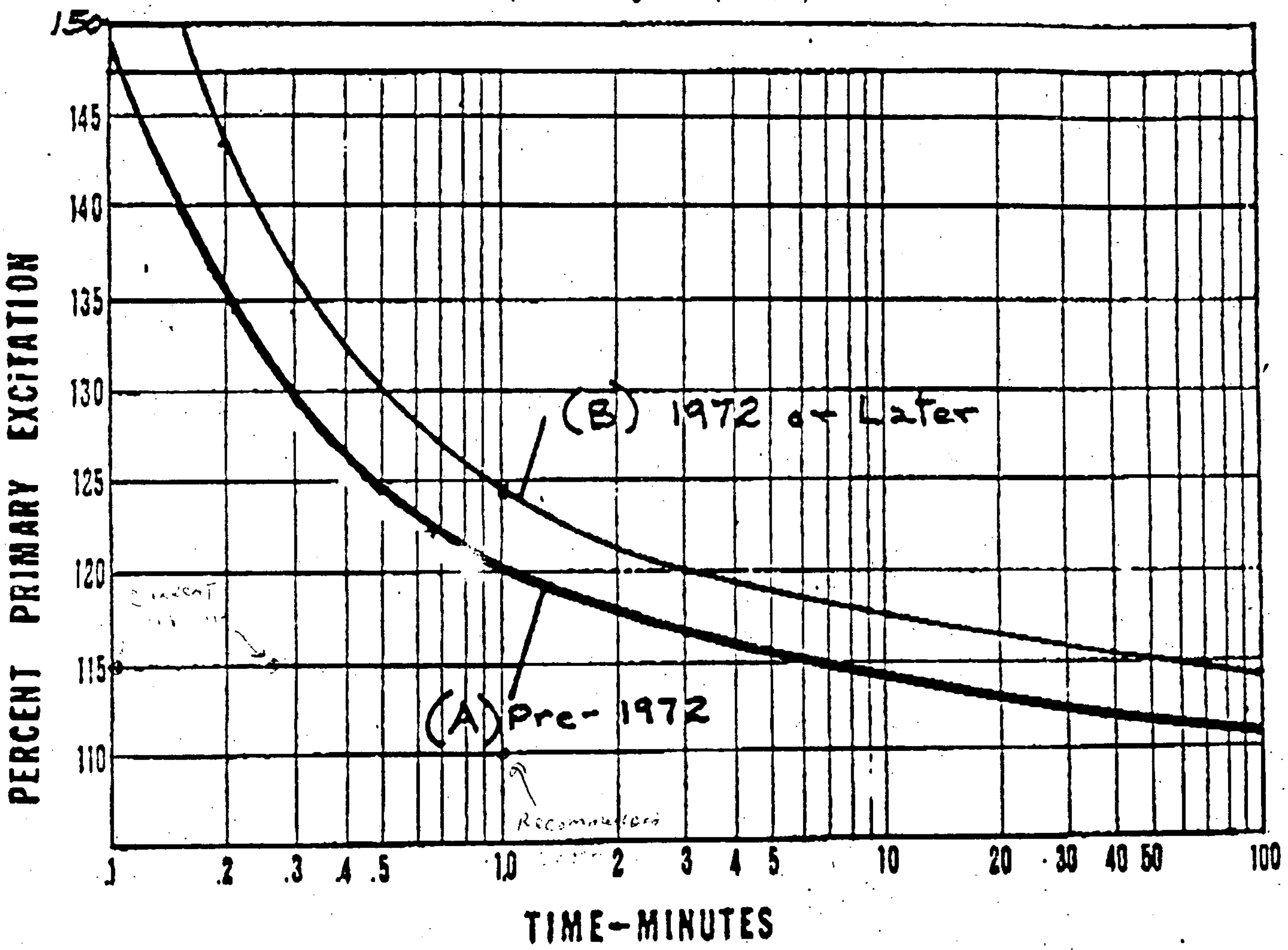


Fig. 1 General guide for permissible short-time overexcitation of power transformers. Curve (A) applies to transformers manufactured before 1972 and curve (B) applies to those manufactured in 1972 or later. The "Percent Primary Excitation" values from the curve should be considered as the percent of rated volts per Hertz applied to the Primary winding at any load.

KC - 2023
ATTACHMENT 8

Reorder by ID No. 0594342828

Form 35530 (6-91)

10/4/93

W/O TASK # 93067874 . 01

ADDITIONAL SHEET FOR TASK COMPLETION COMMENTS

	Step	Date/Time	Actual Hours
Operated breaker with MG6 relay contacts in close & trip circuit. Allowed MG6 to "hammer" or not latch by holding reset lever down. This let MG6 cycle from open to close and back rapidly. The breaker did not attemp to close until reset lever was relased. at 125V dc ~~X relay~~ MG-6 relay takes 63 msec to contact close & MG-6 relay unlatch or reset operation takes 21 (at 125 Vdc) msec. During a "hammer" or "pump" operation the contacts will stay closed about 8 or 9 msec. A "hammer" operation contact close to open & back to close is about 65 msec.		10/4/93	
Could duplicate bkr failure mode by removing cotter key (that was found missing) and pushing pin over in assembly hole just enough to hold armature up and keep trip latch from resetting. When close voltage was applied to ~~Workers.~~ the breaker the armature moved up about 1/4 inch and slid from hole and breaker didnot close and coil remaind energized. The "damage" (insignificant) to the assembly hole matched that of the failure. The factory indicated that they had found breakers without this cotter key but had no reported failures nor did ~~would~~ they fail when electrically operated on the test bench. While inertia latch & trip latch could cause some failure thee (missing cotter pin) fits the noted "damage and failure results the best.		10/5/93	

KC.2043
~~CSC-5638~~
ATTAchment 9
Pg 1 of 2

General Electric Company
Large Transformer Support Operation
100 Woodlawn Avenue
Pittsfield, Massachusetts 01201
February 24, 1995

Chris Schaeffer
Duke Power Company
Oconee Nuclear Station
P.O. Box 1439
Seneca, SC 29679

Chris,

Confirming our recent telephone conversation, I have reviewed the gas-in-oil data from Transformer SN D-596439 which you recently forwarded to me. The following comments are offered:

In evaluating gas-in-oil data, we typically look at three things:

1) the threshold level of the individual gases,
2) the ratios of the various gases, and
3) the rate of generation of combustible gas.

1) The threshold levels of concern for the various gases as established by GE vary somewhat from the ANSI guidelines, but either criteria can be used.

2) There are a number of ratio methods in popular usage for helping evaluate a gassing condition. Most of them result in the same conclusions being drawn. The only caution should be that erroneous conclusions can be drawn when very small amounts of gases are present. For ratio analysis to be useful, it is felt that minimums of 100 ppm should be present, with the exception of Acetylene (C_2H_2), which always should result in investigation.

3) The rate of generation of combustible gase is calculated as follows:

$$R = \frac{(S_2 - S_1) \times V \times 10^{-6}}{7.5 \times T}$$

Where
- R is the rate of generation in cubic feet per day.
- S_1 is the ppm of combustible gas at the initial sample date.
- S_2 is the ppm of combustible gas at the second sample date.
- V is the volume of oil in the unit in gallons.
- T is the difference in days between sample dates.

The constants, 7.5 and 10^{-6}, result in cubic foot units.

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The rate of generation of combustible gas is considered to be "of concern" when it reaches 0.1 cubic ft/day and if it reaches 0.25 cubic ft/day we generally recommend removing the unit from service. This is of course looking at dissolved gas in the oil. Any unit that is "free-gassing" and collecting gas in a gas detector relay should be removed from service immediately and the source of gas investigated.

It should also be noted that the bulk of large GE transformers in the field are of the Atmoseal design. Our evaluations are basically for units of this style and it should be recognized that units with a gas blanket above the oil will release gas into this gas space resulting in less gas in the oil. The equilibrium between the gas in the oil and that in the gas space must be considered in such units.

UNIT SN D-596439

This unit has a couple of gases which exceed the threshold level for concern, i.e., Methane (CH_4) (GE threshold level - 100 ppm) and Ethylene (C_2H_4) (GE threshold level - 200 ppm).

The ratio of gases involved would indicate that there is some breakdown of the oil due to heating, but the level and ratio of Carbon Monoxide (CO) and Carbon Dioxide (CO_2) are in the normal range suggesting no involvement of cellulosic insulation.

The rate of generation of combustible gas based on the latest samples taken in October and November of 1994 is about 0.006 cubic feet per day. This rate of generation in itself is low and does not merit concern.

Based on the above, it appears that the unit does not have a serious gassing condition. However, it should be noted that there has been a slow but consistent increase in gases over the past several samples. It would appear that hydrocarbons caused by a breakdown of oil in contact with bare, hot metal may be occurring. This is consistent with an overexcited condition which we discussed causing some core and stray flux heating.

If you have any questions or would like to discuss these items further, please let me know.

Best regards,

John Perry

John Perry

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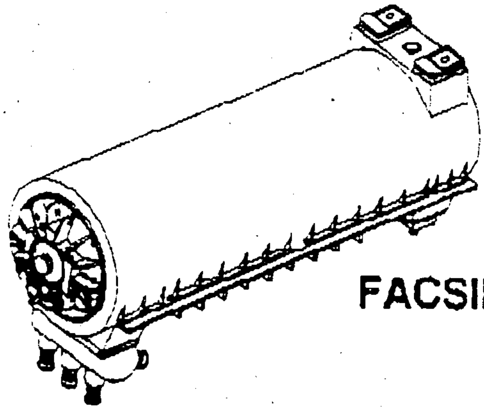
KC-L023

WESTINGHOUSE POWER GENERATION

THE QUADRANGLE
4400 ALAFAYA TRAIL
ORLANDO, FLORIDA 32826-2399



GENERATOR ENGINEERING
MAIL CODE - 00707-100
FAX NO. 407-281-3216 (WIN 439-3216)

FACSIMILE REQUEST FORM

To:

Name: Chris Schafer

Co./Dept: Duke Power

Location: Oconee

Dex Machine No: WIN______

BELL (803) 885-4028

Verification Tele. #: WIN______

BELL______

From:

Name: JOE HURLEY

Dept: GENERATOR ENGINEERING

Tele #: WIN 439-2992

BELL (407) 281-2992

COMMENTS:

No. of Pages Being Transmitted (including this cover sheet): 5

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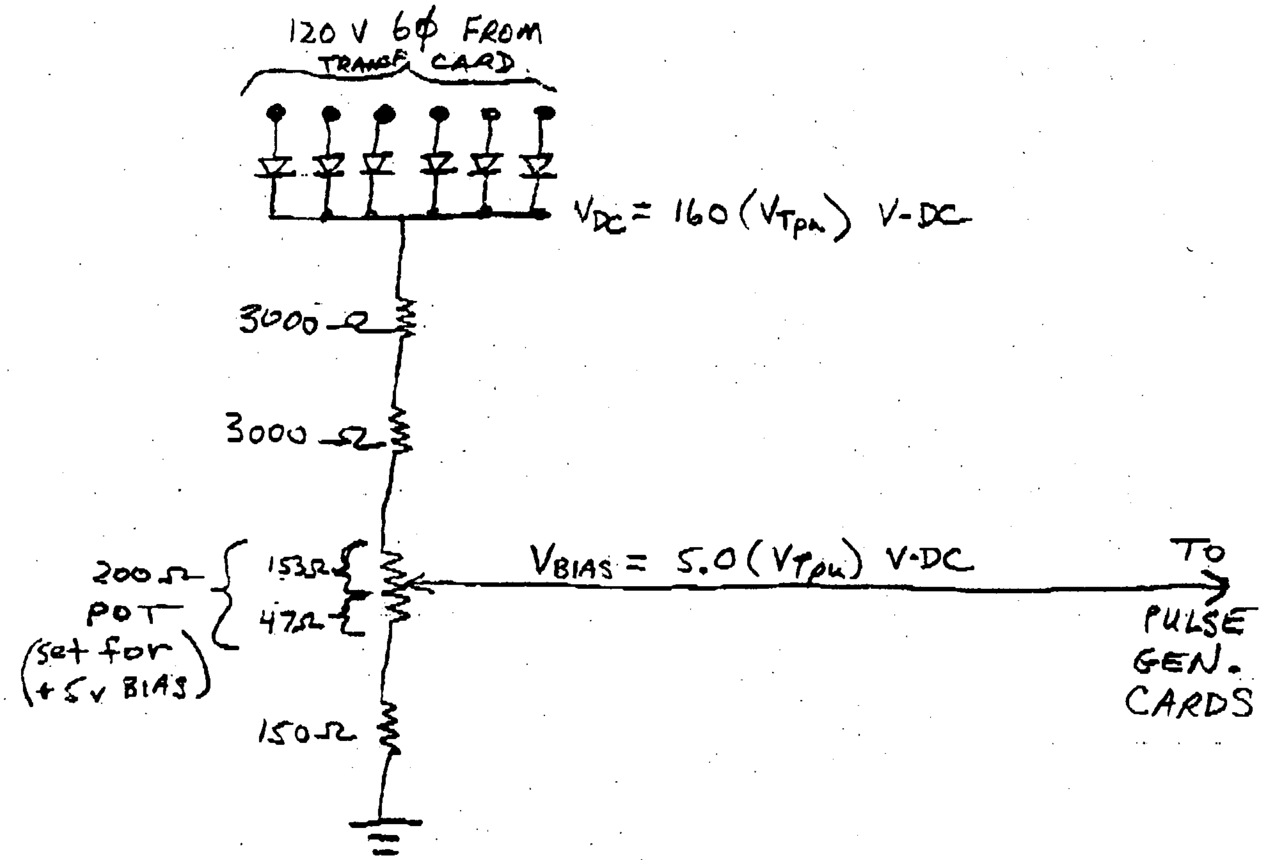
1

INPUT MODULE BIAS CIRCUIT



ΔV_{BIAS} of -10 V causes a $1.25 (240 \text{ VAC}) = 300$ VDC increase in generator field voltage (E_{FD}) at rated terminal voltage.

1) As generator terminal voltage (V_{Tpu}) decreases, V_{BIAS} decreases proportionally, adjusting the firing angle.

2) As gen. term voltage ($V_{Tpu.}$) decreases E_{FD} with fixed firing angle decreases proportionally.

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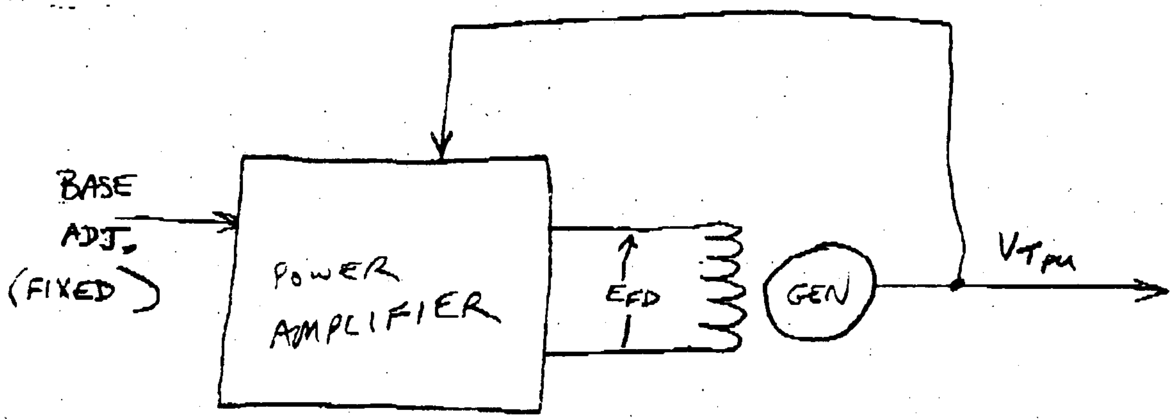
2



$$V_{BIAS} = 5.0\ V_{Tpu}$$

At rated terminal voltage ($V_{Tpu} = 1.0$):

$$E_{FD} = E_{FD_0} - \frac{-\Delta V_{BIAS}}{10\,V} \times 300\,V$$

$$\left[-\Delta V_{BIAS} = 5.0 - V_{BIAS}\right]$$

$$E_{FD} = E_{FD_0} + (5.0 - V_{BIAS})\,30\,V$$

For variations in terminal voltage (V_{Tpu})

$$E_{FD} = V_{Tpu}\left[E_{FD_0} + (5.0 - 5.0V_{Tpu})\,30\,V\right]$$

$$= V_{Tpu}\left[E_{FD_0} + 150\,V(1 - V_{Tpu})\right]$$

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3

At Rated Voltage, No Load:

$$E_{FD_0} = \underbrace{(678A)}_{I_{FD_0}}\underbrace{(.151\,\Omega)}_{R_{fg}} = 102\,V$$

Substituting E_{FD_0}:

$$E_{FD} = V_{Tpu}\left[102\,V + 150\,V\,(1 - V_{Tpu})\right]$$

$$\boxed{E_{FD} = 252V\left[V_{Tpu}\left(1 - 0.595\,V_{Tpu}\right)\right]}$$

This is the power amplifier transfer function with base adjuster set for No Load Excitation

if it is easier to work with gen. field current:

$$I_{FD} = E_{FD}/(0.151\,\Omega) \quad \text{(steady-state)}$$

$$\boxed{I_{FD} = 1670A\left[V_{Tpu}\left(1 - 0.595\,V_{Tpu}\right)\right]}$$

V_{Tpu}	E_{FD}	I_{FD}
1.1	96	634
1.0	102	678
0.9	105	698
0.8	106	699
0.7	103	682
0.6	97	644

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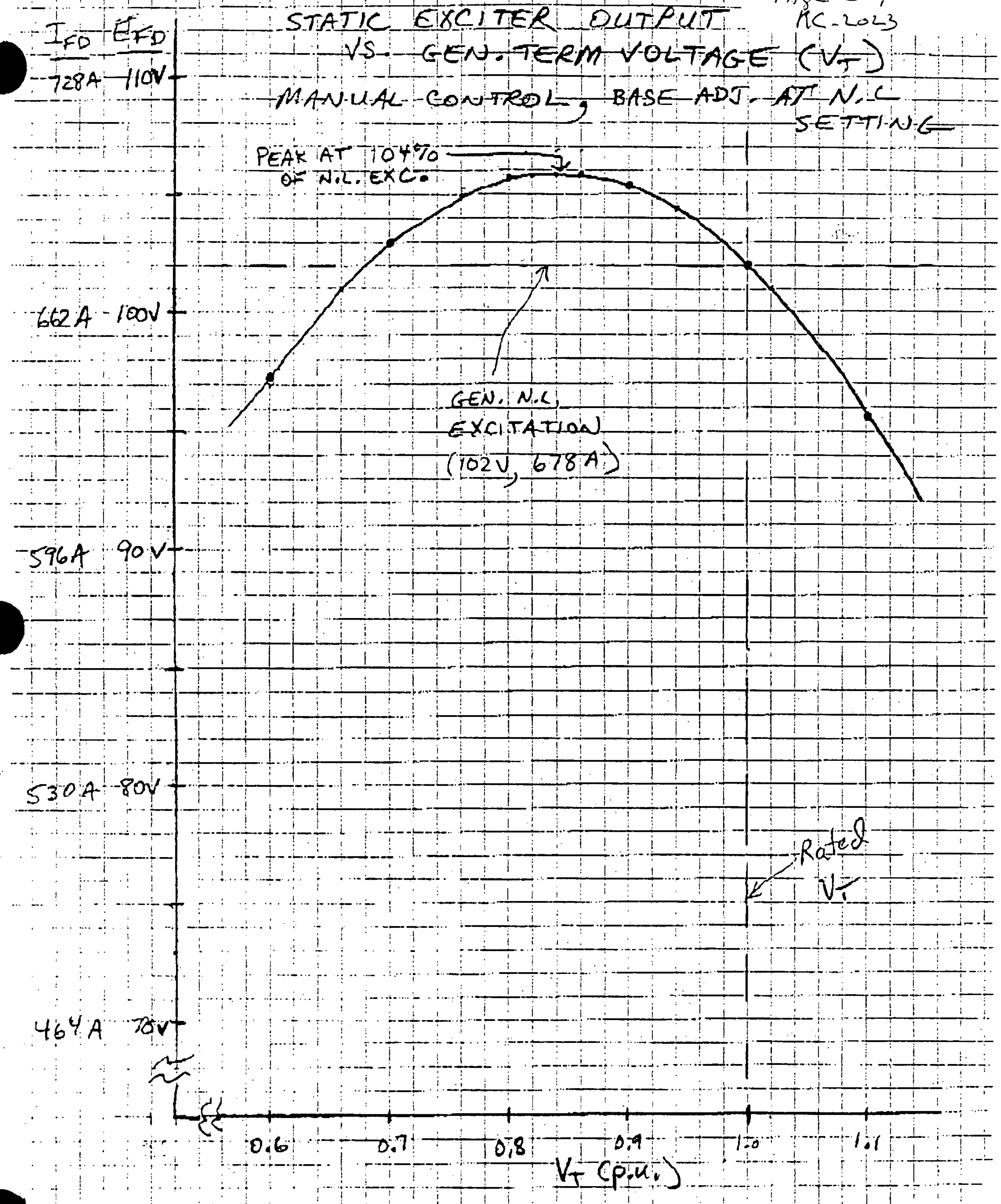

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IEEE Transactions on Power Systems, Vol. 10, No. 1, February 1

FIELD ASSESSMENT OF GENERATORS REACTIVE CAPABILITY

A. Panvini, Sr.Member, IEEE T. J. Yohn, Sr.Member, IEEE

Public Service Company of Colorado
Denver, Colorado

ABSTRACT - Utilizing generators' reactive capability to the fullest became critically important in the last ten years. Voltage stability studies reflect actual system conditions only as long as utilities assess their generators' actual reactive capability. Just as important, the system dispatchers and plant operators should be aware of the system's actual reactive capability and have a good understanding of the impact that power plants' var production has on system voltage. This paper describes the Public Service Company of Colorado's experience in maximizing its generating units' overexcited reactive capability. As a result of PSC's effort, an additional 500 Mvars of previously unused reactive power were "released" to the power system. Furthermore, this paper presents PSC's experience in educating the system dispatchers, plant operators and engineering personnel on the subjects of voltage collapse phenomenon and var scheduling in a power system.

KEY WORDS - Generator reactive capability, voltage control, excitation limiters, transformer voltage taps.

INTRODUCTION

With a great slowdown in new EHV transmission expansion during the last ten years, the existing transmission system is being loaded more heavily, and the transmission reactive losses are skyrocketing. Investments in providing a reactive supply near the load, at both the distribution and the transmission levels, have been subjected to severe cut Hence, utilizing the generator reacti capability is becoming more critical th ever before.

Adequate reactive support is essential f power system voltage stability and t prevention of voltage collaps Generators are the best dynamic source reactive power in power systems and excellent way to control system voltage

Maximization of the reactive capability the generators that are located near th load is especially critical. Normall vars should not be transmitted from remot generation, however, these vars ca partially offset reactive requirements the load by supplying system reactiv losses.

The North American Reliability Counci (NERC) in its Survey of Voltage Collaps Phenomenon [1] recommended that the NER regions and systems should consider th following:

- A program for testing generatin units to establish their actual reactiv capability range.
- Training programs for syste operators, plant operators, and syste planners to increase their awareness o the importance of voltage and va scheduling and the interaction between th plants and the systems.
- Coordination of voltage and va scheduling among neighboring utilities an regions.

In the summer of 1991, Public Servic Company of Colorado (PSC) started program of testing its generating units reactive capability.

HOW IT ALL STARTED

On a hot summer afternoon in 1989, one o the authors was at the PSC dispatch cente while the system was experiencing a peak load demand. All of the generating units

94 WM 214-7 PWRS A paper recommended and approved by the IEEE Power System Engineering Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1994 Winter Meeting, New York, New York, January 30 - February 3, 1994. Manuscript submitted June 14, 1993; made available for printing January 11, 1994.

were on line, and all of the transmission shunt capacitors were switched on. The transmission voltages were in the order of .97 to .99 per unit. At this time, the only reactive sources available in the system were through starting stand-by generation. Based on PSC's previous experience with disturbances that occurred during similar operating conditions, the probability of voltage collapse was real. According to the plant operators, the units had reached what they believed was the units maximum var capability. However, according to the manufacturers var capability curves, the units still had a lot of reactive capability left - some of them as much as one third. It became obvious that the plant operators did not trust that they could safely operate the machines according to the manufacturers capability curves. The need to understand the plant var limitations became clear; and the best way to accomplish that was to test the generating units.

TEST PROCEDURE

Individual generator performance tests were conducted by the plants' personnel under the direction of the authors and with the cooperation of System Operations. A test procedure was developed based on work described in [5]. Prior to the test, each generator's hydrogen pressure was brought to the maximum PSIG level recommended by the manufacturer. Data was collected for two operating points in a generator operating range:

a. Overexcited reactive limit at full MW output.
b. Overexcited reactive limit at reduced MW output. ("Reduced" MW output refers to a minimum MW load with all of the coalmills on line).

While operating at the specified MW output, the generator excitation was raised until the generator or the system operating limits were reached. These limits are described further in the text. At this point, all electrical and thermal data was recorded. After the limits were reached, the excitation level for full and reduced MW tests was maintained until unit temperatures stabilized. At this time, a second set of data was recorded.

WHAT WAS FOUND?

The reactive capability tests identified operating limits that prevented the generators from producing the maximum var output as designated by the manufacturers' var capability curves. These limits were a consequence of minimal emphasis that has been placed on generators' reactive capability over many years. As a result, some perceived limits had developed. These conservative operating practices were too restrictive for today's operating needs.
Based on the authors experience, the generator operating limits described in this paper are common for many other industry utilities.

- Most generator step-up transformers, unit auxiliary transformers, start-up transformers, and load center transformers required adjustment of their no-load tap settings. Several step-up transformers overheated during high ambient, full load conditions. The plant operators would curtail generator reactive power output and spray the transformers with water. In the most severe case encountered, the generator var output was reduced to zero, and water-caused scaling had seriously reduced the transformer cooler effectiveness.

Most generators had limited var output due to excessively high or low station service voltages. At one plant, excessive station service voltage prevented use of about 100 lagging Mvar. In other instances, low station service voltage prevented generator operation in the lead.

- For some units, the stator or field winding temperature alarms were set lower than the manufacturer suggested values and thus limited the var and, in some cases, MW production.

- Some generator meters were out of calibration, causing either underutilization of reactive capability or, at the other extreme, potential damage to the unit. For instance, at one of the plants, a discrepancy of 3 kV was found between 230 kV control room meter and a 230 kV voltage in the switch yard. The control room reading was 3 kV higher than the actual voltage, unnecessarily limiting 230 kV system voltage on this remote plant. At another plant, the field current meter reading was 13 percent lower than actual current, thus the potential for field overheating was real.

- The Maximum Excitation Limiter operates to limit the sustained excitation

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voltage to a safe level (say, 105 percent of full load excitation voltage) to prevent overheating of the field winding [2]. In some cases, an overly low setting of the limiter would not allow the full range of the generator overexcited reactive capability within the var capability curve.

• A purpose of the volts per hertz limiters is to prevent a generator and a step-up transformer overexcitation during start-ups and shut downs. When on line, this protection works to limit the generator voltage and to alarm the operator. During the tests, there were some limiting action and the alarm indications that voltage settings were exceeded. These settings were overly restrictive so that in one case one third of the unit's overexcited capability was not available.

• A transformer drop compensator is a circuit in the excitation system that simulates a voltage drop in the step-up transformer. Usually, a voltage regulator senses voltage at the generator terminals and attempts to keep this voltage at the preset value. The preferred objective in most cases, however, is to hold the high voltage bus at the desired voltage level. Because of the voltage drop across the step-up transformer, the voltage regulator is only partially successful in regulating the high voltage bus. The transformer drop compensator provides a bias signal to compensate for the step-up transformer voltage drop. In one tested case, the transformer drop compensator was set so high that excessive Mvar swings occurred during local capacitor switching.

• Even though the main focus of the test program was to utilize the overexcited capability of the generators, their underexcited capability was also evaluated. Leading var capability of the generators is needed during light load conditions, energization of unloaded lines and the system restoration after a blackout. Utilities can realize measurable savings on reactor installations by using generators underexcited capability. For instance, PSC avoided a $500,000 investment in tertiary reactor installations by realizing an additional 50 Mvar of underexcited capability of one of its generators.

It was found during the test that operation of the generators with leadi power factor was not a common practic This reflected a common, deeply entr ch fear of operating "in the lead" d misconception that underexcited operati of the generators must be prohibited. T URAL circuits were in service, but t setting were very conservative.

• In addition to real operati limits, some "mythical" limits we discovered during the course of the te program. These "mythical" limits we either a reflection of the old operati practices that were not applicable to t current system conditions misconceptions on the part of the pla personnel. The following are some typic misconceptions that the autho encountered at PSC power plants as well the power plants of other utilities.

Some of the generator voltage and curre meters had "red marks" drawn on them as warning to the plant operator not exceed these values. For instance, so generators were restricted to operati below the name plate rated voltage. It a "mythical" limit because the generato are designed to satisfactorily carry t name plate rated kVA at any volta between five percent below and fi percent above rated voltage. For mo generators, the use of a full overe it capability requires operation near .0

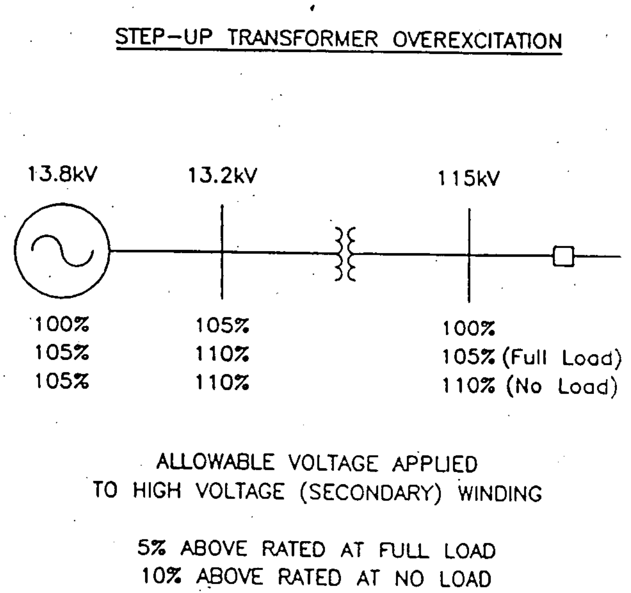

Fig. 1 Allowable step-up transformer voltage according to ANSI/IEEE C57.12.00-1980.

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per unit terminal voltage. The restriction of the terminal voltage to the 1.0 per unit resulted in up to 50 percent reduction of the generator var range.

The generator terminal voltage restriction stemmed from a misconception concerning overexcitation of a generator step-up transformer. Most low voltage ratings of the PSC step-up transformers are approximately 95 percent of the generator voltage rating. (These voltages are 13.2 kV and 13.8 kV respectively in Fig. 1 example). Therefore, the transformer has 105 percent of rated voltage applied when the generator voltage is 100 percent and the 110 percent of rated voltage applied when generator voltage is 105 percent. Since usual generator unit design is to have about 5-percent full load regulation at rated generator kVA and power factor, this permits both a generator and a transformer to operate at the same percent output voltage at full load.

To avoid damage resulting from overexcitation of generator step-up transformers, ANSI Standards [3] require that transformers should be capable of delivering rated KVA at 105 percent of rated secondary voltage and full load, and 110 percent of rated secondary voltage at no load (Fig. 1). Unfortunately, the Standard does not emphasize the fact that the generator step-up transformer differs from other power transformers in that its high voltage winding is always the secondary [4]. The confusion in interpretation of the Standard resulted in unnecessary restriction of the transformer <u>primary</u> voltage to 105 percent at full load and 110 percent at no load, which in turn limited the generator voltage to 100 percent at full load and 105 percent at no load.

- In general, the authors' observation was that the concept of reactive power and its relationship to system voltage was not well understood. Historically, the role of power plants in the power system was believed to be limited to real power production. It is no longer acceptable to underestimate the importance of reactive power production by the power plants.

ACTIONS TAKEN

The following is a list of actions taken at PSC that resulted in maximizing its generators' reactive capability:

- Optimal voltage taps were calculated and set for the step-up transformers, unit auxiliary transformers, load center transformers and start-up transformers. The chosen taps allowed generator operation within system, transformer, station service motor voltage limits all year. The chosen tap usually provided a 1.05 per unit generator voltage at rated generator MVA and power factor while delivering into a 1.04 per unit system voltage. Optimal taps resulted in lower losses, hence, the generator and transformer ran cooler. The step-up transformer radiators were descaled and the water was shut off. No further overheating was experienced in 1992.

The optimal taps for unit auxiliary and load center transformers resulted in a normal station service operating voltage near 1.05 per unit for motors. In one case, the cooler operation of the coal mill motors allowed a MW increase of approximately two percent during poor coal conditions.

- Temperature alarm settings were optimized based on the manufacturer recommendations.

- Temperature recorders and electrical meters were calibrated and many of them were replaced with new models. Some manufacturers believe that the temperature recorders in the field winding are not needed as long as the unit is operated within its var capability curve. However, it is the authors belief that the operators need to have an indication of both the stator and the field winding temperatures, otherwise, the natural tendency is to lower the var output prematurely.

- The Maximum Excitation Limiters were adjusted so that a full range of the generators overexcited capability could be achieved.

- The volts per hertz limiters were adjusted to allow operation at about 1.08 per unit. The volts per hertz relays were set at least three percent above the limiter set point.

- The transformer drop compensators were set. PSC has used an 80 percent compensation level. This has improved transmission voltage regulation without causing the generators to fight each other or overrespond to capacitor switching.

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• URAL circuits are in the process of being set for all of the PSC generators in order to utilize an underexcited capability of the generators. These limiters prevent generator operation below some excitation level that is associated with excessive armature core end heating and prevent operation beyond the steady state stability limit. Most PSC URAL models act on the voltage error function of the voltage regulator, while a few act on high value gate in the excitation control [6].

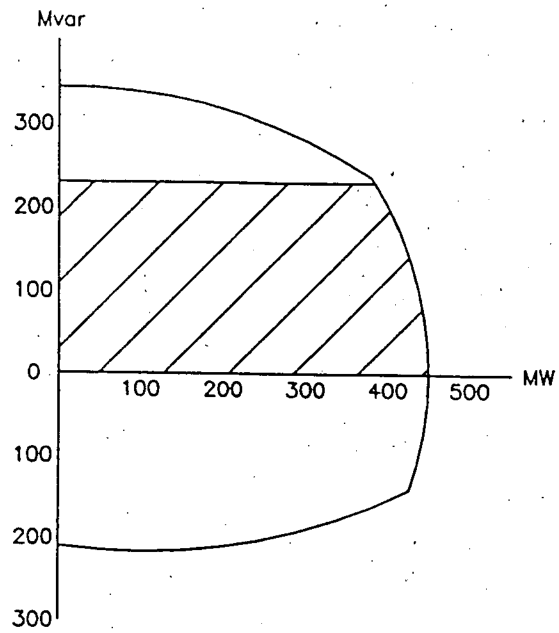

Fig. 2 Cherokee #4 Var Capability Curve with operating area as practiced before generator testing.

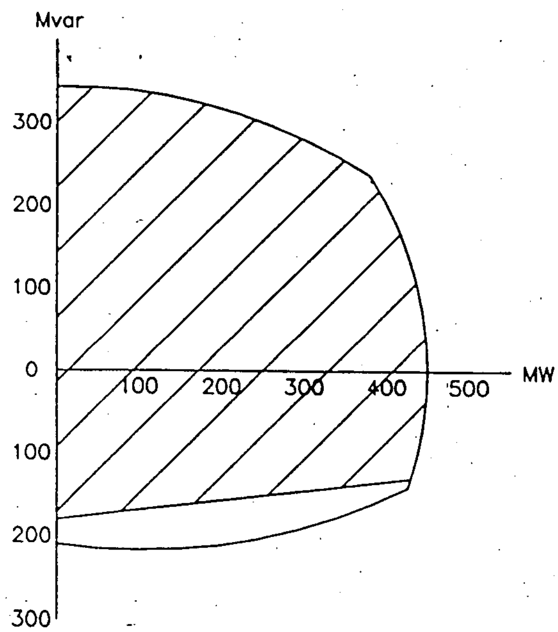

Fig. 3 Cherokee #4 Var Capability Curve with operating area as practiced after generator testing.

• The step-up transformer overexcitation was clarified, and overly conservative generator terminal voltage restrictions were removed. Fig.2 and 3 illustrate an increase of one of the PSC generators' reactive capability range due to the number of corrective measures described in this paper.

• Technical seminars and a tutorial were provided by the authors for the plant operators, system dispatchers and engineering personnel. In these seminars, it was emphasized to the plant operators that holding generator voltages and keeping the units' voltage regulators on "automatic" whenever possible have great benefit to the power system [2]. It was also stressed to the operators that it was safe to operate the generators within their var capability curves. The validity of this operating practice was readily accepted by the operators due to their participation in the previously conducted generator testing program. The reactive power training will become an ongoing process and will be incorporated into the operators' regular training.

• System dispatchers were advised to maintain transmission voltages at a higher level than was previously practiced in order to increase system stability and decrease system losses. An emphasis was also placed on maintaining reactive spinning reserves at the generators and using the static capacitors as a "reactive base" for the system. For instance, after switching on capacitor banks in the Cherokee area, the unit reactive reserve at 300 MW should be at least 200 Mvars (Fig 3).

• Voltage and var scheduling coordination among the Colorado utilities has been initiated by PSC.

RESULTS

As a result of the generator testing and subsequent corrective actions, PSC was able to make available for the system an

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additional 500 gross Mvar of previously unused reactive capability, an increase of approximately 50 percent (Fig. 4). The above activities did not involve any capital costs and only minimal expenses. Using estimated costs of static capacitors ($10 per kvar), and Static Var Compensators ($90 per kvar), the above activities released an investment stranded in PSC generating capacity of between $5 to $45 million.

An improved system voltage profile during the summer of 1992 clearly demonstrated the benefits of operating the system with transmission voltages higher than was previously practiced. The generators were running at approximately 35 percent of their recognized reactive capability as opposed to approximately 90 percent during the previous years. As a result, during contingencies there was still reactive reserve left at the generators. In the summer of 1992, PSC didn't have to run expensive generation just for var support. In addition, on several occasions, during system emergencies; an increased reactive reserves and proper actions on part of the plant operators and system dispatchers prevented the loss of PSC firm load and, possibly, voltage collapse.

PLANT/INIT	Mvar LIMITS AS PRACTICED		INCREASE (MVAR)	INCREASE (%)
	BEFORE TEST*	AFTER TEST*		
Arapahoe 1	20	36	16	
2	20	36	16	
3	25	36	11	
4	73	92	19	
SUBTOTAL:			62	45
Cherokee 1	65	103	38	
2	65	106	41	
3	105	143	38	
4	230	322	92	
SUBTOTAL:			209	45
Pawnee	140	290	150	
SUBTOTAL:			150	107
Valmont 5	100	150	50	
6	36	46	10	
SUBTOTAL:			60	44
Zuni 1	25	34	99	
2	45	64	19	
SUBTOTAL:			28	40
TOTAL	949	1458	509	54

*Mvar output corresponding to a reduced generator MW load with all coalmills on.

Fig. 4 Improvement of PSC generators reactive capability as a result of a generator testing.

CONCLUSION

This paper summarizes Public Service Company of Colorado's experience in testing its generating units reactive capability as well as its experience in training the system dispatchers, plant operators and engineering personnel on the subjects of reactive power, generator var production, and voltage collapse.

Over time, while system conditions change, the operating practices of the past still remain in place. The failure to change the operating practices with changing system conditions results in underutilization of the most valuable asset in a power system: the generating capacity. Periodic generator testing and personnel training are essential for full utilization of the generation capacity. Awareness about the actual system reactive capability allows both planners and operators to avoid a false sense of security about the state of the power system.

PSC experience proved the fact that by employing good operating practices and properly adjusting its equipment, a utility can achieve generator operation according to the manufacturers' reactive capability curves even for 40-year old generating units. Voltage collapse is a very complex problem and is not well understood by the industry. The authors believe that the first crucial step for any utility in attacking this problem should be the assessment of its generating units' actual reactive capability and the education of the personnel responsible for day to day operation of the power system.

Acknowledgments

The authors would like to recognize the PSC Dynamic Var Task Force members and numerous Production and Operation

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personnel that helped to make generator testing and subsequent corrective actions a success.

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Alla Panvini receive her MSEE from Mosco Power Engineerin Institute, Moscow Russia in 1967. Sh then joined the Mosco Power Engineerin Research Institute a an engineer involved i reserve optimization, and multiple solutions of the steady stat differential equations studies. Sh coauthored several papers in variou Russian technical magazines. Afte immigrating to the US in 1978, Alla worke as a production engineer at th Astronautics Corporation of America, Milwaukee, Wisconsin. In 1981 she joine the System Planning division of Publi Service Company of Colorado. At PSC sh conducted various planning studies o major transmission projects, includin dynamic thermal loading of transmissio lines projects. Currently, Alla holds a Sr. System Planning Engineer position i Bulk Power Transmission Planning.

Thomas J. Yohn (M '74, SM '83), rec ec his BSEE in 1971 and MSEE in 1973 fro the University of Colorado at Boulder. He joined Public Service Company of Colorado in 1973 as a protective relaying engineer and became the protective relaying supervisor in 1985. In 1989 he became Principal Engineer in Electric Engineering Services. His current position includes consulting, education, failure analysis special project, and electric syster reliability duties.

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DISCUSSION

M. M. Adibi, IRD Corporation, Bethesda, Maryland: The authors are commended for a timely paper on practical aspects of generator reactive capability. The following discussion is intended to supplement the paper content. Would the authors please respond to the folowing comments and questions:

In evaluating the reactive capabilities of a number of generators, it has been found that:

- the generator's over-excitation largely is limited by the high voltage limits of the generator terminal and auxiliary bus, and not by other limits such as the field current, voltage regulator's maximum output, volts/Hz, URA limits, etc.
- the generators under-excitation is also limited by the low voltage limits of the generator terminal and auxiliary bus, and not by other limits such as core end heating, minimum excitation level, voltage regulator minimum output, URA limits, etc, and
- by changing the main and auxiliary transformers' fixed tap positions, their related curves are moved up and down, changing the proportion of lagging and leading reactive outputs, without changing the sum of generator's lagging and leading reactive capability, which remains the same.

Practically all main and auxiliary transformers are equipped with fixed taps. For selected (fixed) tap positions in the main and auxiliary transformers, the generator's maximum and minimum reactive outputs will be functions of the high and low voltages at the system bus. These system voltages in turn are functions of the generator's reactive outputs and the network which they supply. In other words, the reactive capabilities of generators under changing load conditions can only be assessed by representing the generator reactive models in a power flow program.

In a few power plants, the main and auxiliary transformers have been retro-fitted with tap-changers-under-load (TCUL), so as to increase the over- and under-excitation capabilities of the generators.

Figure 3 of the paper shows that reactive capability of Cherokee #4 "as practiced" reaches the maximum rotor field current rather than the maximum generator terminal voltage limit. The latter normally has a lower value. Would the authors please verify this rather excessive over-excitation operating limit?

A. Panvini and **T. J. Yohn** (Public Service Company of Colorado, Denver, CO):

We wish to thank Mr. Adibi for his comments and questions concerning our paper. Mr. Adibi made several good clarifications in Item one of his comments. For some of our generators, we also experienced limitations on the generator reactive capability range pthat were due to the generator's terminal high or low voltage limits. However, the limitations were greatly reduced or eliminated after the generator main and auxiliary transformer taps were set properly. Even though sometimes high and low terminal voltage limits restrict generator's reactive capability to less than the capability curve limits, these limitations seldom result in an actual operational constraint during most system conditions. For example, a system seldom needs maximum lagging reactive power generation during high system voltage conditions. Maximum reactive power output may be needed with a 1.0 pu system voltage, but the system voltage will restrain the station auxiliary voltages and generator terminal voltage to less than maximum. Conversely, high reactive power absorption is seldom needed during low or unity system voltage conditions but is sometimes needed during high system voltage conditions. The high system voltage boosts the station auxiliary and generator terminal voltages and permits operation near the steady state stability limit. Even though there can be a combination of reactive power needs and system conditions where limits other than the Capability Curve are the limiting factors, such conditions are rare. For instance, heavy load conditions with inadequate system Var reserves that require the use of generators' dynamic Vars in the steady state, could require high Var output at high system voltage, and thus generator terminal voltage can become a limiting factor.

In Item two, Mr. Adibi inquired about the high over-excited operating limit illustrated in Figure 3. During this test, the system voltage was held near unity and the generator and auxiliary transformer taps were set to allow for full overexcited capability (as advocated in Mr. Adibi's paper "Reactive Capability Limitations of Synchronous Machines", 93WM203-OPWRS). Under these conditions, the rotor field current limit was reached before the generator terminal voltage limit was reached. As discussed above, as system voltage increases, the generator terminal voltage becomes the limiting factor. This effect is well illustrated in Mr. Adibi's paper on Figures C and D for the Wagner Unit #4. For practical purposes, the voltage limitations at lower MW generation levels is not a problem since a combination of high reactive power and very low

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active power needs is unlikely. Also, large coal units seldom operate below about half of their active power capability due to limitations in the boiler automatic controls.

In Item three, Mr. Adibi makes an appropriate point about the need for generator reactive model with an on-line power flow program. We agree that this is the ideal way to get an accurate value for each unit's reactive capability during changing system load conditions. In our experience, a number of other factors played a more significant role in realizing the full reactive capability of the generators. These factors are described in detail in our paper For instance, improperly e Maximum or Minimum Excitatio Limiters, V/Hertz relays etc introduce a much larger error than an adjustment of the capability curve according to real time system operation. Moreover, common plant operators' entrenched practices, like being afraid to operate on the lead would also represent a much more serious and immediate problem. Training and maintenance programs are essential and the dominant factors in achieving a day-to-day understanding of the generators' actual reactive limits.

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Originated By: C.E. Schaeffer CES Date: 05-18-95
Checked By: F.E. Siurua Date: 05-18-95

6.9 GENERATOR NO. 2 FIELD FLASHING, Reference KM-312-8 & K-1726

Field flash power is supplied through cable 2EDA20 which is 183' of 250 mcm, a 0.025Ω resistor assembly (reference the resistor name plate in the back of cabinet EC5), three diodes in parallel (used to prevent current flow into the positive DC bus as voltage builds up out of the exciter), the 31 and 41 breakers (4 breaker contacts which will be assumed to have the same contact resistance as the molded case breakers, 0.03mΩ), and cable 2VR1 (63' of 500MCM cable, 0.02648Ω/1000ft). Per OSC-5638, the field resistance is 0.1283Ω @ 25°C. The field resistance at 100°C (0.165Ω as calculated using appendix O) will be used for this calculation. A 1 volt loss will be assumed through the diode assembly. The short runs of #1 cable internal to the excitation cabinet between the resistors, diodes, 31 & 41 breakers will be estimated to be 30ft with a resistance of 0.160Ω/1000ft. According to Joe Hurley of Westinghouse (ref. Appendix Q), the **nominal flashing current is 80 amps**. The total resistance of the path including the field winding will be:

Cable 2EDA20 - 2.1 * 183' * 0.95355Ω/1000'	= 0.3664Ω
Resistor assembly -	= 0.025Ω
4 Breaker Contacts - 4 * 0.03mΩ	= 0.00012Ω
Internal Wire - 30ft * 0.160Ω/1000ft	= 0.0048Ω
Cable 2VR1 - 2.1 * 63' * 0.02648Ω/1000ft	= 0.0035Ω
field resistance - 0.1283Ω * 2	= 0.165Ω
Total R	= 0.564Ω

Total Voltage Drop across circuit at breaker 2DA terminals at 80A = 1V + 80 * 0.564Ω = 46.2VDC.

Thus, voltage at 2DA would have to be 46.2VDC to assure current is above 80A. The 2DA minimum voltage of 100.14VDC is adequate to ensure the generator will flash.