DIGITAL LOAD CONTROL FOR HYDROELECTRIC POWERPLANTS

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16. ABSTRACT

A typical load controller for a hydroelectric powerplant utilizing a digital computer is described. Flow charts indicating the necessary timing, interface program interaction, logic, and calculations are included. Notes and suggestions to adapt the algorithm to specific applications are also included.

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a. *DESCRIPTORS*-- / *load-frequency control/ *computer applications/ *algorithms/ *supervisory control (power)/ automatic control/ control systems/ computer programing/ governors/ data transmission/ feedback/ power dispatching/ power system operations/ generating capacity/ spinning reserve/ hydroelectric power/ electric generators/

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by

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August 1977

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Division of General Research
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Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR * Bureau of Reclamation

ACKNOWLEDGMENT

The load control concept was developed through research on digital load and voltage controllers under the supervision of C. L. Clemans, Chief, Electric Power Branch. Mr. T. R. Whittemore contributed greatly to the error detector design.

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INTRODUCTION

Effective and efficient load control for hydroelectric powerplants has been the subject of recent research by the Bureau of Reclamation. Although most power systems in the United States rely on steam-driven generators for load and frequency control [1],[1] hydroelectric generation (when available) offers certain advantages such as quick large-signal load response and high efficiencies over the entire loading range and no restrictions on critical steam temperatures or fuel control limitations. However, the hydroelectric plant is not without some disadvantages, principal among these are long penstocks and inherent water delays which can present challenging control problems.

The most common load-frequency control or AGC (automatic generation control) technique uses the powerplant in an open loop [2]. The dispatch center sends raise and lower pulses to the speed-level motor to control governor setpoint. Distribution of these pulses are usually accomplished by ingenious methods to determine the generator farthest from equal generator loading. The generator response is combined in the plant total generation signal that is transmitted to the dispatch center. These systems which benefit from simple communications procedures work satisfactorily but suffer from the nonlinearity and dead band within the speed-level motor, and the difficulty of predicting the response of any one generator.

A practical solution to these problems is to enclose each generator in a power feedback loop. The load controller installed at Hungry Horse Powerplant uses power and rate of change of power to control individual generators [3]. Unfortunately, this controller causes high speed-level motor activity. Also, the controller does not provide predictable power response, constraint detection and correction without operator intervention, and complete governor droop characteristics to power system disturbances.

The load control algorithm described in this report uses power feedback to control the individual generators. A predictor model with feedback error correction and adaptive gain provides predictable power amplitude and time response. The natural governor response is used in the model to provide minimum speed-level motor activity. Constraints such as gate limit or load rejection are detected from the power response error calculations and are properly treated without operator intervention. Calculations using system frequency bias the load control to each generator to allow the normal governor droop to function for system disturbances. The allocator is based on equal allocation techniques for maximum plant efficiency and allows either the plant operator or the PSCC (Power System Control Center) to set the plant power requirement.

Digital computers are versatile and provide powerful implementation of control techniques because of the ability to make numerous logical decisions as well as computations. However, this same versatility forces the control system to be totally defined without assumptions. The 16 flow charts included in this algorithm tend to indicate a controller of great complexity. However, most of the flow charts provide the necessary definition for digital systems; this definition is often assumed and seldom documented for an equivalent analog control system.

CONCLUSIONS

The typical load controller described in this report is designed for a hydroelectric powerplant. The characteristics of speed-level motors, dashpots, water starting times, variable hydraulic head, turbine rough zones, and efficiency of equal generator loading have been studied. Since optimization of the various characteristics cause control conflicts, compromises have been made which favor accurate, predictable control over fast control. Ease of operator interaction and minimum governor activity have been stressed. The result is an algorithm which requires a minimum of changes to an existing plant and allows the generator to respond to load changes rapidly, accurately, and predictably.

The interaction with the power system has also been studied. The controller maintains the normal governor droop function necessary to the

[1] Numbers in brackets identify references listed in the Bibliography.

power system stability and operation but also allows for time-correction actions. Response to high-speed system oscillations has been sacrificed for accurate and predictable response to the AGC load balancing directives.

APPLICATIONS

The typical load controller described herein can be utilized in most hydroelectric powerplants. The concept can be modified to accommodate a powerplant with widely divergent generator ratings, pump-generators, or plants with generators connected to two separate power systems. The control uses plant power requirements sent from the dispatch controller rather than station error. Dispatch systems using this method include the RODS (Realtime Operations Dispatch and Scheduling) computer used by Bonneville Power Administration or the PSCC being designed for the Watertown Power System Operations Center.

However, minor changes in the allocator concept will allow an existing station control error signal to be used in place of plant requirement. In addition, replacement of the load-head characteristics with fuel control characteristics and changes in generator controller parameters will allow the algorithm to be used for steam turbogenerators.

Modifications of the basic controller have been used in the designs for the Coulee Third Interim Controller [4], Grand Coulee Programmable Master Supervisory Controller [5], and the proposed Yellowtail Powerplant Generation Controller. A few notes on the flow charts refer to reports of these applications.

ALGORITHM DATA STRUCTURE

The algorithm depicted by the flow charts in figures 1 through 13 is fully defined and required interactions are noted. Thus, the algorithm may be used without further modification or addition. The flow charts have notes of where modifications may be advantageous for various circumstances.

Since the design is not centered around a specific application, no specific assumptions of computer size or capabilities, peripheral storage, timing, operator interface, or operating system design are made. To aid in algorithm interface, the buffered concept is assumed.

Data Buffers

All data used by the program are assumed stored in data buffers. These buffers may be modified, updated, or used by other computer programs. When the algorithm is executed, the data in the buffers are transferred to a common working data area. The program then manipulates the data and returns the data from the working area to the data buffers. All data except certain operator entries are designed to be independent of the algorithm execution. The buffers (not the working area) may be updated or used even when the agorithm is executing.

The special operator entries shown on figure 13 should not be updated by the operator during algorithm execution. The algorithm will update these quantities at the end of execution and the operator entered data will be lost. A double buffer will eliminate the problem but such a concept would detract from the interface description.

The alarm buffer operates in the same manner as the data buffer. At the beginning of the algorithm execution, all alarms are assumed clear in a temporary alarm flag buffer. As alarm conditions are detected, the algorithm sets the appropriate alarm flag. When execution is completed, the actual alarm buffer is modified by the temporary alarm buffer. Alarms previously clear and not set remain clear. Alarms previously set which are still valid remain set without "chattering." Alarms previously set which are no longer valid are cleared and new valid alarms are set. If time of alarm is required, the time of the transfer of the temporary alarm buffer to the alarm buffer is normally used. This concept allows the software alarms to be handled in the same manner as hardware alarms.

Variable Data Requirements

The variables used in the algorithm have been successfully implemented in either fixed or floating point arithmetic. To aid in scaling variable data, the following description of variables is given:

- Time is required to be accurate to 100-ms intervals with a deviation of plus or minus 10 ms. The longest time measurement is 30 seconds.

- Power is required to have a least-significant-bit accuracy of 0.1 percent of the rated power of the smallest generator in the plant. Data from the transducers should be accurate to plus or minus 0.5 percent of rated power. The power variables should have a range which is 30 percent greater than rated generator power or 30 percent greater than the maximum plant output.

- Frequency is required to have a least-significant-bit accuracy of 0.005 Hz. The frequency range should be at least 57 to 63 Hz. Actual transducer accuracy should be better than plus or minus 0.01 Hz.

Listing of Variables and Constants

The appendix contains a listing of all the variables and constants used in the algorithm along with units, description, and subroutines which use the data. To aid in understanding, every variable or constant is given a separate name. The discerning programer will realize that many variables define data used temporarily and separate storage locations need not be assigned. The type of computer and programing language used will determine the storage of various temporary variables, and the resultant data base size.

HARDWARE INPUTS

The required hardware inputs for the algorithm include power from each generator and plant frequency. Many other operational units may be used to aid the operator or to modify the algorithm for special operating conditions. All inputs should be sampled every 2 seconds and stored in the real data input buffer after necessary scaling and conversions are made. The algorithm will work satisfactorily if the algorithm is called within 2 seconds after the input data is sampled. The algorithm will lose accuracy but will not become erratic should the sample time be delayed to a maximum of 4 seconds when computer processing delays are unavoidable. Similarly, the algorithm will remain stable if the call is as much as 4 seconds behind the data sample. Since the algorithm is time independent, data sampling and algorithm calls more frequent than 2-second intervals are allowed providing round off errors within the mathematics are sufficiently accurate to correctly calculate rates without excessive digital "noise."

Generator Power

Generator power is the basic feedback variable of the generator controller. The transducer should measure the generator power with an accuracy of at least plus or minus 0.5 percent and have a response time no greater than 0.5 second. The transducer signal should be followed by a simple analog filter with a time constant of 3 seconds. This filter removes natural power disturbances from turbine rough zones or system oscillations, and reduces aliasing from the 2-second sample rate.

The generator powers are summed within the algorithm to form total plant power eliminating the need for a total plant power transducer. If total plant power is to be modified by station-service or other local loads, transducers to monitor this extra power should be installed. An alternative is to allow the operator to enter the station-service totals into the substitution generation data provided by the operator interface.

If generator dropping to improve system stability is required, several methods may be used to adjust the load controller. If the generator to be dropped is identified by preset selectors, the generator drop signal should be used to place that unit in the off or manual mode and remove the generated power from plant totals as well as directly trip the unit breaker. If the generator to be dropped is not individually identified, the generator drop signal can also be used to place the plant in manual load control. The algorithm should provide a wait of 20 seconds, and return the plant to local plant control utilizing the normal initializing procedures within the algorithm. Return to dispatch control should be made only when the dispatch computer is aware of the change, and the plant requirement is readjusted.

The algorithm assumes that all generators are connected to the same power system, and share a common system frequency. If generators become isolated from the common system, provisions for transferring that generator to manual and adjusting plant totals should be made. If normal operating practice uses the generators for two independent systems, the algorithm may be expanded to include two allocators; such an algorithm has been designed for Yellowtail Powerplant.

Should a power transducer fail or be out of service, the operator may enter the desired power manually into the substitute generation input. The generator must be kept in the manual mode.

Frequency

The algorithm uses system frequency as measured at the plant to bias the generator requirements. This allows the normal governor droop to function to meet system demands. The frequency transducer accuracy should be plus or minus 0.01 Hz or better with a response time of 1 second or less. An analog filter of 1 to 3 seconds should be used to prevent aliasing. If generators are normally connected to more than one independent power system, a transducer for each system is required.

If the frequency transducer is out of service for calibration or repair, a programer may set the computer value to a fixed 60 Hz. The agorithm will operate but no governor droop will be present. These outages should be of short duration.

Water Levels

The forebay and tailbay elevations are used to calculate gross plant head. The transducers should be accurate to plus or minus 0.1 m and should have a response time of less than 2 minutes. If no level transducers are available, the head may be entered manuallly through the operator entry called substitute head.

Generator Motoring Status

A contact to indicate the motoring, condensing, or water depression status of the generator aids in resolving an undefined mode within the generator controller. If the generator has had the water depressed while the load controller is in the manual mode and the load mode is changed to ramp for loading, the generator controller will detect a "no response" condition until the speed-level motor is manually returned to a position near no load. However, the additional status input would allow the load controller to position the speed-level motor near no load before starting the ramp.

Generator Breaker Status

As in generator motoring status, the generator breaker status is not required for algorithm operation. When it is available, the conditions of the generator off line and the generator in manual mode can be discerned. This also allows the spinning reserve and generator frequency bias to be calculated more accurately.

HARDWARE OUTPUTS

The required hardware outputs include speed-level-motor control and governor dashpot bypass control. Any type of compatible interposing relay system may be used between the computer and the governor control circuits. The relay contacts should be controlled to the nearest 0.1 plus or minus 0.02 second. Should the computer fail in any manner, the relays should open within 0.1 second.

Speed-level Motor Relays

The speed-level motor is controlled by the SLM variable. The count in the SLM variable represents the 0.1-second increments the relays are to remain closed. A positive count should close the raise relay and a negative count should close the lower relay. An arrangement of relay contacts to avoid closing both raise and lower circuits simultaneously should be used. Also, a simple detection circuit to insure the relays are open when they should be will help overcome hardware failure problems.

Governor Dashpot Bypass Relay

A governor with a bypassed dashpot relies on the system to supply damping power to maintain governor stability. This is accomplished through the synchronizing and damping torques of the generator. As the number of bypassed dashpots increase, a system oscillation becomes a greater possibility. Therefore, the dashpots should be kept closed on as many governors as possible. In this algorithm, dashpots will be bypassed for

10 to 40 seconds following a reference change command. The time duration can be adjusted to meet individual governor requirements. The PSCC dispatch computer will attempt to keep the number of dashpots bypassed to a minimum. The control variable GDB contains the time in 0.1-second intervals that the dashpots should be bypassed. Dashpots should be closed when the load control mode is transferred to manual or the generator is taken offline.

Analog Outputs

To aid in calibration of the algorithms, analog outputs should be provided as shown in figure 13. It is required to have 4 to 8 channels of plus and minus 10 volts output, capable of driving strip chart recorder inputs. These outputs should be provided with scaling and offset using the maintenance console and an interactive maintenance program. The analog outputs may conveniently be terminated on or near the maintenance console.

OPERATOR INTERFACE

No specific operator interface has been assumed. The algorithm has been incorporated into control computers with teletypes, simple CRT displays, or complex color CRT displays with light pens. The manner in which the data is presented to the operator does not effect algorithm operation. Once the operator has initiated an action, no further operator interaction is required unless an alarm is set.

There are many types of algorithm related data that may be useful to the operator. The most useful data are shown in figure 13. The designer of a specific application should feel free to modify that list to suit the operating needs of the plant.

CALIBRATION

The calibration capability of the Load Control-Engineering Interface shown in figure 13 is very important to good operation of the algorithm. The analog outputs suitable for a strip chart recorder allow an engineer to measure the generator responses easily and accurately. Also, poor responses can be observed and algorithm constants or governor settings may be modified as necessary. The calibration system can be a tremendous help in verifying operation or troubleshooting the algorithm.

The most important constant to determine is TG, the governor time constant. This constant should be within plus or minus 10 percent of the actual value for the governor response with the dashpot bypassed (TGB) or with the dashpot in service (TGD). The time constant is defined as the time for the insertion of a step into the speed-level motor drive relay to 63 percent of the final power response. Water starting time and rapid response at the start of the power response need not affect the calculation. Also, the response time is usually not repeatable within more than plus or minus 10 percent and the average of at least three tests in both the load and unload directions should be used. The change in load for each step should be between 5 and 10 percent.

A typical test sequence may be as follows:

> The generator is placed into the "man" manual mode while generating online. The chart recorder multipliers, dividers, and offsets should be adjusted by programer input to conveniently monitor generator power over a plus or minus 20-percent range about the operating point. A second channel may be adjusted to monitor the SLM for the generator. These adjustments are usually done in computer machine language by an engineer with the aid of memory maps and program listings.
>
> A selected XL of 1 or 2 seconds is entered and TFL is set through the calibration console. The speed-level motor runs and the generator power responds until steady. This has unwound the speed-level motor. Readings of power are taken. Then a second step in the same direction is initiated. The time constant is measured from this response; when the response is again steady, power readings are taken. A step is initiated in the opposite direction and when the response is steady, power readings are taken. This response determines speed-level motor backlash. Finally, another step in the second direction allows another measurement of the time constant. Power readings should again be taken when the response is steady.

The run time of the speed-level motor (TSLM) may be calculated and also the dead band time (DBT) may be determined. This process should be repeated 3 or 4 times with and without the dashpot in service. The error time constant TEB or TED can be calculated as 25 percent of TGB or TGD, or 10 seconds, whichever is greater.

The governor time constant is a function of the governor mechanics and hydraulics and does not change with generator load or head. Therefore, the time constant should be measured after governor maintenance. The TSLM (speed-level run time) and DBT (dead band time) are a function of load, head, and the frequency of the raise and lower pulses. Once values have been calculated, the gain should be monitored for load ramps and TSLM adjusted to give a nominal gain of one. The algorithm will then automatically adjust gain as the head and load change.

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[5] Gish, W. B., "Load and Voltage Control Algorithms for Grand Coulee Powerplant," Bureau of Reclamation Research Report, REC-ERC-76-3, March 1976.

FIGURES

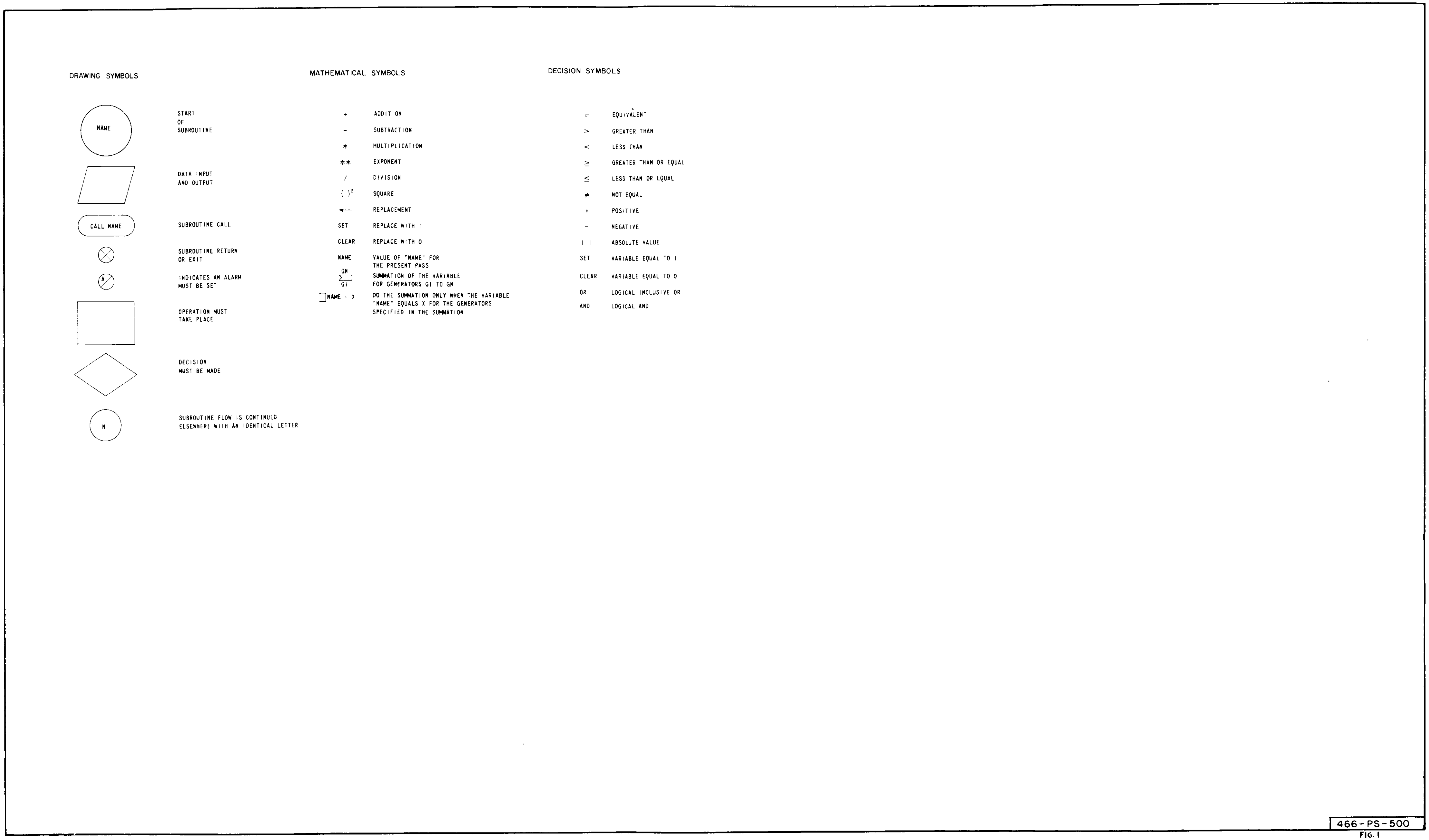


Figure 1.–Flow chart definitions. Photo 466-PS-500

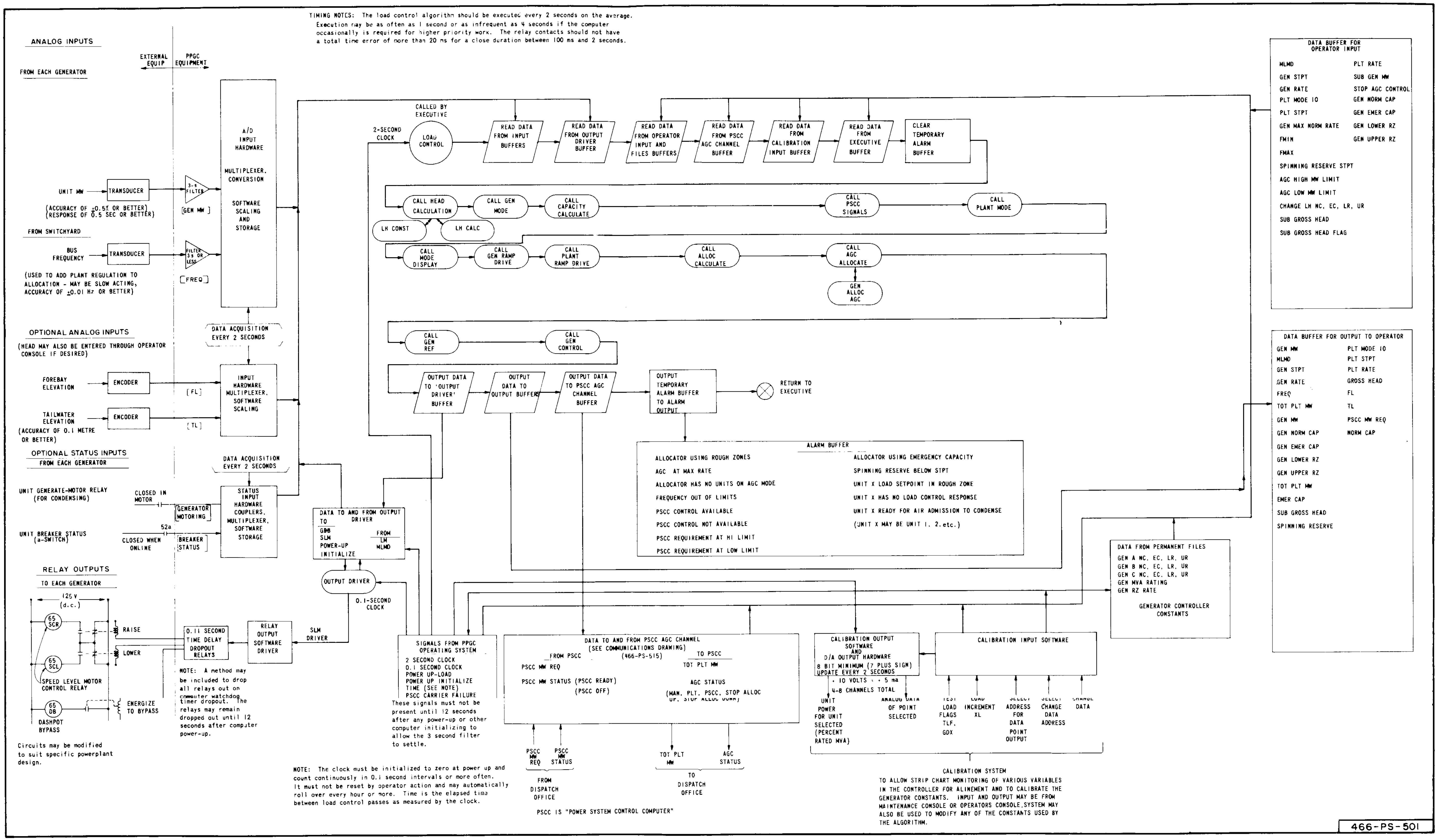


Figure 2.–Load control data flow. Photo 466-PS-501

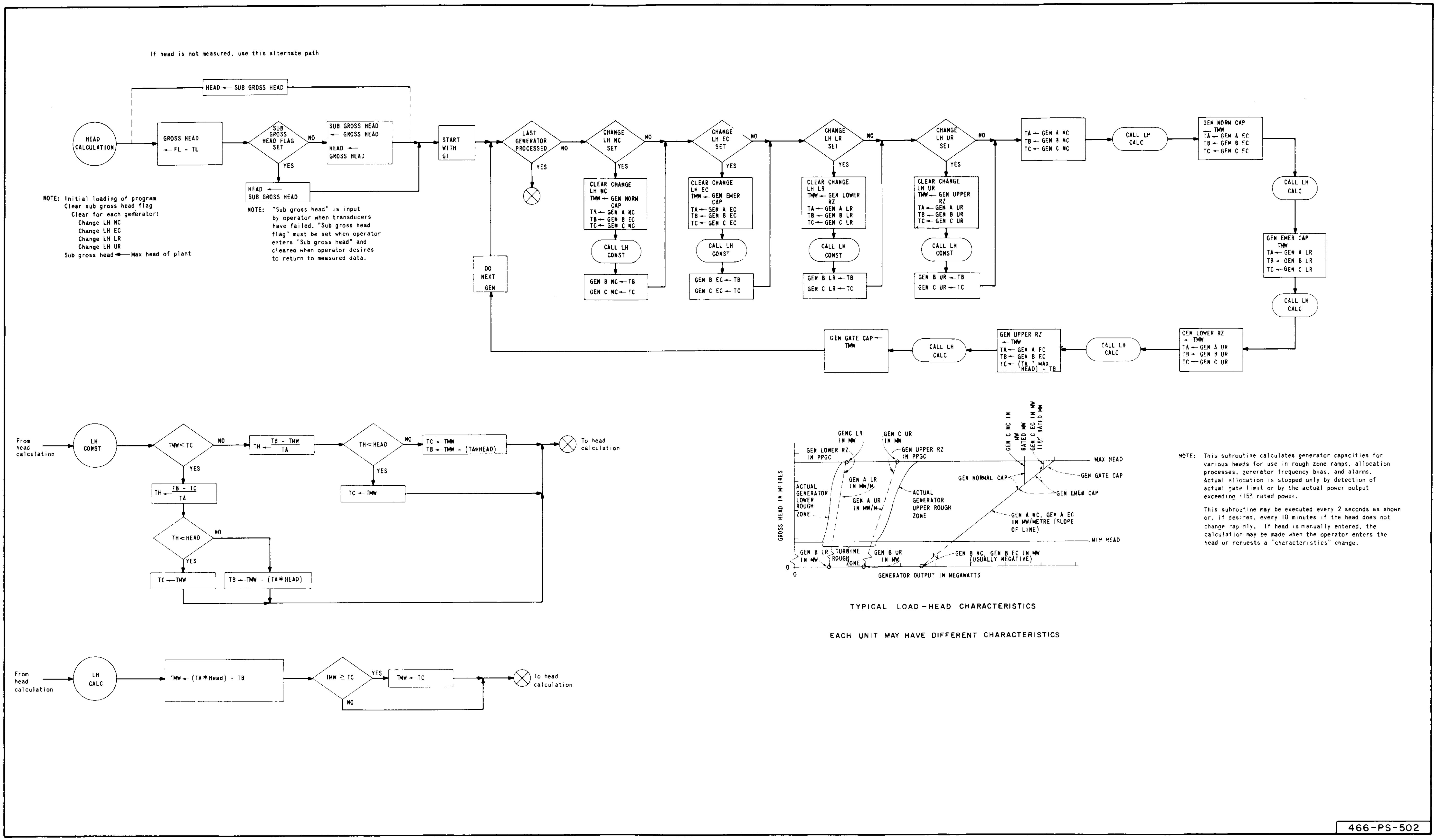


Figure 3.–Head calculation subroutine. Photo 466-PS-502

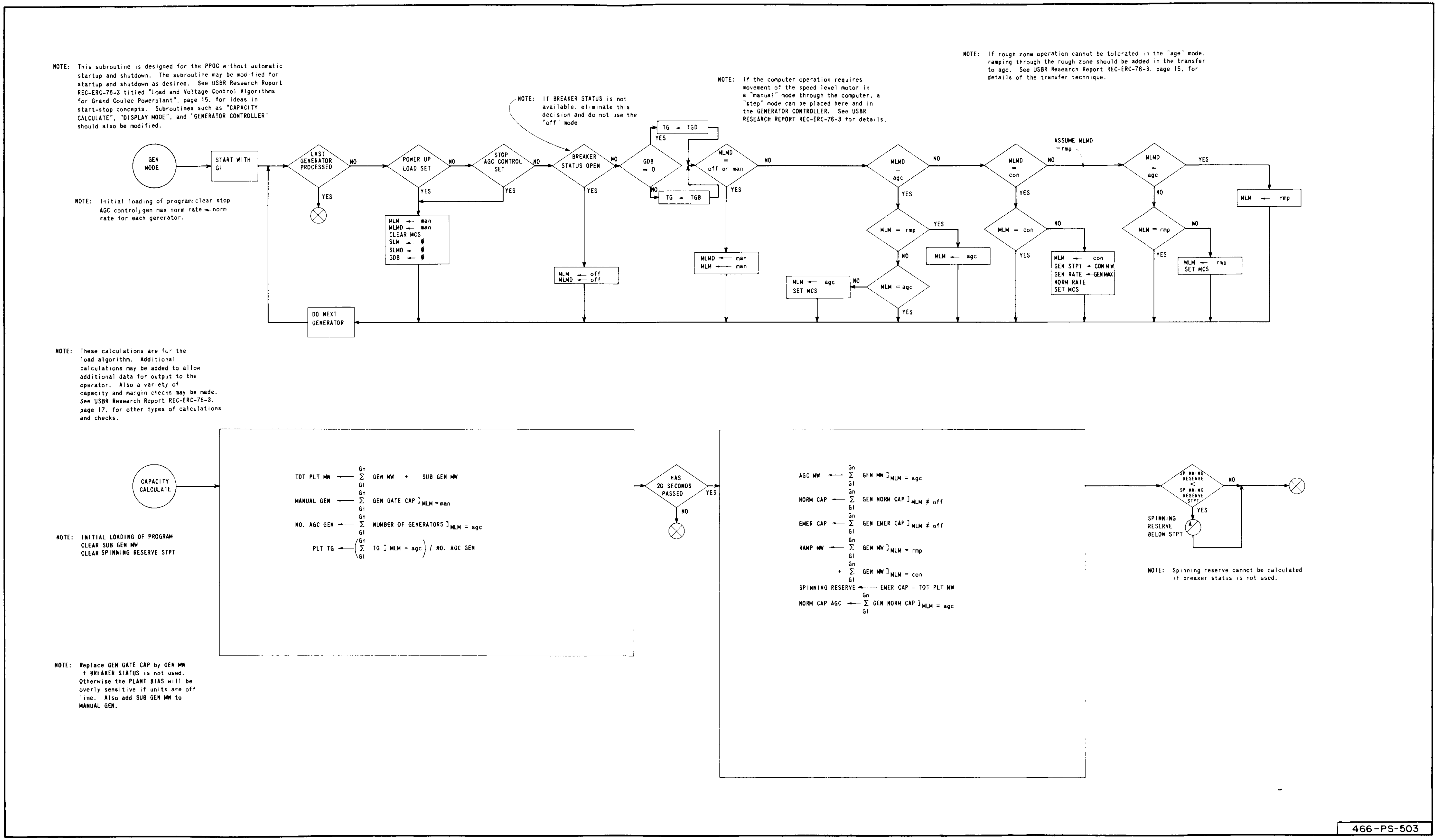


Figure 4.-General mode subroutine and capacity calculate subroutine. Photo 466-PS-503

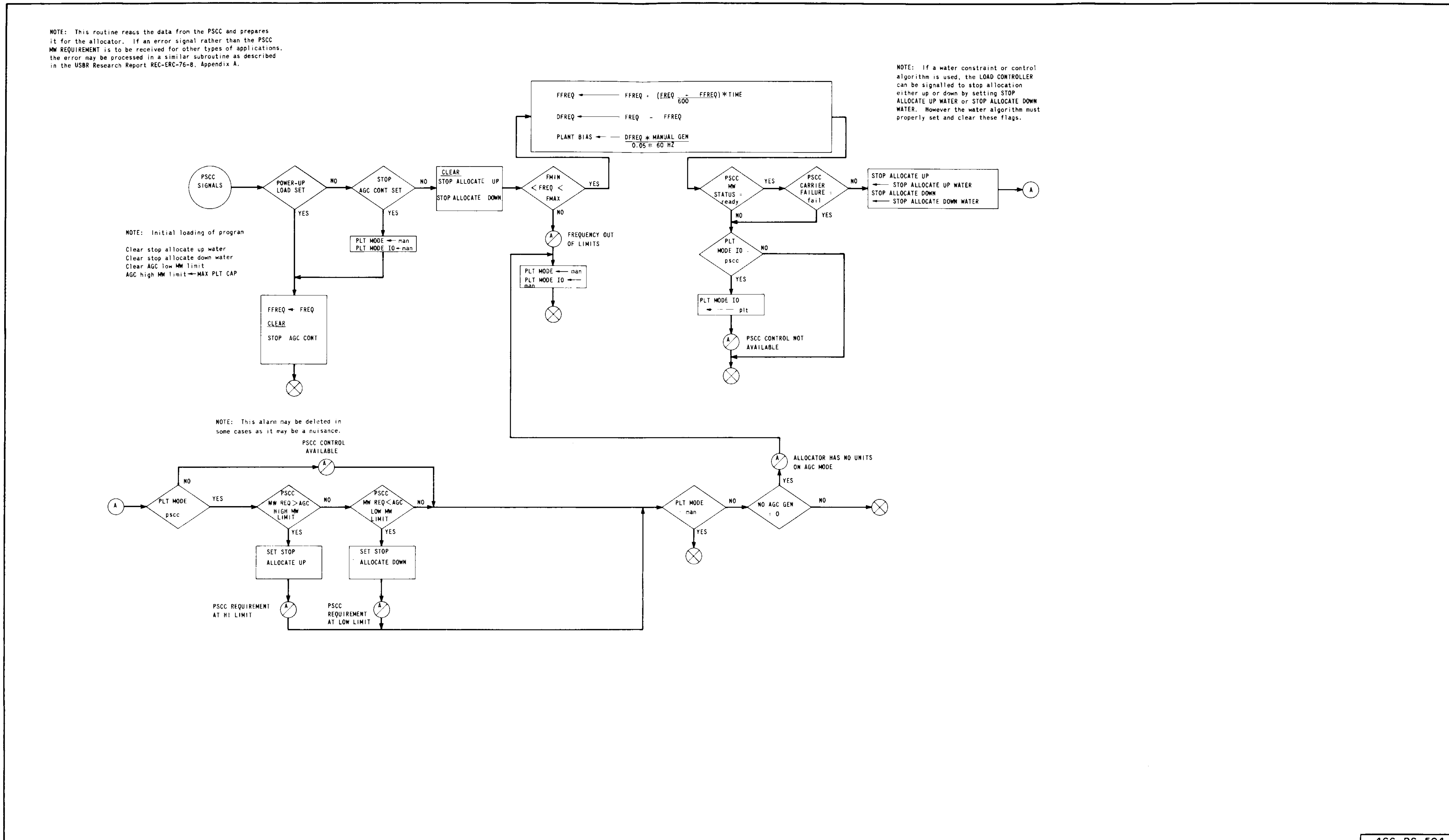
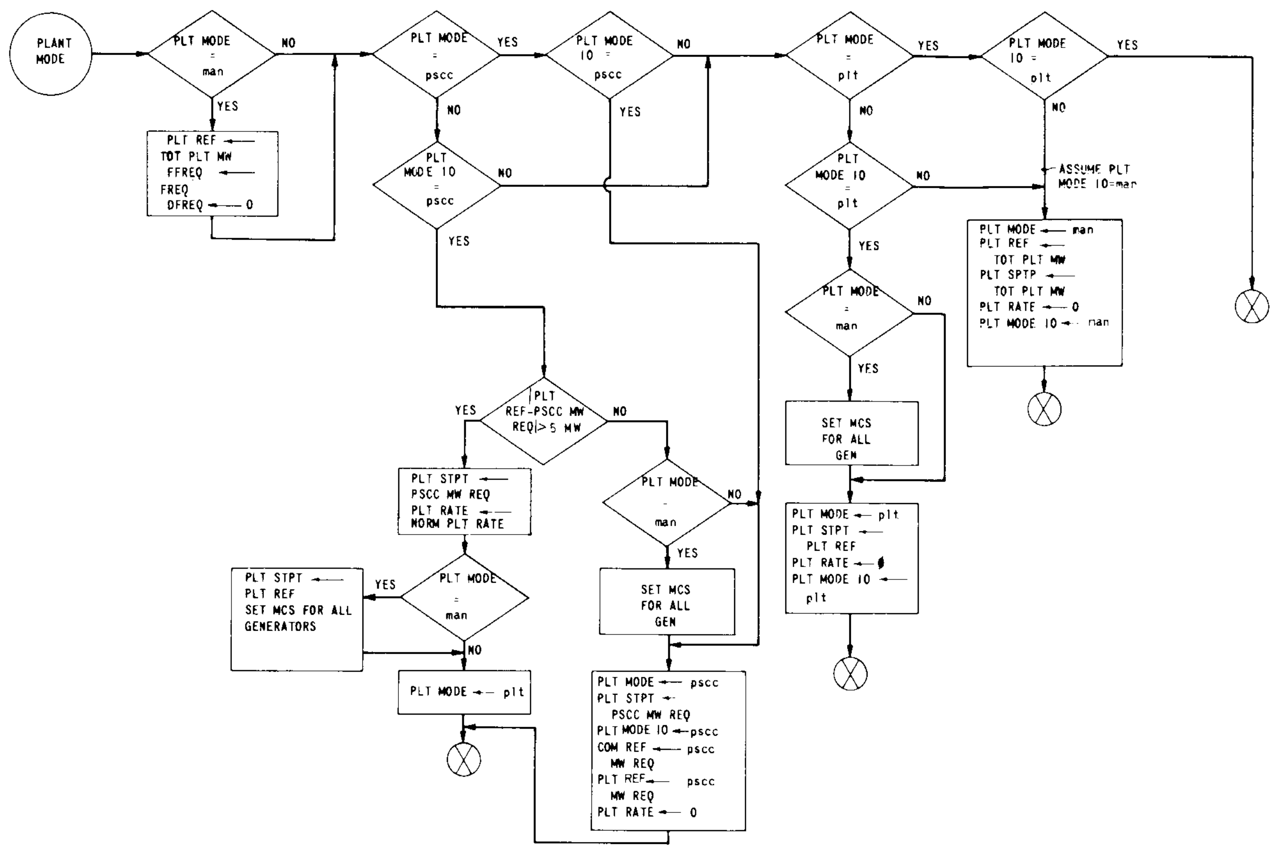


Figure 5.–PSCC signals subroutine. Photo 466-PS-504

NOTE: This subroutine performs various control transfers of modes for the plant and changes the operator output accordingly. The transfer from "man" to "plt" to "pscc" first ramps the plant to near PSCC MW REQ then transfers to "pscc" mode.



466-PS-505

Figure 6.–Plant mode subroutine. Photo 466-PS-505

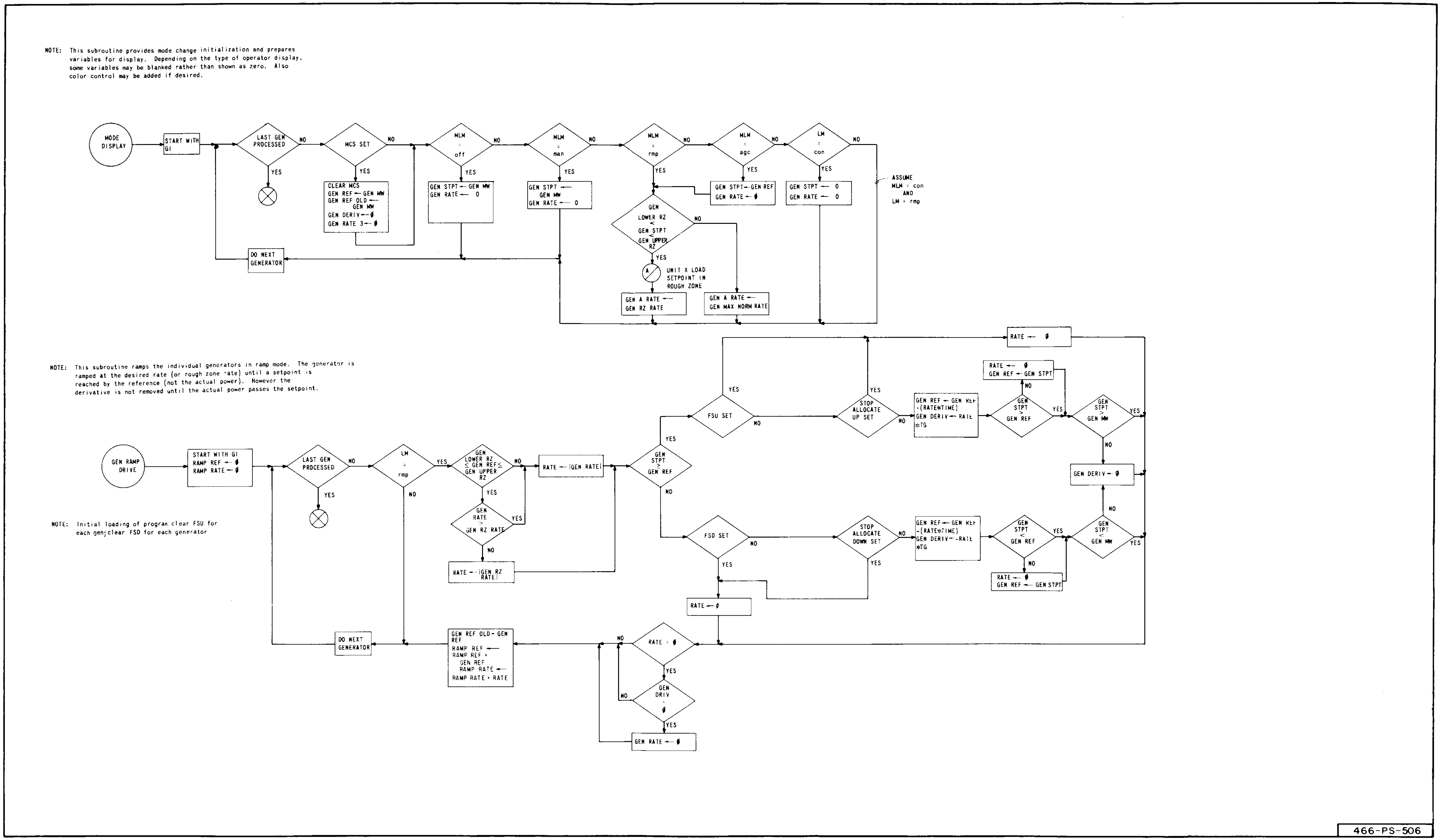


Figure 7.–Mode display subroutine and general ramp drive subroutine. Photo 466-PS-506

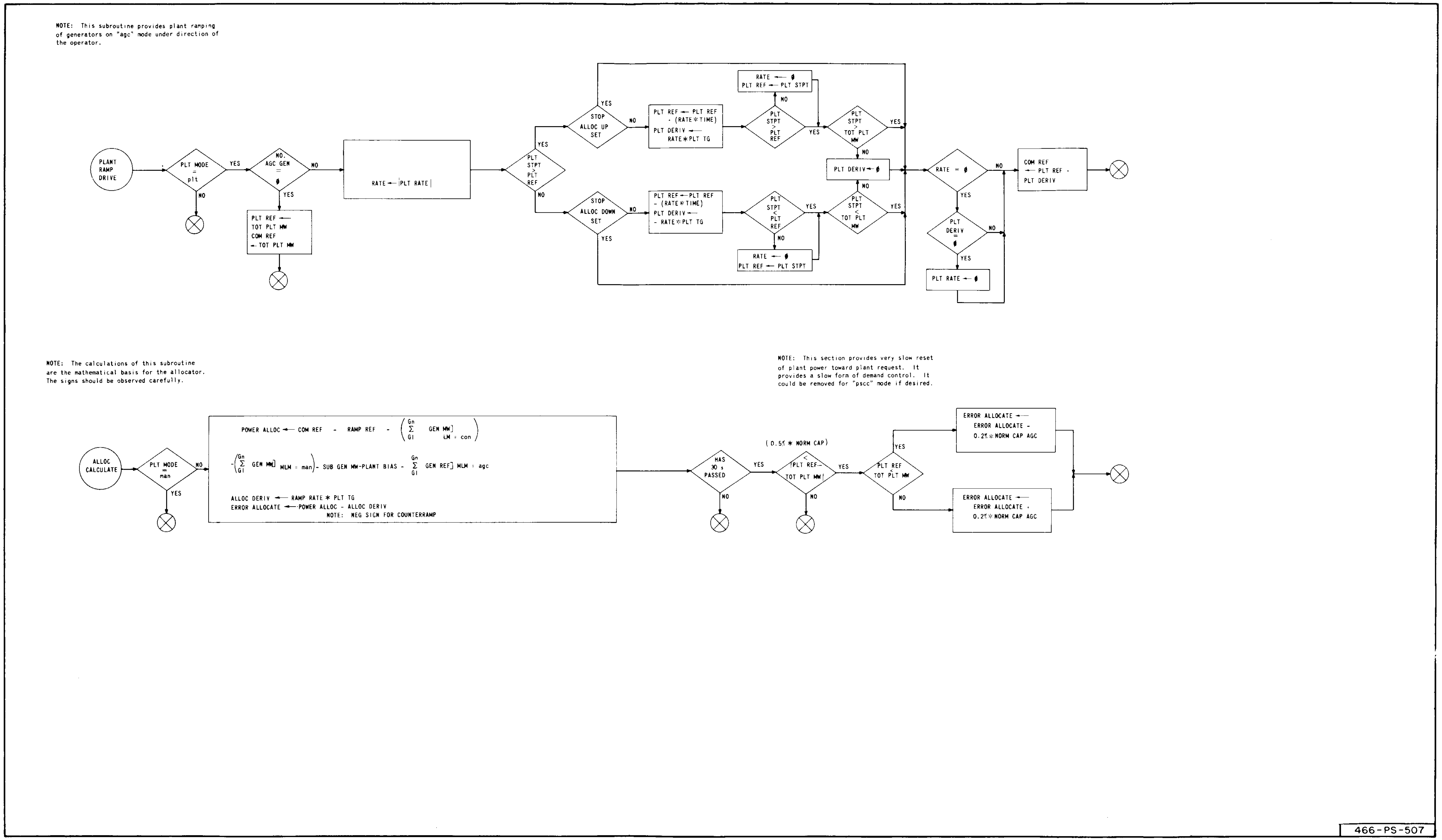


Figure 8.–Plant ramp drive subroutine and allocation calculate subroutine. Photo 466-PS-507

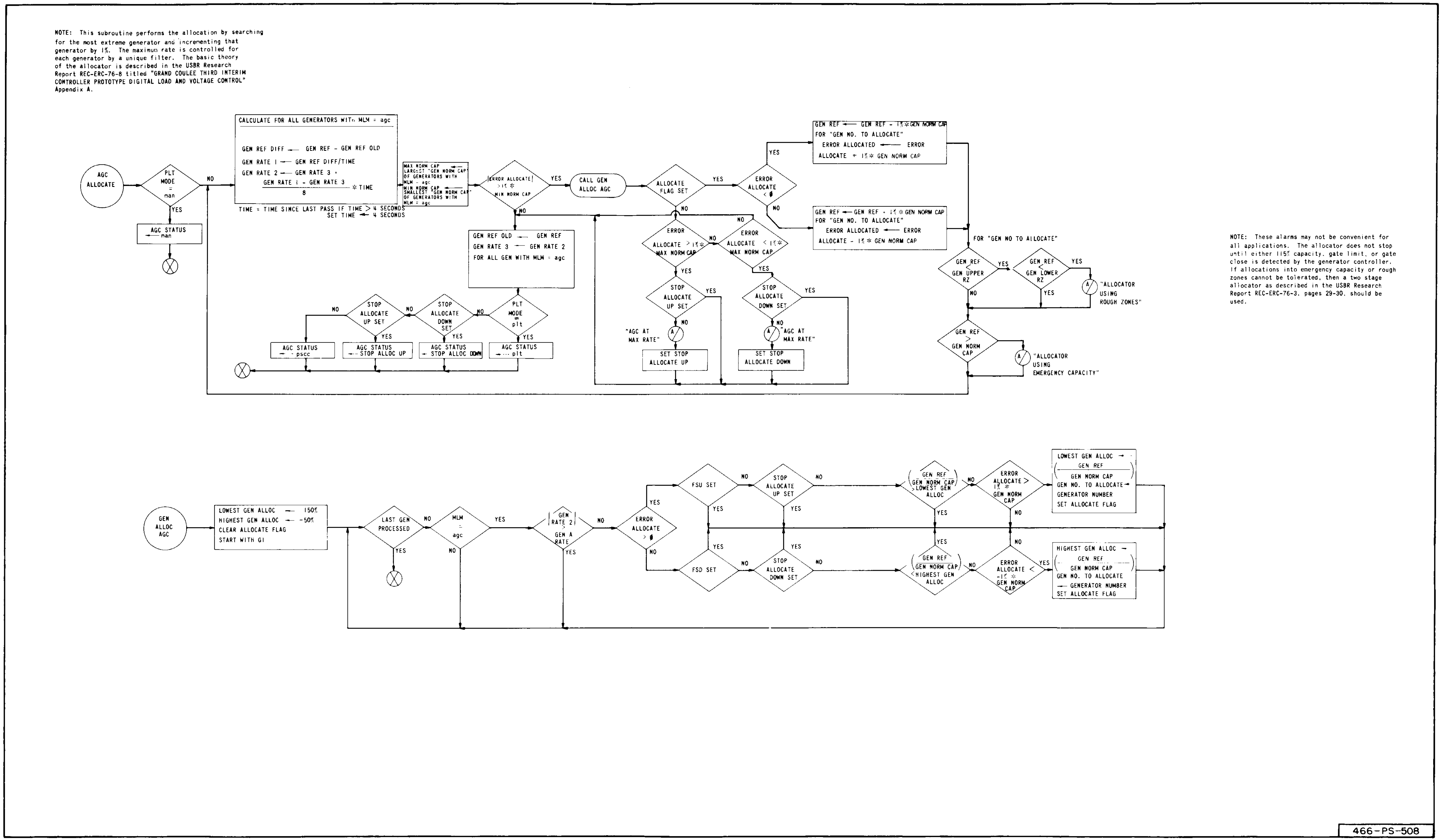


Figure 9.–AGC allocate subroutine and general allocation AGC subroutine. Photo 466-PS-508

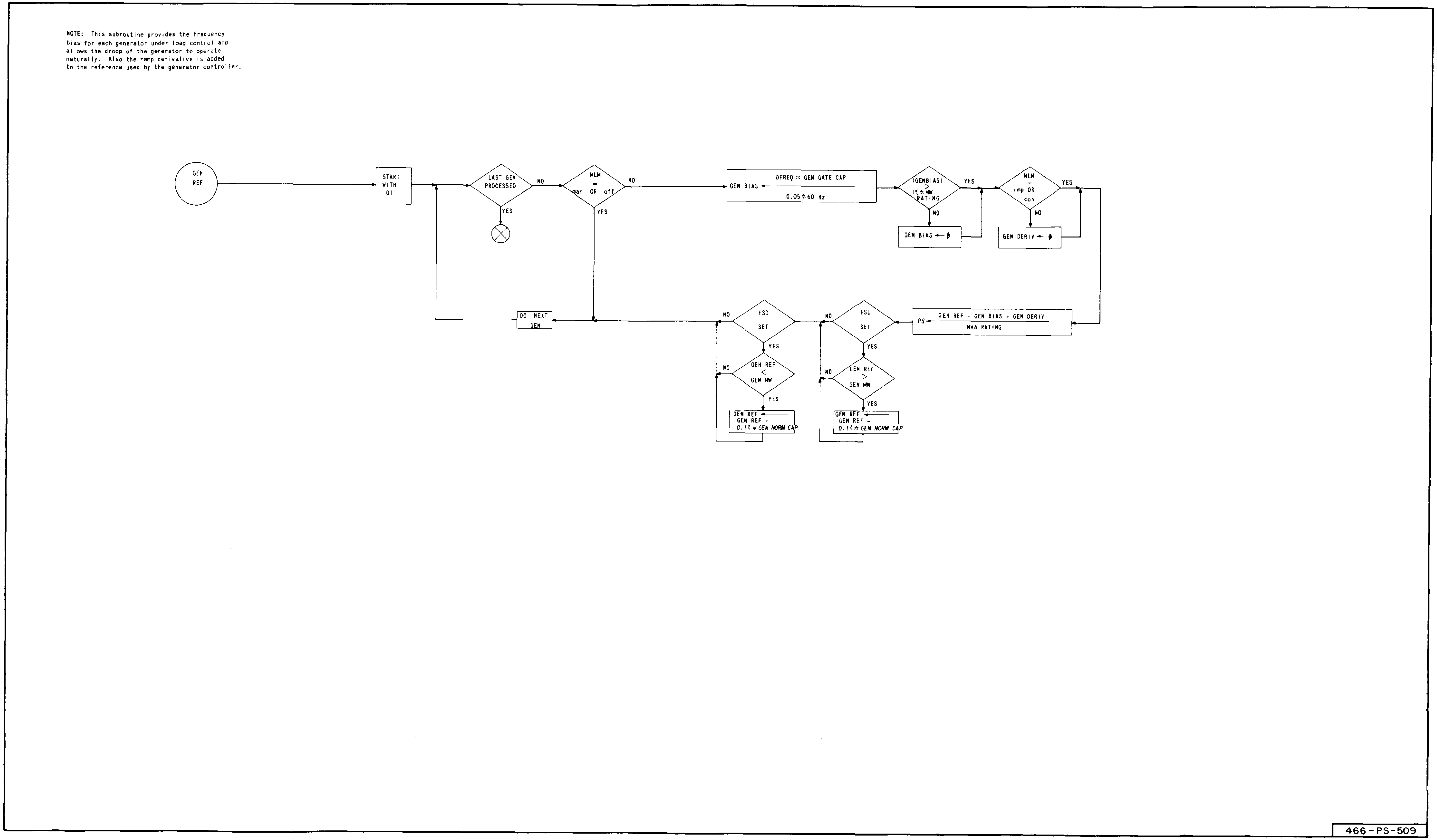


Figure 10.–General reference subroutine. Photo 466-PS-509

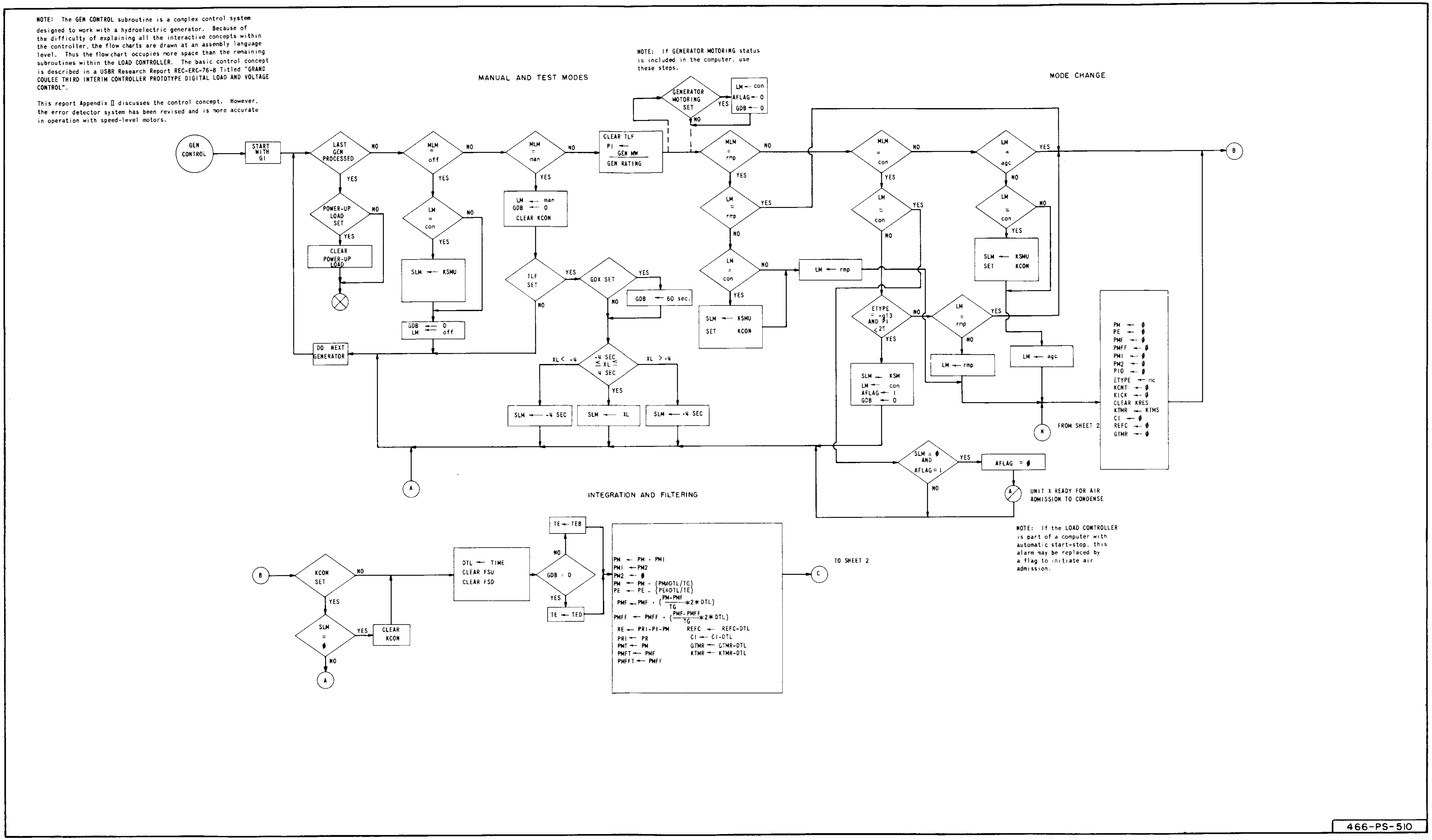


Figure 11.–Generator control (sheet 1 of 4). Photo 466-PS-510

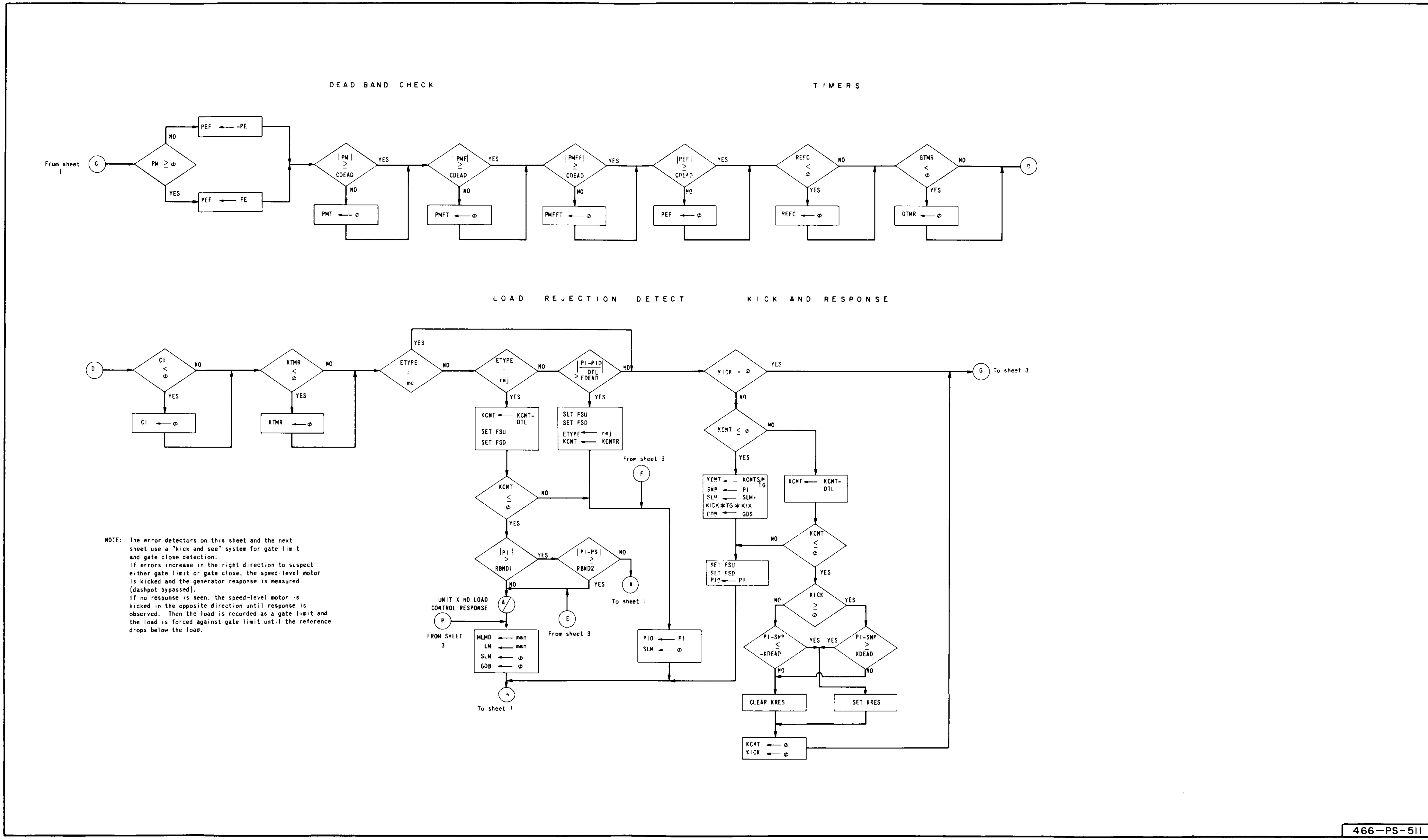


Figure 11.–Generator control (sheet 2 of 4). Photo 466-PS-511

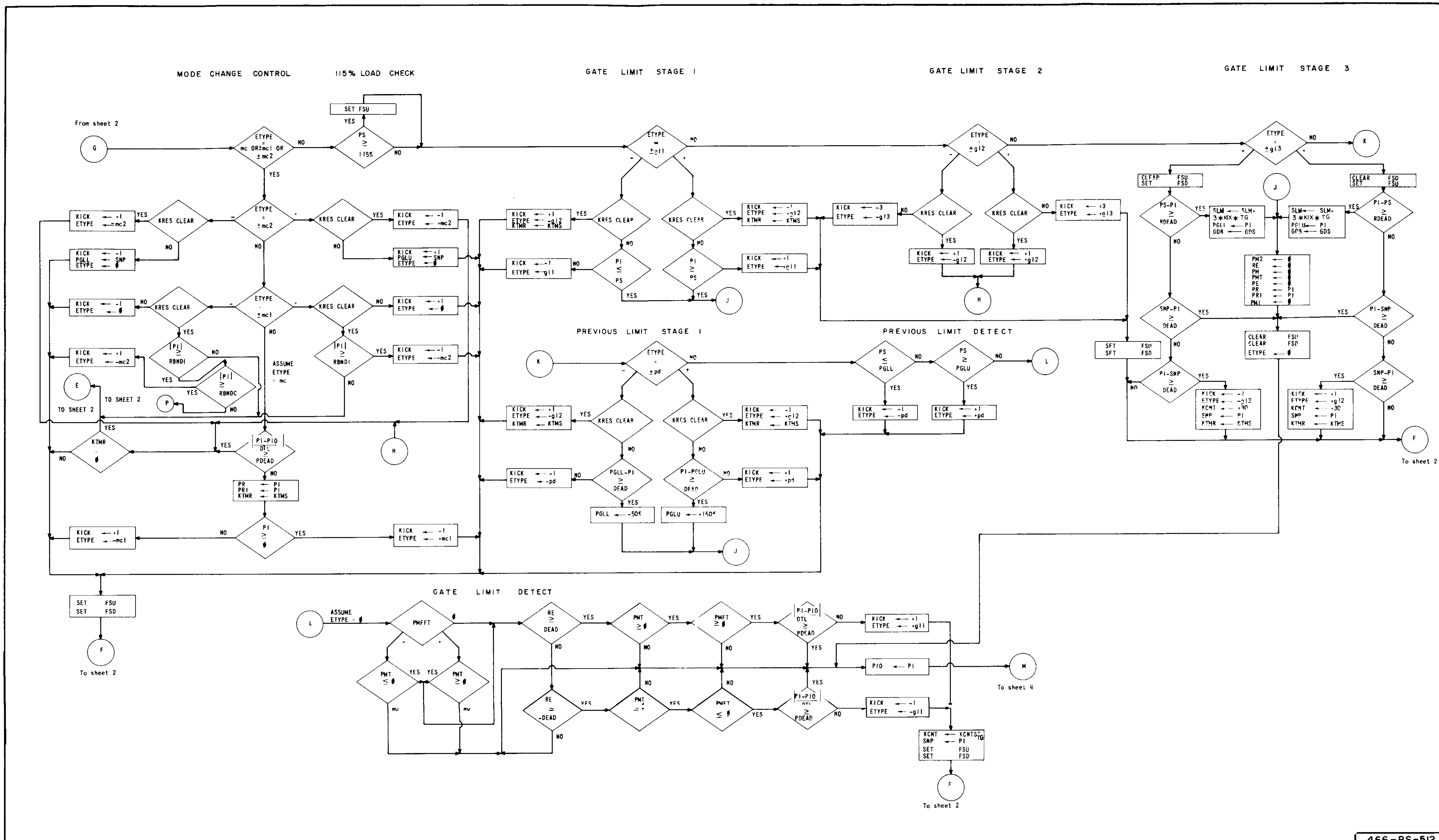


Figure 11.–Generator control (sheet 3 of 4). Photo 466-PS-512

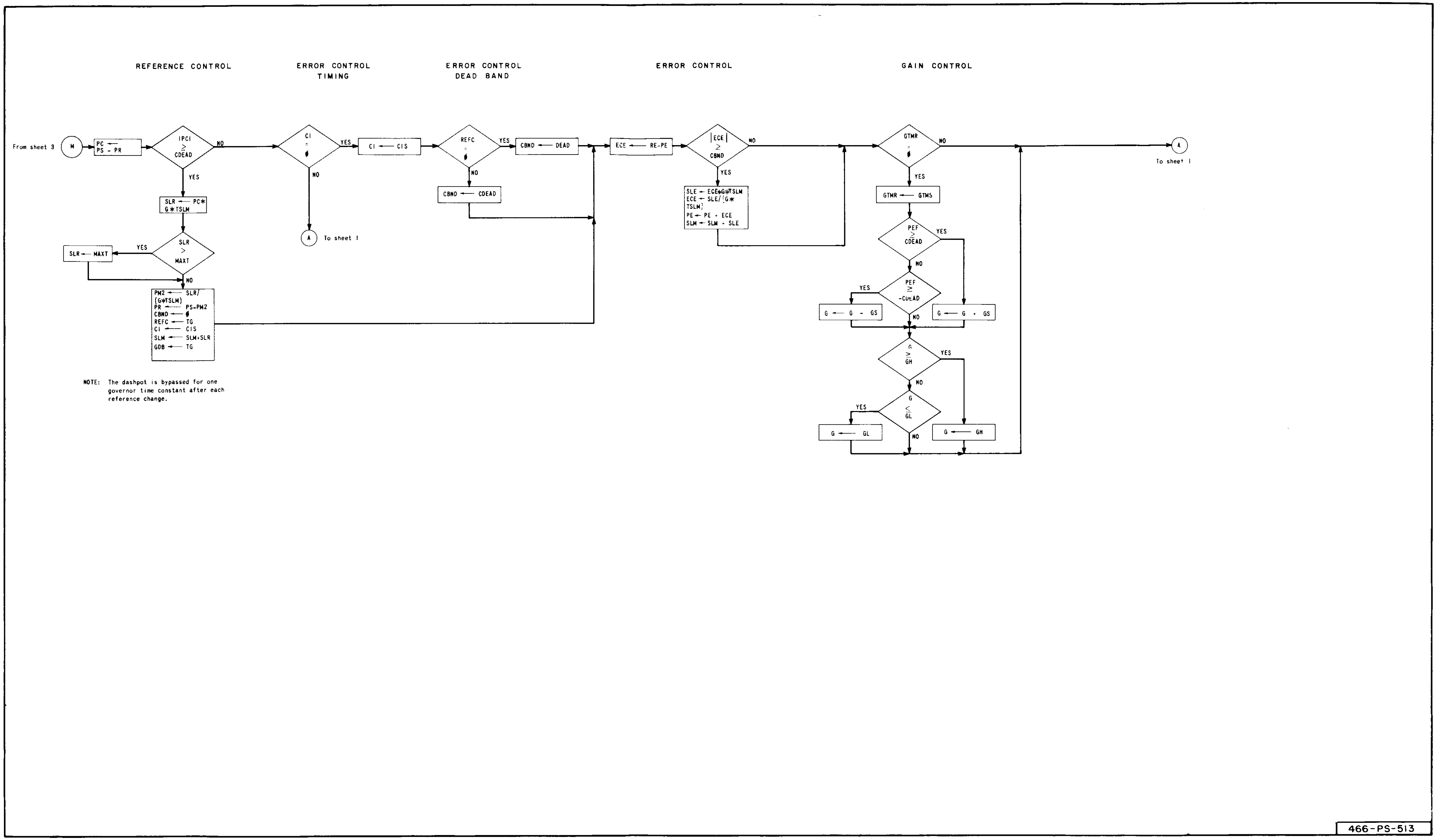


Figure 11.–Generator control (sheet 4 of 4). Photo 466-PS-513

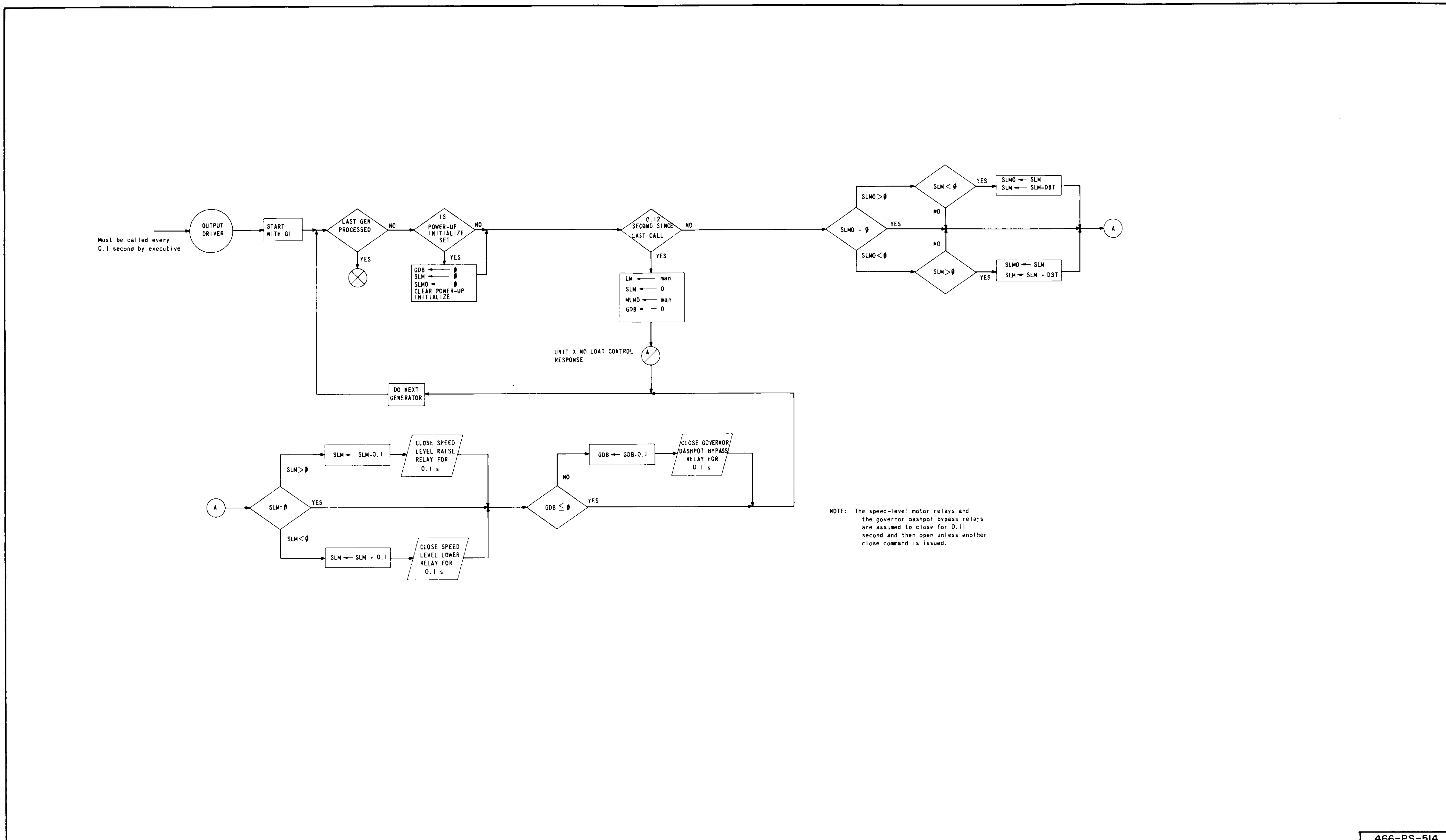


Figure 12.–Output driver. Photo 466-PS-514

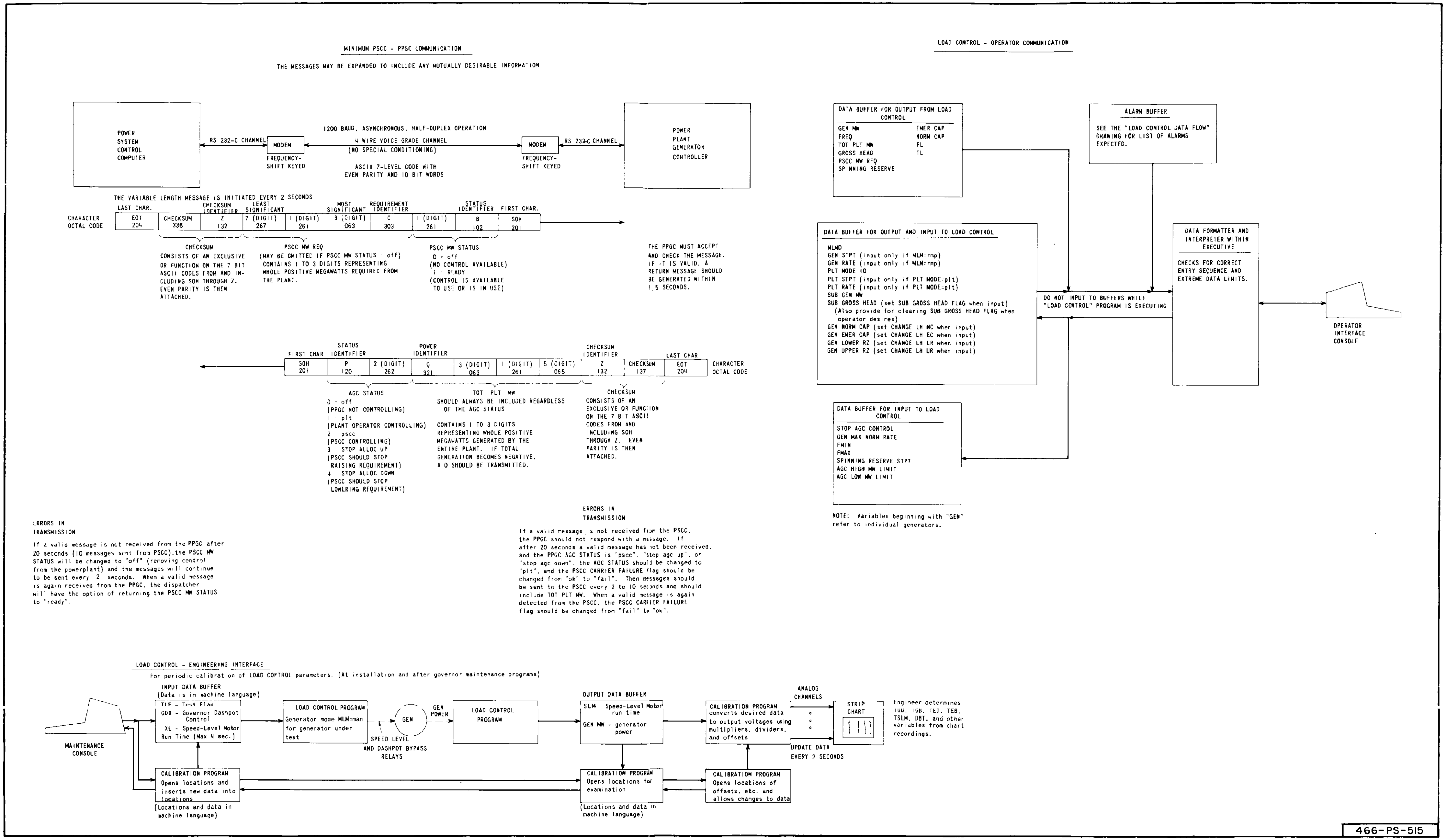


Figure 13.–Communication interface. Photo 466-PS-515

APPENDIX

APPENDIX

ALGORITHM VARIABLES AND CONSTANTS

The variables and constants are listed alphabetically. Each entry has the following format:

NAME [1] — Definition. [2]	
[Unit] [3]	
{Number of storage spaces required} [4]	Constant [5]
Comments. [6]	
(Subroutines using the variable) (subroutine) [7]	
Initializing requirements at program compilation. [8]	

1. The name of the variable is underlined.

2. If the name is not self-defining, a definition follows.

3. The unit is then given if the variable can be dimensioned. This allows the programmer to understand the computer scaling.

4. The number of storage spaces required indicates the size of the variable array needed. If storage is not given, only one storage location is needed.

5. The designation "constant" implies the data must be determined before compilation of the program or adjusted by the calibration routine.

6. If comments are given, special characteristics of the variable are described.

7. The subroutines which use the variable are listed in abbreviated form.

8. Finally, the initialization required at compilation or computer loading time is given. The lack of an initialization requirement means no initial data need be supplied.

AFLAG–Flag to indicate the alarm for air admission has been set.

{One flag per generator}

(Gen Con)

AGC HIGH MW LIMIT

[MW]

Set by operator to stop PSCC load control at a predetermined point.

(PSCC Sig)

Initialize to MAX PLT CAP.

AGC LOW MW LIMIT

[MW]

Set by operator to stop PSCC load control at a predetermined point.

(PSCC Sig)

Initialize clear.

AGC MW–Total power output (megawatts) of AGC generators.

(Cap Calc)

AGC STATUS

Status may be "man (plant on manual)," "plt (Plant under operator control)," "pscc (plant under PSCC control)," "stop alloc up (plant under PSCC control but cannot accept higher requirement)," and "stop alloc down (plant under PSCC control but cannot accept lower requirement)."

(AGC Alloc)

ALLOC DERIV–Allocator derivative.

[MW]

(Alloc Calc)

ALLOCATE FLAG

Indicates to the Allocator if any generators can be allocated.

(Gen Alloc AGC) (AGC Alloc)

BREAKER STATUS–Generator breaker status.

{One flag per generator}

OPEN means generator is offline.
CLOSED means generator is online.
Controlled by an a-switch input from unit breaker.

(Gen Mode)

CBND–Control dead band temporary.

[percent MVA]

(Gen Con)

CDEAD–Control variable dead band.

[percent MVA]   Constant

Normally set at 0.5 percent MVA.

(Gen Con)

CHANGE LH EC–Change load-head emergency capacity characteristics flag.

{One flag per generator}

Set when operator enters new GEN EMER CAP number. Clear in HEAD CALC subroutine.

(Head Calc)

Initialize clear.

CHANGE LH LR–Change load-head lower rough zone characteristic flag.

{One flag per generator}

Set when operator enters new GEN LOWER RZ number. Clear in HEAD CALC subroutine.

(Head Calc)

Initialize clear.

CHANGE LH NC–Change load-head normal capacity characteristics flag.

{One flag for each generator}

Set when operator enters new GEN NORM CAP number. Clear in HEAD CALC subroutine.

(Head Calc)

Initialize clear.

CHANGE LH UR–Change load-head upper rough zone characteristic flag.

{One flag per generator}

Set when operator enters new GEN UPPER RZ number. Clear in HEAD CALC subroutine.

(Head Calc)

Initialize clear.

CI–Counter for control interval.

[s]

{One value per generator}

(Gen Con)

CIS–Control interval setpoint.

[s] Constant

Normally set to 6 seconds.

(Gen Con)

COM REF–Combined plant reference.

[MW]

Used by the allocators.

(Plant Mode) (Plt Ramp Drive) (Alloc Calc)

CON MW–Condense mode setpoint.

[MW] Constant

{One value per generator}

The setting of the governor in megawatts for condenser operation; normally minus 2 percent speed level or minus 40 percent rated power (megawatts).

(Gen Mode)

DBT–Dead band time for speed-level motor.

[s] Constant

{One value per generator}

Values chosen by calibration procedure. The DBT is the average time taken to reverse the speed-level motor.

(Output Driver)

DEAD–Dead band for stage 3 gate limit exit.

[percent MVA] Constant

Normally 3 percent MVA.

(Gen Con)

DFREQ–Delta frequency.

[Hz]

The change in frequency from the filtered frequency.

(PSCC Sig) (Plant Mode)

DTL–Difference in time from last pass.

[s]

Same as TIME.

(Gen Con)

ECE–Temporary error control error.

[percent MVA]

(Gen Con)

EDEAD–Error dead band for load rejection.

[percent MVA/s]   Constant

Normally 5 percent MVA/s.

(Gen Con)

EMER CAP–Total emergency capacity of online generators.

[MW]

(Cap Calc)

ERROR ALLOC–Allocation error for actual allocation of plant power.

[MW]

(Alloc Calc) (Gen Alloc AGC) (AGC Alloc)

ETYPE–Flag for error in generator controller.

{One set of flags per generator}

ETYPE may have status of "rej (load rejection)," "mc, +mc1, –mc1, +mc2, –mc2 (mode change stages 0, 1 up, 1 down, 2 up, and 2 down)," "+gl1, –gl1, +gl2, –gl2, +gl3, –gl3 (gate limit stages 1 up, 1 down, 2 up, 2 down, 3 up, and 3 down)," "+pd, –pd (previous detect up and down)," " Ø (no errors)."

(Gen Con)

FFREQ–Filtered bus frequency.

[Hz]

Calculated frequency with reset.

(PSCC Sig) (Plant Mode)

FL–Forebay level.

[m]

From transducer or encoder output.

(Head Calc)

FMAX–Maximum frequency for load controller.

[Hz] Constant

The maximum or high frequency where the load controller is switched to manual. Usually set to 60.2 Hz.

(PSCC Sig)

FMIN–Minimum frequency for load controller.

[Hz] Constant

The minimum or low frequency where the load controller is switched to manual. Usually set to 59.8 Hz.

(PSCC Sig)

FREQ–Measured bus frequency.

[Hz]

From transducer output.

(PSCC Sig) (Plant Mode)

FSD–Flag to stop down allocation.

{One flag per generator}

Stops allocation down for an individual unit.
Set and cleared by GEN CONTROLLER.

(Gen Ramp Drive) (Gen Alloc AGC) (Gen Con)

Initialize clear.

FSU–Flag to stop up allocation.

{One flag per generator}

Stops allocation up for an individual unit.
Set and cleared by the Generator Controller.

(Gen Ramp Drive) (Gen Alloc AGC) (Gen Con)

Initialize clear.

G–Adaptive control gain.

[percent]

{One value per generator}

(Gen Con)

Initialize to 100 percent.

GDB–Governor dashpot bypass relay driver.

[0.1-s increments]

{One value per generator}

Time in 0.1 second to close dashpot bypass.

(Gen Mode) (Gen Con) (Output Driver)

GDS–Governor dashpot time to bypass.

[0.1-s increments] Constant

Normally 10 seconds.

(Gen Con)

GDX–Governor dashpot test flag.

{One flag per generator}

Allows the Governor dashpot bypass to be closed or open during calibration tests (set = dashpot bypassed). Entered through calibration console.

(Gen Con)

GEN A EC–Generator A constant for emergency capacity.

[MW/m] Constant

{One value for each generator}

Slope of load-head line for emergency (115 percent rated) or gate limit operation. Usually the same value as GEN A NC.

(Head Calc)

GEN A LR– Generator A constant for lower rough zone.

[MW/m] Constant

{One value per generator}

Slope of load-head line for lower rough zone boundary.

(Head Calc)

GEN A NC–Generator A constant for normal capacity.

[MW/m] Constant

{One value for each generator}

Slope of load-head line for normal (rated) or gate limit operation.

(Head Calc)

GEN A RATE–Generator allocator rate.

[MW/min]

{One value per generator}

Used by the allocator.

(Mode Display) (Gen Alloc AGC)

GEN A UR–Generator A constant for upper rough zone.

[MW/m] Constant

{One value per generator}

Slope of load-head line for upper rough zone boundary.

(Head Calc)

GEN BE EC–Generator B constant for emergency capacity.

[MW] Constant

{One value per generator}

Zero-head intercept of load-head line for emergency (115 percent rated) or gate-limit operation; usually negative and the same as GEN B NC.

(Head Calc)

GEN B LR–Generator B constant for lower rough zone.

[MW] Constant

{One value per generator}

Zero-head intercept of load-head line for lower rough zone boundary; may be negative.

(Head Calc)

GEN B NC–Generator B constant for normal capacity.

[MW] Constant

{One value for each generator}

Zero-head intercept of load-head line for normal (rated) or gate-limit operation; usually negative.

(Head Calc)

GEN B UR–Generator B constant for upper rough zone.

[MW] Constant

{One value per generator}

Zero-head intercept of load-head line for upper rough zone boundary; this may be negative.

(Head Calc)

GEN C EC–Generator C constant for emergency capacity.

[MW] Constant

{One value per generator}

This is 115 percent rated power (megawatts) of generator.

(Head Calc)

GEN C LR–Generator C constant for lower rough zone.

[MW] Constant

{One value per generator}

Intercept of lower rough zone boundary with maximum head.

(Head Calc)

GEN C NC–Generator C constant for normal capacity.

[MW] Constant

{One value per generator}

Rated power (megawatts) of generator.

(Head Calc)

GEN C UR–Generator C constant for upper rough zone.

[MW] Constant

{One value per generator}

Intercept of upper rough zone boundary with maximum head.

(Head Calc)

GEN DERIV–Generator requested derivative power (megawatts).

{One value per generator}

Derivative used in ramping.

(Mode Display) (Gen Ramp Drive)

GEN EMER CAP–Generator emergency capacity.

[MW]

{One value per generator}

Calculated by HEAD CALC subroutine. Also may be entered (changed) by operator (CHANGE LH EC must be set when changed). Output to operator.

(Head Calc)

GEN GATE CAP–Generator maximum gate capacity.

[MW]

{One value per generator}

Calculated by HEAD CALC subroutine for frequency bias of each generator.

(Head Calc)

GEN LOWER RZ–Load where lower rough zone is entered.

[MW]

{One value per generator}

Calculated by HEAD CALC subroutine. Also may be entered (changed) by the operator (CHANGE LH LR must be set when changed). Output to operator.

(Head Calc) (Mode Display) (Gen Ramp Drive)

GEN MAX NORM RATE–Maximum normal loading rate for generator.

[MW/min]

{One value per generator}

Entered by operator for maximum normal ramp rate desired for load ramps (not for AGC).

(Gen Mode) (Mode Display)

Initialize to NORM RATE.

GEN MW–Generator output power (megawatts).

[MW]

{One value per generator}

Actual generator power (megawatts) measured and filtered with a 3-second filter. Output to operator.

(Cap Calc) (Mode Display) (Gen Ramp Drive) (Alloc Calc) (Gen Con)

GEN NO TO ALLOCATE–Generator number presently being allocated.

[number]

(Gen Alloc AGC) (AGC Alloc)

GEN NORM CAP–Generator normal capacity.

[MW]

{One value per generator}

Calculated by HEAD CALC subroutine. Also may be entered (changed) by operator (CHANGE LH NC must be set when changed). Output to the operator.

(Head Calc) (Cap Calc) (Gen Alloc AGC) (AGC Alloc)

GENERATOR NUMBER

Generator number used in "DO" loops.

(Gen Alloc AGC)

GEN RATE–Loading rate for generator ramps.

[MW/min]

{One value per generator}

Entered by operator or program. Output to operator.

(Gen Mode) (Mode Display) (Gen Ramp Drive)

GEN RATE 1–Rate filter for generator loading.

[MW/time]

{One value per generator}

Rate used in allocator limiting.

(AGC Alloc)

GEN RATE 2–Rate filter for generator loading.

[MW/time]

{One value per generator}

Rate used in allocator rate limiting.

(Gen Alloc AGC) (AGC Alloc)

GEN RATE 3–Rate filter for generator loading.

[MW/time]

{One value per generator}

Used by allocator for maximum generator ramping rates. Must not be updated until allocation cycle is complete.

(Mode Display) (AGC Alloc)

GEN RATING–Generator rating in megawatts.

[MW] Constant

{One value per generator}

Rated power (MW or MVA) may be used.

(Gen Con)

GEN REF–Requested generator power (megawatts) at current time.

[MW]

{One value per generator}

(Mode Display) (Gen Ramp Drive) (Gen Alloc AGC) (AGC Alloc)

GEN REF DIFF–Difference between old and new reference.

[MW]

{One value per generator}

(AGC Alloc)

GEN REF OLD–Previous generator power (megawatts) reference.

[MW]

{One value per generator}

Used to check generator loading rates. Do not update until entire allocation is completed.

(Mode Display) (Gen Ramp Drive) (AGC Alloc)

GEN RZ RATE–Rate for loading through rough zones.

[MW/min] Constant

{One value per generator}

Normally set to a value slightly below the maximum governor ramp when the governor remains in linear operation.

$$\text{Maximum rate} = \frac{1200\ (\text{Rated MW})}{(\text{Governor gain})\ (\text{Governor time constant})\ (\text{Servomotor closing time})}$$

See reference 4 for details.

(Mode Display) (Gen Ramp Drive)

GEN STPT–Generator power setpoint for ramps.

[MW]

{One value per generator}

Entered by operator or program. Output to operator.

(Gen Mode) (Mode Display) (Gen Ramp Drive)

GEN UPPER RZ–Load where power is above the rough zone.

[MW]

{One value per generator}

Calculated by HEAD CALC subroutine. Also may be entered (changed) by operator (CHANGE LH UR must be set when changed). Output to operator.

(Head Calc) (Mode Display) (Gen Ramp Drive)

GENERATOR MOTORING–Flag to indicate generator is motoring or condensing.

{One flag per generator}

The flag is set when the generator has air admission applied for condensing.

(Gen Con)

GH–High gain setting.

[percent] Constant

Usually set to 150 percent.

(Gen Con)

GL–Low gain setting.

[percent] Constant

Usually set to 50 percent.

(Gen Con)

GROSS HEAD

[m]

Calculated from water elevations. Output to operator as required.

(Head Calc)

GS–Gain step.

[percent] Constant

Usually set to 1 percent.

(Gen Con)

GTMR–Gain interval timer.

[s]

{One value per generator}

(Gen Con)

GTMS–Gain time setpoint.

[s] Constant

Usually set to 16 seconds

(Gen Con)

HEAD

[m]

HEAD value used by the load-head calculations.

(Head Calc)

HIGHEST GEN ALLOC–Highest generator power to allocate.

[percent power]

Based on GEN NORM CAP.

(Gen Alloc AGC)

KCNT–The kick count for timing generator response after a kick.

[2-s counts]

{One value per generator}

Used in the kick and wait system.

(Gen Con)

KCNTR–Load reject counter.

[s] Constant

Usually set to 30 seconds.

(Gen Con)

KCNTS–Kick counter setpoint.

{One value per generator} Constant

Time is (KCNTS) (TG). Usually set to 0.3 second per second of generator time constant.

(Gen Con)

KCON–Flag for the condenser operation.

{One flag per generator

Flag to detect run completion of the speed-level motor for returning to the "generate" operation.

(Gen Con)

KDEAD–Kick deadband.

[percent MVA] Constant

Usually 0.3 percent MVA

(Gen Con)

KICK–Direction flag for kicking.

{One set of flags per generator}

Used to set the direction and lengths of the kick pulse.

(Gen Con)

KIX–Kick constant.

[percent MVA/s] Constant

{One value per generator}

Usually set to 0.08 percent MVA/s. Amplitude is (KIX) (TG).

(Gen Con)

KRES–Kick response flag.

{One flag per generator}

Set when generator power responds to kick.

(Gen Con)

KSM–Time to run the speed-level motor from zero load to condense.

[0.1-s intervals] Constant

{One value per generator}

Time to run speed level minus 40 percent load or minus 2 percent speed level.

(Gen Con)

KSMU–The run time to run the speed-level motor from condense position to 0 generate.

[0.1-s increments] Constant

{One value per generator}

Time to run speed-level motor 40 percent load or 2 percent speed level.

(Gen Con)

KTMR–Time for error messages.

[s]

{One value per generator}

(Gen Con)

KTMS–Time setpoint for error messages.

[s] Constant

{One value per generator}

Usually set to 180 seconds.

(Gen Con)

LM–Local mode for generator controller.

{One set of flags per generator}

Modes are "man (manual)," "rmp (ramp)," "agc (auto gen control)," and "con (condense)."

(Mode Display) (Gen Ramp Drive) (Alloc Calc) (Gen Con) (Output Driver)

LOWEST GEN ALLOC–Lowest generator power to allocate.

[percent power]

Based on GEN NORM CAP.

(Gen Alloc AGC)

MANUAL GEN–Total gate limit capacity in manual mode.

[MW]

Used for plant frequency bias calculations.

(Cap Calc)

MAX HEAD

[m]   Constant

Maximum difference between forebay and tailbay elevation for the plant.

(Head Calc)

MAX NORM CAP–Maximum normal capacity of generators on AGC.

[MW]

(AGC Alloc)

MAX PLT CAP–Maximum plant capacity.

[MW]   Constant

Used to initialize AGC HIGH MW LIMIT. Set to maximum power (megawatts) the plant can produce.

(PSCC Sig)

MAXT–Maximum SLM run time.

[s]   Constant

Usually set to the iteration time of the alogrithm or 2 seconds.

(Gen Con)

MCS–Mode change status flag.

{One flag per generator}

Set when operator requests mode changes by GEN MODE subroutine. Cleared by MODE DISPLAY SUBROUTINE.

(Gen Mode) (Plant Mode) (Mode Display)

MIN NORM CAP–Lowest normal capacity of generators on AGC.

[MW]

(AGC Alloc)

MLM–Master load mode.

{One set of flags per generator}

The MLM may be "off (offline)," "man (manual)," "rmp (ramp)," "agc (auto gen control)," "con (condense)."

(Gen Mode) (Mode Display) (Cap Calc) (Alloc Calc) (Gen Alloc AGC) (AGC Alloc) (Gen Con)

MLMD–Master load mode for display.

{One set of flags per generator}

The MLMD is output to the operator and may be changed by the operator. Separating this mode from MLM allows "handshaking" between the program and the operator. The MLMD may be "off," "man," "rmp," "agc," "con."

(Output Driver) (Gen Mode) (Mode Display)

NO. AGC GEN–Number of generators on AGC mode.

[count]

Count of AGC generators for the allocator.

(Cap Calc) (PSCC Sig) (Plt Ramp Drive)

NORM CAP–Total normal capacity of online generators.

[MW]

(Cap Calc)

NORM CAP AGC–Normal capacity total of AGC generators.

[MW]

(Alloc Calc) (Cap Calc)

NORM RATE–Normal generator loading rate.

[MW/min] Constant

{One value common to all generators}

Used for initializing operator output. Usually set to 10 percent rated power rate (MW/min).

(Gen Mode)

NORM PLT RATE–Normal plant rate.

[MW/min] Constant

Ramp rate for moving plant toward the PSCC MW REQ when transferring to "pscc" mode. Usually set to 10 percent rated plant power rate (MW/min)

(Plant Mode)

PC–Temporary power reference change.

[percent MVA]

(Gen Con)

PDEAD–Power dead band.

[percent MVA/s] Constant

Usually set to 0.1 percent MVA/s.

(Gen Con)

PE–Power calculated by the error model.

[percent MVA]

{One value per generator}

(Gen Con)

PEF–Temporary filtered error model power.

[percent MVA]

(Gen Con)

PGLL–Previous gate lower limit.

[percent MVA]

{One value per generator}

(Gen Con)

Initialize to minus 50 percent MVA.

PGLU–Previous gate limit upper.

[percent MVA]

{One value per generator}

(Gen Con)

Initialize to plus 150 percent MVA.

PI–Power input.

[percent MVA]

{One value per generator}

(Gen Con)

PIO–Input power from last pass.

[percent MVA]

{One value per generator}

Used to generate power rates.

(Gen Con)

PLANT BIAS–Plant frequency bias for generation on manual.

[MW]

Plant bias insures the allocator will not fight the normal droop of generators on manual control.

(PSCC Sig) (Alloc Calc)

PLT DERIV–Plant derivative.

[MW]

(Plt Ramp Drive)

PLT MODE–Plant load control mode.

Modes may be "man (manual)," "plt (plant or local operator)," and "pscc (control from PSCC)."

(PSCC Sig) (Plant Mode) (Plt Ramp Drive) (AGC Alloc)

PLT MODE IO–Plant mode for input/output.

Carries the plant mode to and from the operator and allows handshaking techniques.

(PSCC Sig) (Plant Mode)

PLT RATE–Plant rate for ramps.

[MW/min]

Entered by operator or program for speed of plant ramps. Output to operator.

(Plant Mode) (Plt Ramp Drive)

PLT REF–Plant reference.

[MW]

The value is the present power desired by the allocator.

(Plant Mode) (Plt Ramp Drive) (Alloc Calc)

PLT STPT–Plant setpoint.

[MW]

Endpoint of ramps.

(Plant Mode) (Plt Ramp Drive)

PLT TG–Average governor time constant of generators on AGC.

[s]

(Cap Calc) (Plt Ramp Drive) (Alloc Calc)

PM–Power calculated by the reference model.

[percent MVA]

{One value per generator}

(Gen Con)

PM1–First stage delay of reference model power.

[percent MVA]

{One value per generator}

Used by the control feedback.

(Gen Con)

PMF–Filtered power of the reference model.

[percent MVA]

{One value per generator}

Used by the error detector.

(Gen Con)

PMFF–Double filtered power of the reference model.

[percent MVA]

{One value per generator}

Used by the error detector.

(Gen Con)

PMFFT–Temporary double filtered reference power.

[percent MVA]

(Gen Con)

PMFT–Temporary filtered reference power.

[percent MVA]

(Gen Con)

PMT–Temporary reference model power.

[percent MVA]

(Gen Con)

POWER ALLOC–Power to be allocated.

[MW]

(Alloc Calc)

POWER UP LOAD–Flag indicating the processor has just powered up.

Set by executive. Cleared by GEN CONTROL.

(Gen Mode) (PSCC Sig) (Gen Con)

POWER UP INTIALIZE

Flag set by executive at compute power-up. Cleared by the OUTPUT DRIVER Subroutine.

(Output Driver)

PR–Reference power.

[percent MVA]

{One value per generator}

(Gen Con)

PR1–First stage delay of reference power.

[percent MVA]

{One value per generator}

(Gen Con)

PS–Power setpoint.

[percent MVA]

{One value per generator}

The reference requirement for the generator from the allocator.

(Gen Con) (Gen Ref)

PSCC CARRIER FAILURE

Modes may be "OK (PSCC transmitted correct information within the last 20 seconds)" or "fail (PSCC has not transmitted a correct message for more than 20 seconds)."

(PSCC Sig)

PSCC MW REQ–Power requirement (megawatts) from PSCC.

[MW]

(PSCC Sig) (Plant Mode)

PSCC MW STATUS–Status of PSCC control.

Modes may be "off (PSCC not able to control)" and "ready (PSCC can control or is controlling)."

(PSCC Sig)

RAMP RATE–Sum of rates of generators in the ramp mode.

[MW/min]

Used in the allocator.

(Gen Ramp Drive) (Alloc Calc)

RAMP REF–Sum of references of generators in the ramp mode.

[MW]

Used in the allocator.

(Gen Ramp Drive) (Alloc Calc)

RAMP MW–Total power (megawatts) of ramping generators.

[MW]

(Cap Calc)

RATE–Temporary rate storage.

[MW/min]

Rate of loading used by the generator ramp driver and plant ramp driver.

(Gen Ramp Drive) (Plt Ramp Drive)

RBND1–Load reject dead band stage 1.

[percent MVA]   Constant

Usually set to 3 percent MVA.

(Gen Con)

RBND2–Load reject dead band stage 2.

[percent MVA]   Constant

Usually set to 15 percent MVA

(Gen Con)

RBNDC–Dead band for condense.

[percent MVA]   Constant

Usually set to 2 percent MVA.

(Gen Con)

RDEAD–Dead band for stage 3 gate limit.

[percent MVA]   Constant

Usually set to 0.1 percent MVA.

(Gen Con)

RE–Reference error.

[percent MVA]

Temporary location of reference error.

(Gen Con)

REFC–Reference control counter.

[s]

{One value per generator}

(Gen Con)

SLE–Temporary speed-level time for error change.

[s]

(Gen Con)

SLM–Speed-level motor output.

[0.1-s increments]

{One value per generator}

Time in 0.1 s for speed-level motor relays to be closed. Plus SLM closes raise relay. Negative SLM closes lower relay.

(Gen Mode) (Gen Con) (Output Driver)

SLMO–Speed-level motor output old.

[0.1-s increments]

{One value per generator}

Retains the last value of SLM for backlash calculations.

(Gen Mode) (Output Driver)

SLR–Temporary speed-level time for reference change.

[s]

(Gen Con)

SNP–Snapshot power.

[percent MVA]

{One value per generator}

Used in the kick process.

(Gen Con)

SPINNING RESERVE

[MW]

Emergency capacity of online units minus the present total plant output.

(Cap Calc)

SPINNING RESERVE STPT

[MW]

Entered by Operator.

(Cap Calc)

Initialize clear.

STOP AGC CONTROL–Panic button for load control.

Set by operator through a panic button or keyboard entry. Cleared by PSCC SIGNAL subroutine.

(Gen Mode) (PSCC Sig)

Initialize clear.

STOP ALLOCATE DOWN–Stop main load allocator from lowering load.

Cleared in PSCC SIG subroutine. Set as needed.

(PSCC Sig) (Gen Ramp Drive) (Plt Ramp Drive) (Gen Alloc AGC) (AGC Alloc)

STOP ALLOCATE UP–Stop main load allocator from raising load.

Cleared in PSCC SIG subroutine. Set as needed.

(PSCC Sig) (Gen Ramp Drive) (Plt Ramp Drive) (Gen Alloc AGC) (AGC Alloc)

STOP ALLOCATE DOWN WATER

Flag from water constraint algorithm to stop load control allocation.

(PSCC Sig)

Initialize clear.

STOP ALLOCATE UP WATER

Flag from water constraint algorithm to stop load control allocation.

(PSCC Sig)

Initialize clear.

SUB GEN MW–Substitute generator power (megawatts).

[MW]

{One value for plant}

Entered by operator to compensate for generator transducer failure, or other unmonitored generation.

(Cap Calc) (Alloc Calc)

Initialize clear.

SUB GROSS HEAD

[m]

Value entered by operator to substitute for measured head (during testing or repair of forebay or tailbay level encoders).

(Head Calc)

Initialize to MAX HEAD.

SUB GROSS HEAD FLAG

Set when SUB GROSS HEAD is entered by the operator. Cleared when operator requests return to measured head.

(Head Calc)

Initialize clear.

TA–Temporary A constant.

[MW/m]

(Head Calc)

TB–Temporary B constant.

[MW]

(Head Calc)

TC–Temporary C constant.

[MW]

(Head Calc)

TE–Time constant of error controller.

[s]

{One value per generator}

(Gen Con)

TEB–Time constant of error control with dashpot bypassed.

[s] Constant

{One value per generator}

Set using calibration procedure.

(Gen Con)

TED–Time constant of error control with dashpot normal.

[s] Constant

{One value per generator}

Set using calibration procedure.

(Gen Con)

TG–Time constant of the governor.

[s]

{One value per generator}

Governor time constant presently in use.

(Gen Ramp Drive) (Cap Calc) (Gen Con)

TGB–Time constant of governor with the dashpot bypassed.

[s] Constant

{One value per generator}

This constant is calibrated using the calibration system.

(Gen Mode)

TGD–Time constant of governor with the dashpot in service.

[s] Constant

{One value per generator}

This constant is calibrated using the calibration system.

(Gen Mode)

TH–Temporary head.

[m]

(Head Calc)

TIME–Time of control algorithm.

[s]

Generated by the executive and is the time passed since the last time the load algorithm was executed.

(PSCC Sig) (Gen Ramp Drive) (Plt Ramp Drive) (AGC Alloc)

TL–Tailbay level.

[m]

From transducer or encoder output to operator.

(Head Calc)

TLF–Test load flag.

{One flag per generator}

Flag set and cleared from the maintenance console with the calibration program.

(Gen Con)

TMW–Temporary power (megawatts).

[MW]

(Head Calc)

TOT PLT MW–Total plant power output (megawatts).

[MW]

Sum of generator outputs. Output to Operator. Output to PSCC.

(Cap Calc) (Plt Mode) (Plt Ramp Drive) (Alloc Calc)

TSLM–Run time of speed-level motor

[s] Constant

{One value per generator}

Run time from 0 to 5 percent speed adjust setting calculated from calibration procedure.

(Gen Con)

XL–Run time increment for load test.

[0.1-s increments]

{One value per generator}

Time to run speed-level motor for calibration tests. (+ for raise, – for lower). Maximum time is 4 seconds.

(Gen Con)

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Bur Reclam Rep REC-ERC-77-10, Div Gen Res, Aug 1977, Bureau of Reclamation, Denver, 76 p, 13 fig

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IDENTIFIERS–/ minicomputers

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