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WECC Guideline:
Guidelines for Over Excitation Limiter (OEL) and Over Excitation Protection (OEP)
Testing

Date: 2/11/2000

Introduction

This guideline provides instructions regarding testing and modeling Over Excitation Limiters (OEL) and Over Excitation Protection (OEP). It was written to provide guidance on how to perform OEL and OEP testing as required by the WECC Generating Unit Model Validation Policy.

Approved By:

Approving Committee, Entity or Person	Date
WECC Modeling and Validation Work Group	February 2000

Guidelines for Over Excitation System Limiter (OEL) and Over Excitation Protection (OEP) Testing

Introduction

The test guidelines for dynamic testing of synchronous machines were developed in February 1997 and are given in the following document available through WECC.

Test Guidelines For Synchronous Unit Dynamic Testing And Model Validation, prepared by WSCC Control Work Group and Modeling & Validation Work Group, February 1997.

Although the guidelines for testing overexcitation limiters and protection were included in the above document (Section 10.0, page6), a detailed test procedure was not included. The following guidelines and the attachment provide detailed information and clarification regarding the data necessary for modeling these devices in stability programs.

The purpose of the Overexcitation Limiter (OEL) is to insure that the thermal capability of the field winding is not exceeded while the automatic voltage regulator is in control. It is important to distinguish between an Overexcitation Limiter and an Overexcitation Protection Device (OEP). While an OEL acts through the voltage regulator to reduce and maintain field current within the capability of the field winding, an OEP serves to remove the voltage regulator from service or trip the generator off line.

Data submitted for these devices (OEL or OEP) should include the following:

1. Minimum Pickup Value in per unit. This is the minimum value of field current for which the device will operate (begin timing).
2. Maximum Field Current Limit in per unit (if applicable). This is the maximum field current allowable by the device. This is an instantaneous limit or trip.
3. Timed Field Current Limit in per unit. This is the field current level after the limiter has taken control or transferred to manual.
4. Time Delay between pickup and limit or trip in seconds for at least 3 different current levels. For a fixed time delay (no inverse-time characteristic), only one value is necessary.
5. Whether or not the voltage regulator remains in service, control is transferred to manual, or the unit is tripped when the device operates.

Test Methods: Test methods are briefly described below. More details and sample test guidelines, PSLF OEL model description and the Per Unit System Description can be found in the Appendix -H.

- Limits and trips related to overexcited operation should be field checked by tests in which changes are applied to the voltage regulator to drive it to a high or low output within prudence. The high or low output should be allowed to remain in effect until corrected by limiters or trips.
- The pickup levels, time delays, and levels at which the limiters or trips operate should be recorded.
- Limiter and/or trip settings may need to be temporarily changed during testing in order to avoid excessive currents and or voltages.
- Alternatively, limiter or trips can be calibrated while the unit is shut down using conventional relay test techniques. This method is likely to be the preferred method for steam units, since any testing of this sort carries with it the possibility of an unexpected unit trip. However, where practical, limits and trip settings should be determined by challenging the limits in loaded operation. Where appropriate, the limiter and trip elements can be described by graphs and/or tables.

Appendix – H

Example Test Guidelines for Overexcitation Limiters (OEL) and Overexcitation Protection Devices (OEP)

Introduction

The purpose of the Overexcitation Limiter (OEL) is to insure that the thermal capability of the field circuit is not exceeded while the automatic voltage regulator is in control. The ANSI C 50.13 field winding short time thermal capability curve should be used as the guideline for protecting the machine field winding. Although it is noted that this standard addresses only round rotor machines, it is to be assumed that it applies also to salient pole machines, since currently there is no standard that specifically addresses them. Other portions of the field circuit, such as thyristor bridges, also have a thermal capability limit (current rating) and need to be considered when applying overexcitation limiters and protection.

It is important to distinguish between an Overexcitation Limiter and an Overexcitation Protection Device (OEP). While an OEL acts through the voltage regulator to reduce and maintain field current within the capability of the field winding, an OEP serves to remove the voltage regulator from service or trip the generator off line. When employed with an OEL, the OEP serves as a backup to the OEL, and should be set to coordinate with the OEL and the ANSI capability curve. For the purpose of computer modeling, it is necessary to model the first line of defense only. In the case where both an OEL and an OEP are present, this means that only the OEL is modeled. However, to insure that the OEL and OEP characteristics coordinate properly (i.e., do not cross each other), it is desirable that each device be tested. This will guarantee that there are no operating points that would result in the unit tripping rather than limiting field current.

Older systems may not have an OEL or OEP, while most modern systems offer both at least as an option. There are numerous variations on the design of OEL and OEP devices, but they all operate upon the same principles: Monitor the machine excitation level (field current or perhaps field voltage), allow the excitation to be raised above a determined level (the continuous field current rating) for a short period of time, and reduce or remove excitation after the time period is exceeded. This allows a machine to support a stressed power system as much as possible without incurring thermal damage to its field winding.

Since the capability of the field winding and other elements of the field circuit are of a thermal nature, as illustrated by the referenced ANSI curve, most modern OEL and OEP devices have an inverse time functionality, along with an instantaneous unit which sets the maximum allowable field current. However, there are also simpler devices, which operate after a fixed time delay when the minimum pickup value is exceeded.

There is also some variation among limiters with respect to how the output signal is used. The limiter output signal may be used to lower the reference of the voltage regulator, or it may be a take-over limiter, which bypasses the voltage regulator and directly controls the level of excitation. In order to determine the structure of the OEL and identify any filtering and gain stages and variable parameters, it is advantageous to have access to the circuit diagrams in the manufacturer's operation manual.

The input signal used for the OEL and OEP circuits is usually the output of an isolated field current transducer, which provides a small dc signal representing field current. In some cases, field voltage is the quantity represented by the input signal. If the input signal is derived from field voltage, the results of the test will be dependent upon the temperature of

the field winding, since the field resistance, and therefore the field voltage vary with temperature. It is therefore important in this case to maintain a constant field temperature while conducting the tests. The characteristics of the OEL and OEP will become slightly more conservative as the field temperature increases.

Since there are so many different variations of overexcitation devices, it is not possible to develop a detailed test procedure that will be appropriate for all systems. Therefore, the simplest and most reliable approach to testing these devices is by challenging the devices while in service with their normal settings. This method is preferred since it not only ensures that the devices function properly, but that the machine responds as desired and there are no coordination conflicts with other devices, such as a field overvoltage or overcurrent relay.

In some cases, performing an on-line, functional test of the OEL will not be practical, and testing will have to be performed by temporarily lowering the settings, or while the unit is shut down. The preferred test method will be described first, followed by alternate methods. It is recognized that the first method will generally only be appropriate for hydro units, while steam units will probably require an alternate method with the unit shut down.

A. Testing under loaded, overexcited conditions (Typically Hydro Units Only)

It is first necessary to establish the value for rated field current. This is the field current required to obtain the full load, rated megawatts at the rated power factor. Alternately, this may be the maximum continuous field current allowed due to an operating restriction.

Testing of the devices will require the unit to be forced into an overexcited condition. The quicker the field current is raised to the test value, the more accurate the timing data. Therefore, it is preferable to make a step change in the voltage regulator reference. This can be accomplished by connecting a power supply through a switch into the summing junction of the voltage regulator. Some systems include a spare input for this purpose. It will be necessary to examine the voltage regulator circuit schematic to determine the location to insert the signal, and the magnitude of the input required. Alternately, a step input may be achieved by making an unbalanced transfer from manual field control to voltage regulator control, with the voltage regulator reference adjusted to produce the desired test excitation level. A third, less exact, alternative is to raise excitation through normal means using the voltage adjust control. This method should only be used if both of the first two methods are impractical.

To perform a test of an OEL

1. Load the machine to at least 80 percent rated load. At all times during the testing, monitor the stator current and terminal voltage. If it is apparent that the test cannot be conducted without exceeding prudent levels of terminal voltage or stator current, another method of testing should be substituted.
2. Increase excitation until rated field current is reached. Make sure that the OEL has not picked up. Measure the input signal into the limiter circuit. This will be a signal representing field current or field voltage. Record this value.
3. Slowly increase excitation to determine the minimum level of field current at which the limiter picks up and begins timing. A typical level of pickup is around 105 percent of rated field current. Some systems have some sort of indication when the limiter has picked up or an output signal that can be monitored. Often there is an extra output signal, which can be used to alarm when the pickup value is exceeded. It may be required to monitor the output of the pickup circuit with a voltmeter. Record the value of field current at which the limiter picks up as the MINIMUM PICKUP VALUE. Also record the value of the input signal at this point. Reduce the field current to a point below the pickup value.
4. Prepare to insert a step input into the voltage regulator by determining the magnitude of change in reference signal necessary to increase the field current to a value about 5 percent above the pickup value. It is prudent to test the step input at very small signal levels and slowly increase the step size until the desired field current level is obtained.
5. Before inserting the step, ensure that the field current is below the pickup point and the timing circuit of the limiter is completely reset. Insert the step and record the level of actual field current, the input signal into the limiter, the time it takes until the limiter reduces the excitation (record as TIME DELAY), and the final value of field current when the limiter is in control. A chart recorder will facilitate the measurement of this data. Once a steady state value of field current has been reached with the OEL in control, remove the step signal. The final steady state field current is the TIMED FIELD CURRENT LIMIT. NOTE: The final value of field current when the limiter is in control should be

slightly higher than the pickup value. If not, limit cycling will occur, and the limiter will repeatedly drop out and then pick up, unless an alternate method of hysteresis is employed within the limiter.

6. If the OEL has a fixed time delay, the testing of the timing portion of the limiter is complete. If the OEL is an inverse-time type of device, at least two more data points should be taken by inserting successively larger step signals. The number and location of data points will determine how accurate the characteristic curve can be drawn. Data should be taken to the highest field current level as practicable, keeping within other machine ratings and operating restrictions. For each step input, record the maximum value of field current reached and the time until the limiter acts to reduce excitation.

7. If the limiter has an instantaneous, maximum field current function, it will probably not be practical to challenge the limit, since it is usually set between 150 and 200 percent of rated current. Therefore, it will be necessary to measure the value of the set point in the circuit. Then using the measured values of the OEL input signal and the field current from steps 2, 3, and 5 above, calculate the approximate field current corresponding to the measured set point value. This value of current is the MAXIMUM FIELD CURRENT LIMIT. The measurement of the set point for the maximum field current limit can usually be made with the unit shut down, provided that the regulator circuits remain powered up.

To test an OEP

If an overexcitation protection device is to be tested, the above guidelines for the testing of the OEL should be followed with the following exceptions and notes:

1. If the excitation system incorporates both an OEL and an OEP, it will be necessary to temporarily disable the OEL or adjust the pickup setting to a value above the OEP. If this is done, it is important to record all set point data so the settings can be accurately restored.
2. It is the function of the OEP to either trip the unit after a sustained level of overexcitation, or to transfer control of the exciter to manual after the manual field current set point has been automatically readjusted to a safe level. If the OEP initiates a transfer to manual control, it is necessary to measure the value of field current after this transfer has occurred. Record this value of current as the OEP CURRENT LIMIT. If a trip of the unit is initiated, there will be no value for OEP CURRENT LIMIT. The time to transfer or trip should be recorded as in the OEL test guidelines. **NOTE:** If it is undesirable to trip the unit during the test, it will be necessary to defeat the trip signal before performing this test.
3. The OEP may not have an instantaneous maximum current limit setting. If it does, it can be tested as in the OEL guidelines. If not, this function may be provided by an external relay, which can be tested with standard relay test methods with the unit shut down.
4. If testing both an OEL and an OEP, it is important to note that the input signals to these devices are often supplied from separate sources. If this is so, it is important to measure input signals for both devices, as the signal calibration for each device is likely to be different.

Testing under load at reduced excitation levels (Typically Hydro Units Only)

It is also possible to perform functional tests of the OEL or OEP at reduced excitation levels by reducing the pickup set points of the OEL or OEP and performing the tests in the same fashion as under full excitation levels. This method reduces the stress to the machine and the system, but requires a more detailed knowledge of the OEL circuit. This method will test whether the devices will operate as desired, but will not guarantee against miscoordination with other devices.

If this method is chosen, it is necessary to record the calibration of the input signals to actual generator excitation levels, so that the actual limiter characteristics can be calculated, and so that the original settings can be restored after testing. In most cases there is a linear relationship between the input signal and the excitation level, but this is not always true.

A possible alternative, in this method, to placing a step input into the voltage regulator, is to place a step input signal into the OEL/OEP input circuit. Different size steps may be used to simulate various levels of overexcitation, without actually increasing the level of excitation of the machine. The calibration between input signal and excitation level must be calculated in advance from actual measurements. If this method is chosen, it is particularly important to know how the

excitation system responds to the overexcitation condition. A strong negative forcing signal to a nonexistent, simulated overexcitation condition can result in very low excitation levels, which may incur a loss-of-field relay trip.

To perform the test of the OEL

1. Load the machine to about 50 percent of rated load. This loading will provide some margin for overshoot when the limiter reduces excitation, thereby avoiding interaction with underexcitation limiters or protective devices. This is particularly a concern for limiters that take over control of the voltage regulator, as the corrective signal is designed to overcome a large voltage reference, i.e., a reference causing sustained overexcitation. When the limiter takes control, it may result in a large negative forcing signal, which will momentarily cause a large dip in terminal voltage. At all times during the testing, monitor the stator current and terminal voltage. If it is apparent that the test cannot be conducted without exceeding prudent levels of terminal voltage or stator current, another method of testing should be substituted.
2. Measure the input signal into the OEL and the corresponding field quantity (current or voltage), at least two different levels of excitation and calibrate the relationship between the two. If possible, a measurement of the input signal should be taken with the machine at rated field current. If not possible, the input signal corresponding to rated field current will have to be calculated using the relationship calculated in this step.
3. Measure and record the set point for the minimum pickup of the OEL. Using the relationship calculated in step 2, calculate the field current corresponding to this set point value and record it as the MINIMUM PICKUP VALUE.
4. Adjust the field current to obtain zero MVARs. Measure the input signal to the OEL at this level of field current.
5. Lower the set point for the minimum pickup for the OEL to a level 5 percent above the input signal level.
6. Prepare to insert a step input into the voltage regulator by determining the magnitude of the change in reference signal necessary to increase the field current to a value about 5 percent above the pickup value. It is prudent to test the step input at very small signal levels and slowly increase the step size until the desired field current level is obtained.
7. Before inserting the step, ensure that the field current is below the pickup point and the timing circuit of the limiter is completely reset. Insert the step and record the level of field current, the input signal into the limiter, the time it takes until the limiter reduces the excitation (record as TIME DELAY), and the final value of the input signal to the OEL when the limiter is in control. A chart recorder will facilitate the measurement of this data. Once a steady state value of field current has been reached with the OEL in control, remove the step signal. Using the final steady state value of the input signal into the OEL and the relationship between the original pickup setting and the adjusted pickup setting, calculate the actual final steady state value of field current and record it as the TIMED FIELD CURRENT LIMIT. **NOTE:** The final value of field current when the limiter is in control should be higher than the pickup value. If not, limit cycling may occur, where the limiter will repeatedly drop out and then pick up.
8. It is possible that the circuit that resets the excitation level is independent of the pickup setting of the OEL. Therefore, in this case, it will be necessary to monitor the output of the circuit that initiates the control action. Since there is no actual overexcitation condition to overcome, the limiting signal may not be high enough to override the regulator signal.
9. If the OEL has a fixed time delay, the testing of the timing portion of the limiter is complete. If the OEL is an inverse-time type of device, at least two more data points should be taken by inserting successively larger step signals. The number and location of data points will determine how accurate the characteristic curve can be drawn. Data should be taken to the highest field current level as practicable, keeping within other machine ratings and operating restrictions. At each data point, record the value of the input signal and the time it takes for the limiter to reduce excitation.
10. If the limiter has an instantaneous, maximum field current function, it will probably not be practical to challenge the limit, since it is usually set between 150 and 200 percent of rated current. Therefore, it will be necessary to measure the value of the set point in the circuit. Then using the measured values of the OEL input signal and the field current levels from above, calculate the approximate field current corresponding to the measured set point value. This value of current is the MAXIMUM FIELD CURRENT LIMIT. The measurement of the set point for the maximum field current limit can usually be made with the unit shut down.

To test an OEP

If an overexcitation protection device is to be tested, the above guidelines for the testing of the OEL should be followed with the following exceptions and notes:

1. If the excitation system incorporates both an OEL and an OEP, it may be necessary to temporarily disable the OEL or adjust the pickup setting to a value above the OEP. If this is done, it is important to record all set point data so the settings can be accurately restored.
2. It is the function of the OEP to either trip the unit after a sustained level of overexcitation, or to transfer control of the exciter to manual after the manual field current set point has been automatically readjusted to a safe level. With the machine at reduced excitation, if the OEP initiates a transfer to manual control, it is probable that the set point of the manual reference adjuster will be high enough to result in the field current being much higher than the test level. In this case, it is not a good idea to allow this transfer to occur. Therefore, the value for the OEP CURRENT LIMIT will have to be obtained using the above guidelines for overexcited test conditions, or by examining the manual reference adjuster to determine what the set point will be for a runback after the OEP picks up. If a trip of the unit is initiated, there will be no value for OEP CURRENT LIMIT. The time to transfer or trip should be recorded as in the OEL test guidelines. **NOTE:** If it is undesirable to trip the unit or transfer to manual during the test, it will be necessary to defeat the trip signal before performing this test.
3. It is possible that the OEP will not have an instantaneous maximum current limit setting. If it does, it can be tested as in the OEL guidelines. If not, this function may be provided by an external relay, which can be tested with standard relay test methods with the unit shut down.
4. If testing both an OEL and an OEP, it is important to note that the input signals to these devices are often supplied from separate sources. If this is so, it is important to measure input signals for both devices, as the signal calibration for each device is likely to be different.

Testing while the unit is shut down (Steam Units)

If the OEL and/or OEP can be powered up while the machine is shut down, tests similar to those above can be performed by monitoring appropriate pickup points and feeding input signals as appropriate. Alternatively, if the circuits can be removed from the excitation system, similar tests can be performed on a bench with the circuits suitably energized by bench top power supplies. It is essential that complete calibration data be taken with the machine running under load, so that a relationship between OEL/OEP input and output signals and actual machine quantities can be calculated. Very detailed knowledge of the voltage regulator system will also be necessary in order to calculate the effects of the OEL on the excitation level.

This test method poses the least amount of risk to the machine and the power system. However, it is the most complicated, and requires the most detailed knowledge of the circuits to be tested. It will result in characteristic data of the tested devices being obtained, but will not guarantee their actual functionality. Therefore, if the devices are tested in this manner, in-service functionality should be verified by testing at one operating point using one of the in-service methods described above.

OEL Model in GE's PSLF Program

Model Name: oel1

Descriptions: Over excitation limiter for synchronous machine excitation systems

Prerequisites: Generator model ahead of this model in dynamic models table

Inputs: Generator field current

Output Channels:

Record Level	Name	Description
1		Limiter output value signal, elimv
1		Limiter output type signal, elimt

Invocation: oel1 [<n>] {<name> <kv>} <id> :

Parameters:

<i>EPCL Name</i>	<i>Variable</i>	<i>Description</i>
Ifdset	ifdset	Pickup level of time dependent field current limit, per unit
Ifdmax	ifdmaxt	Level of hard field current limit, per unit
Tpickup	tpickup	Timer setting for time dependent limit
Runback	runback	Parameter of voltage regulator reference adjustment
Tmax	tmax	Definate time delay for generator trip if
field		current exceeds Ifdmax
Tset	tset	Definate time delay for generator trip if
field		current exceeds Ifdset

Notes:

- a) This limiter is intended to represent the generic behavior of a wide range of excitation limiters. It is not an exact representation of any one specific type or model of excitation limiter, but is capable of representing the effect of many such units.

This model may be used with the following excitation system models:

exac1 exac1a exac2 exbas exbbb exbbc exdc1 exdc2 exdc2a
exst1 rexs

- b) The per unit base for the field current levels *Ifdset* and *Ifdmax* is the field current required to give one per unit stator voltage on open circuit in the absence of saturation.

The parameter *Ifdset* should normally be the maximum continuous value of field current. The typical full load excitation current of a generator is from about 1.8 per unit to 2.8 per unit. The value of *Ifdset* is normally equal to or slightly greater than this value of full load excitation.

The parameter *Ifdmax* should normally be set to the maximum permissible field current.

Ifdmax should be greater than *Ifdset*. *oel1* normally lets field current exceed *Ifdset* for a period determined by *Tpickup* but acts immediately to limit field current if it reaches *Ifdmax*.

- c) *oel1* includes three separate elements:

1. A time dependent element whose timer starts when the main generator field current exceeds *Ifdset* and which may have either an inverse time or a definite time characteristic. When this element times out the limiter sends a signal to the voltage reference summing junction of the voltage regulator.
2. An instantaneous acting hard limiter that operates when main generator field current reaches *Ifdmax*. When this element operates the limiter sends a signal to the excitation system to be used as an overriding upper limit on field voltage.
3. Trip devices that will trip the generator if its field current exceeds *Ifdmax* for a definite time of *Tmax* seconds or exceeds *Ifdset* for a definite time of *Tset* seconds.

- d) If (*Tpickup* > 0) - the field current limit timer has an inverse characteristic
- *Tpickup* is the delay in operation of the limiter for a constant input of 1 per unit (i.e. field current exceeds *Ifdset* by 1 per unit).

If (*Tpickup* < 0) - the field current limit timer has a definite time characteristic

- *Tpickup* is the time for which the field current must remain above *Ifdset* for the limiter to operate.

Both types of timer reset instantaneously if field current falls below *Ifdset* before the timer has timed out.

- e) The parameter *Runback* specifies the action of the limiter when the time dependent element operates.

If (*Runback* > 0) - The voltage regulator reference is biased by the output, *elimv*, of *oel1*. This output is ramped in the negative direction at the rate of $1/Runback$ per unit per second as long as field current exceeds *Ifdset*. When field current falls below *Ifdset* the ramping of *elimv* is stopped and the value of the voltage regulator reference remains frozen at its biased value. *oel1* does not remove the bias from the voltage regulator reference. The original value of the voltage regulator reference is lost. Signals are set to

```

genbc[].elimt = 1
genbc[].elimv = <bias>

```

If (*Runback* < 0) - The voltage regulator reference is biased by the output, *elimv*, of *oel1*. This output is set immediately to *Runback* per unit. The value of the voltage regulator reference is frozen at its biased value. The value of the voltage regulator reference is lost. Signals are set to

```

genbc[].elimt = 1
genbc[].elimv = Runback

```

If (*Runback* = 0) - The excitation system is instructed to apply an immediate mandatory limit of *Ifdset* to the excitation system output voltage. This limit is permanent. Signals are set to

```

genbc[].elimt = 2
genbc[].elimv = Ifdset

```

f) The hard limiter acts instantaneously to instruct the excitation system to apply an immediate mandatory limit to the excitation system output voltage. This limit is permanent.

```

If (Ifdmax > 0) - Field voltage is limited to Ifdmax
If (Ifdmax < 0) - Field voltage is reduced to and limited to Ifdset

```

Signals are set to

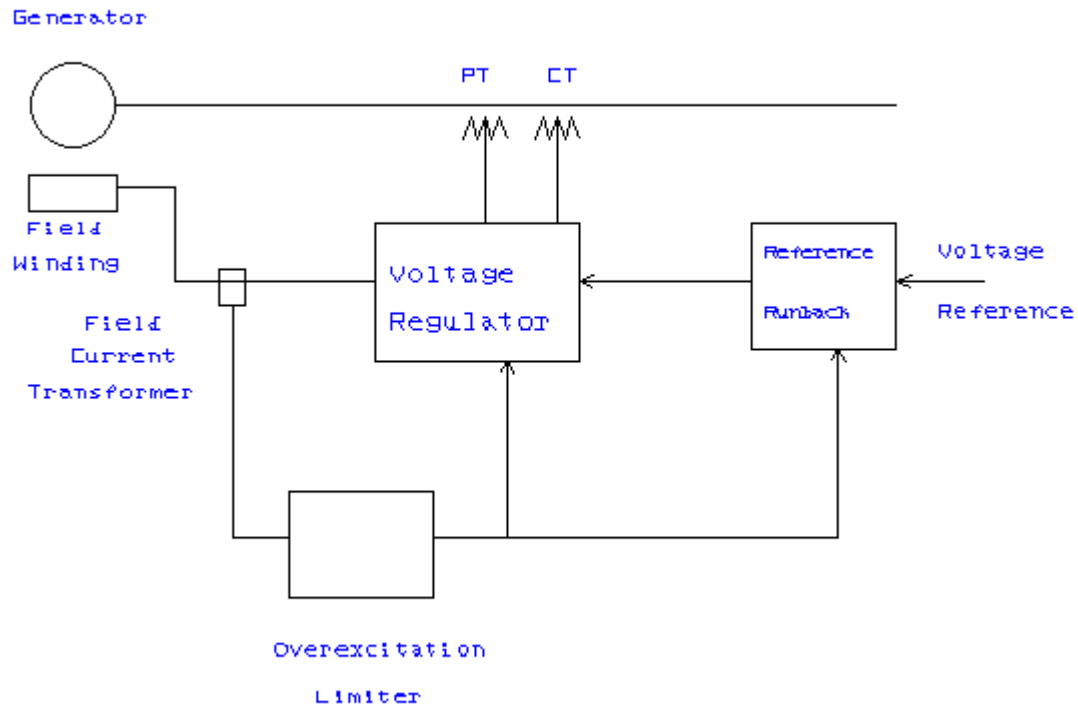
```

genbc[].elimt = 2
genbc[].elimv = <limit value>

```

g) The biasing of the voltage regulator reference when the signal *genbc[].elimt* = 1 is independent of the type of the excitation system and is implemented in the same way for all excitation system models. All excitation system models respond to this action of *oel1*.

- h) The implementation of the mandatory limit on excitation voltage when the signal `genbc[].elimt = 2` is dependent on the type of the excitation system. Not all excitation system models respond to the action of `oel1` when `genbc[].elimv = 2`. Only those excitation systems listed under note a respond to this action of `oel1`.



BASE VALUES FOR PER UNIT PARAMETERS

The GE dynamic simulation program, whose data sheets and parameter lists are shown in Appendix A, requires that all per unit parameters and per unit variables are specified with respect to base values equal to *generator nameplate rated values*.

The bases to be used in converting measured electrical values and mechanical power of electrical machine rotors (volts, amps, ohms, and other physical-unit measures) to per unit values are as follows:

	Parameter or Variable	Base Value	Name of Base Value
	Electrical MVA	Generator rated MVA	Sbase
B.	Electrical MW	Generator rated MVA	Sbase
C.	Electrical MVAR	Generator rated WA	Sbase
D.	Shaft Speed	Generator rated speed	Wbase
E.	Electrical Torque	Generator rated torque	Tbase/Sbase/Wbase
F.	Mechanical Power	Generator rated MVA	Sbase
G.	Mechanical Torque	Generator rated torque	Tbase
H.	Stator AC Voltage	Generator rated voltage	Vsbase
I.	Stator AC Current	Isbase=Sbase/(1.732*Vsbase)	Isbase
J.	Field DC Current	DC current in field Ifbase – winding for AC voltage equal to Vsbase on air gap line when on open circuit at rated speed	
K.	Field DC Voltage	Ifbase * (DC resistance of field winding when hot)	Vfbase

The bases to be used for variables and parameters in excitation systems and associated subsystems such as power system stabilizers must be those given above.

The bases to be used for mechanical positions (such as valve openings) and other signals in governors and turbine controls should be the full-range values of these quantities.

These base values are frequently related to the generator NWA base by gains other than unity.

Example:

The following example illustrates the per unit conventions:

A hydro generator is observed to require a turbine gate opening of 3 inches at speed-no-load and a gate opening of 21 inches at rated generator output. The open circuit magnetization curve shows the air gap line field current at speed-no-load and 14.4Kv to be 420 Amps, and the actual field current in this condition to be 441 Amps. The field voltage in this speed-no-load condition is 145 volts

The full stroke of the servomotor is 25 inches.

The generator nameplate ratings are:

125 MVA
0.8 power factor
14.4 Kv
1050 Amps DC
350 Volts DC

The turbine nameplate ratings are:

120 Ft head
1750000 Hp

The excitation transformer and rectifier can provide a maximum DC field voltage of 600V

The base values are as follows:

$S_{base} = 125 \text{ MVA}$
 $V_{base} = 14.4 \text{ Kv}$
 $I_{base} = 125 \text{ e}6 / (1.732 * 14.4\text{e}3) = 5012 \text{ Amps}$
 $I_{fbase} = 420 \text{ Amps}$
B. $V_{fbase} = 350 * 420 / 1050 = 140 \text{ Volts}$
Stroke = 25 inches

Running at speed no load the per unit variables are

$MVA = MW = MVAR = 0.0$
Stator voltage = 1.0
Stator current = 0.0
Field current = $441 / 420 = 1.05$
Field voltage = $145 / 140 = 1.036$

Gate opening = $3 / 25 = 0.12$

Running at rated conditions the per unit variables are:

- C. MVA (= 125) = 1.0
D. MW (= 100) = 0.8
MVAR(= 60) = 0.6
Stator voltage = 1.0
Stator current = 1.0
Field current = $1050 / 420 = 2.5$
Field voltage = $350 / 140 = 2.5$
Gateopening = $21 / 25 = 0.84$

The maximum per unit excitation voltage is:

$$\text{Max Excitation Voltage} = 600 / 140 = 4.3$$

Note that:

The per unit field voltage at speed-no-load is less than the per unit field current, but the per unit values of the field variables are equal at rated conditions. This is because the base value of field voltage is stated for rated conditions with the field winding hot while the field winding was cool when the speed-no-load measurements were taken.

Rated generator power output is *not* one per unit because the rated power factor is not unity.

The turbine ratings are information items *only*; they are not used in establishing per unit bases or values. The power rating of the turbine ($175000 \times 0.746 = 130.6\text{MW}$) is substantially greater than the 100 MW rated output of the generator and sufficient to run it at rated MVA and unity power factor at a head slightly below rated. (Such turbine sizing is quite common in hydro plants whose head variations can be large, but would be unusual in a thermal plant).

The gain relating gate position to turbine power must be

$$A_t = \frac{\text{Change in per unit power}}{\text{Change in per unit gate}}$$

$$1/(0.84 - 0.12) = 1.39$$