Designing a Voltage Regulation System

Introduction

This presentation will address many of the issues that need to be considered when designing an excitation system. The discussion is aimed at the prime power application, such as a stationary power plant. However, many of the principles can be applied to other applications, such as distributed generation, co-generation, islanded systems, and stand-alone machines. Some of the common characteristics for most power plant applications include the need to operate generators in parallel with other generators, operation in parallel with a utility grid, remote control of the excitation system from a control room, manual and automatic control of the excitation, and many other factors. These issues add to the complexity of the excitation system and help to distinguish the power plant application from the portable or emergency standby power system that is normally equipped with a simple voltage regulator for its excitation control. This talk will discuss several of the functions commonly used in power plant excitation systems.

Legacy Excitation Control Systems

The oldest systems still in service are generators with rotating brush-type exciters. See Figures 1, 2 and 3. These units are commonly equipped with a manual control rheostat and provisions for an automatic voltage regulator. Older voltage regulators were of electromechanical design. Because they used moving parts and contacts for their operation, the AVR often was taken out of service while the generator remained on line, providing power under manual excitation control. With large machines operating in parallel on a grid or network, it is possible to allow one machine to run in manual and allow the other generators to maintain the grid voltage. At least that was the case years ago, but today, with the increasing loads on the grid, operation in manual control is allowed on a limited basis and pressure to get AVR control back in service can be intense.

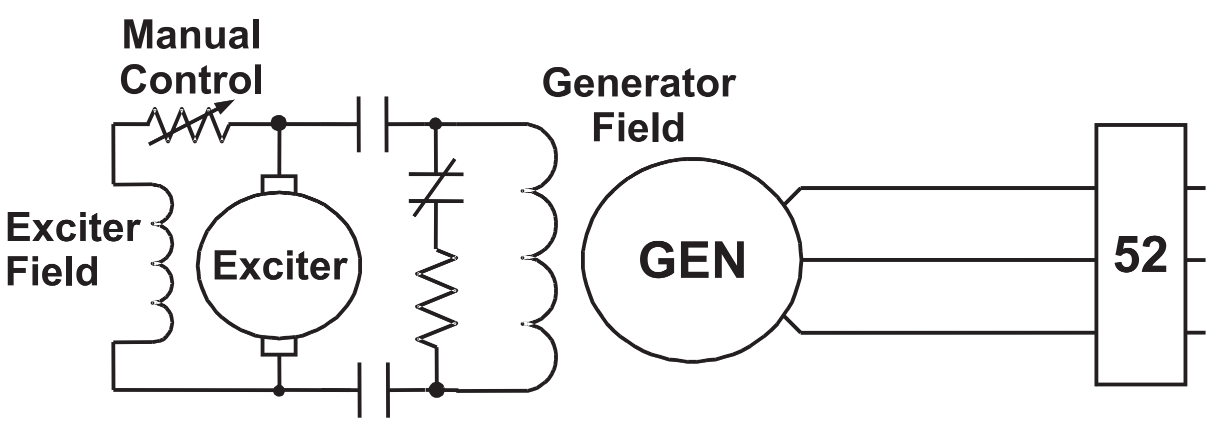


Figure 1: Legacy Excitation System

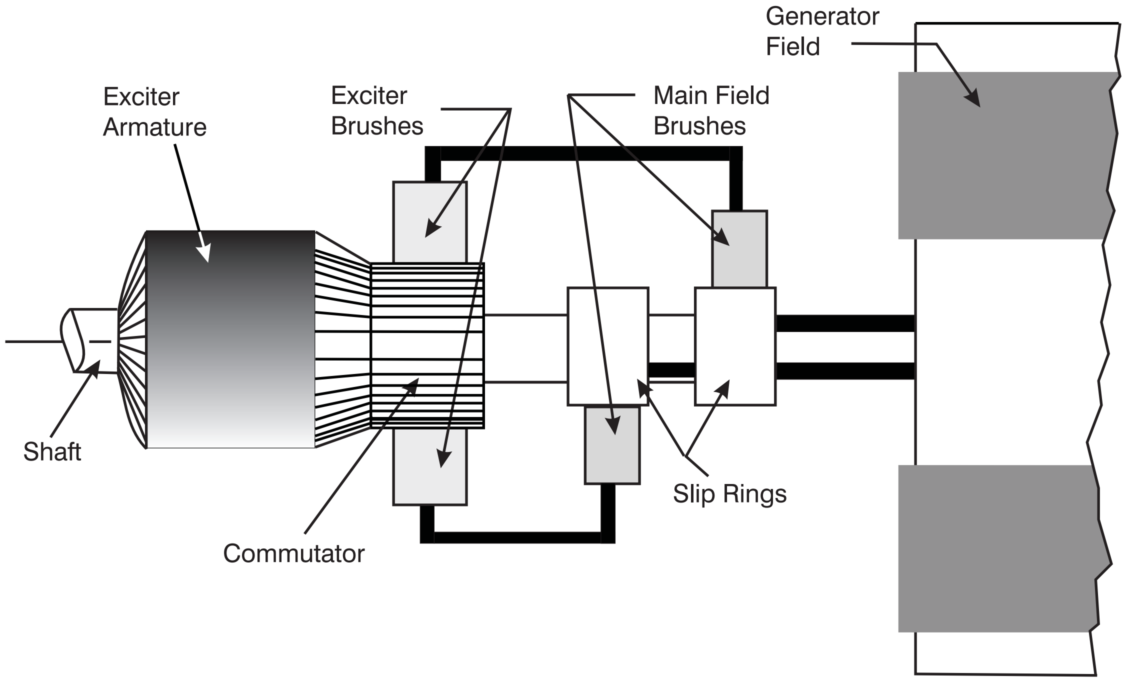


Figure 2: DC exciter commutator and brushes, rotor slip rings and brushes

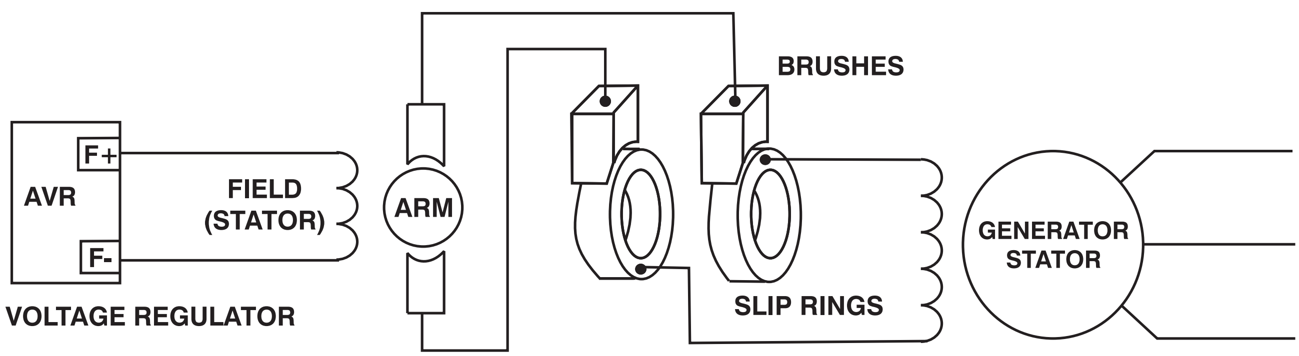


Figure 3: Rotary Excited, Brush-Type Generator

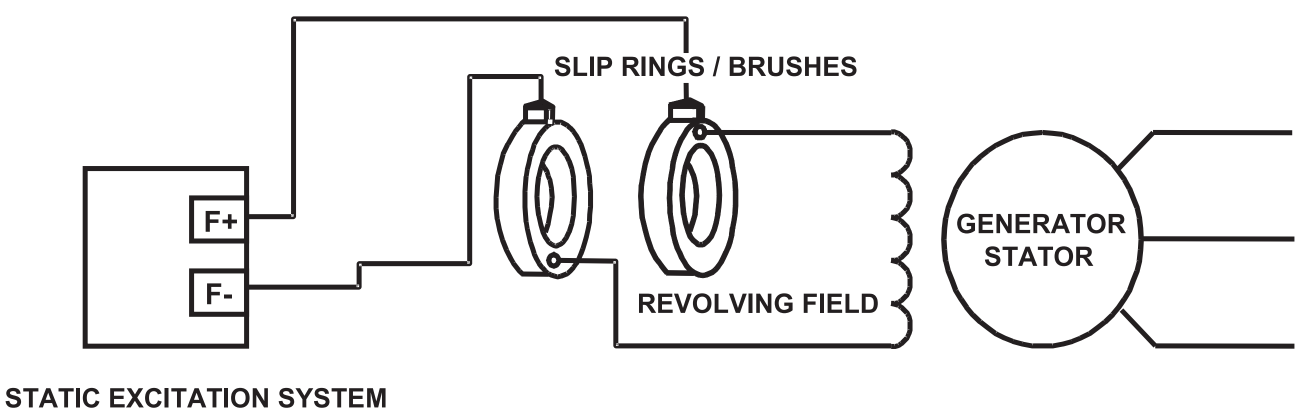


Figure 4: Static/Slip Ring Generator

To understand the demand for AVR control, one must understand the need to substantially increase the reliability of the grid. To improve the grid reliability, a very high speed fault detection scheme with high speed interrupting of fault current, (see Figure 6) and high speed (officially, high initial response, per IEEE) excitation systems on all grid connected generating units with high field forcing capability should be implemented. By these two means, the existing grid limitations for transferring power may be extended, allowing existing grids to be optimized to carry the load until additional grid lines may be designed and built. This need creates pressure to replace electromechanical AVRs with high forcing, high speed excitation systems to improve the performance of generating units, thus improving the reliability of the grid.

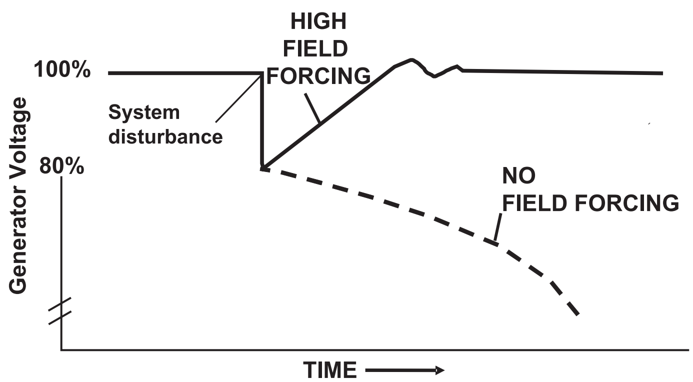


Figure 5: High Initial Response

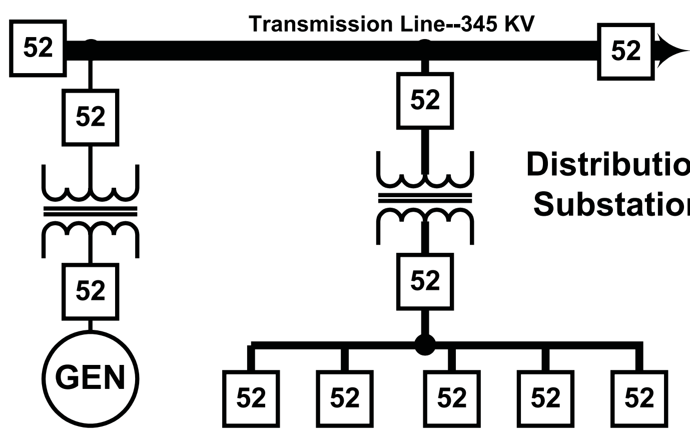


Figure 6: Utility Electrical System

To perform such a replacement, the new equipment will be expected to have several standard capabilities. Remote control of the generator is normal with metering, control switches and set point adjustments accessible from the control room. The reason a control room is normally provided is to exclude noise, dust, dirt and moisture from the control environment. It also allows the temperature to be controlled independently from the rest of the plant, a benefit to the equipment inside and to the operators. Annunciation of system status and alarms is installed in the control room to keep the operator informed about the condition and status of generator unit. We will look at excitation controls, but keep in mind there are many other aspects relating to power plant control than those discussed in this paper.

MECHANICAL REQUIREMENTS

What will be done with the old equipment? Where will new equipment be located? How big will new equipment be compared to the old? These questions are the starting point for decision making about a replacement voltage regulation system. Mechanical requirements are not always the first questions to be asked, but they are certainly very important. Most of the answer will depend on the plant, but some of the answer will also be decided by the needs of the new equipment. Since most voltage regulation system replacements are purchased to specification, almost any requirements may be incorporated in the specification document, but some information is generally available to keep the voltage regulation system within conventional limits.

It is important to evaluate the location and mounting of the voltage regulation system. Consideration should be given to temperature, moisture, shock, vibration, EMI, and other conditions that may be present when designing the voltage regulation system.

Temperature limits for most electronic equipment will allow for its use in the same ambient temperature range as the generator. Most equipment will function well up to 60 degrees Celsius and down to -40 degrees C. If ambient conditions exceed these limits, it may be necessary to control the environment where the voltage regulation equipment will be installed, or it may be necessary to heat or cool the interior of an excitation cubicle. Of course, a benefit from such temperature control is a likely improvement in reliability over the same equipment installed in an uncontrolled environment.

Moisture and high humidity can affect the operation of voltage regulation equipment. Normally, humidity is a problem if it reaches the stage of condensation. Moisture can be a big problem for reliable operation of regulation equipment. A common practice is to include space heaters and thermostats, set to keep the temperature inside a cubicle slightly higher than the exterior ambient temperature, thus keeping humidity from condensing inside the voltage regulation equipment.

Dust and dirt may be present in the power plant where the voltage regulation equipment is installed. If forced air cooling is used to keep the equipment cool, filtering of the air intake may be beneficial to keep dust from being drawn into the control equipment. This filter will require some maintenance to keep dirt build-up down and air flow rates up.

If the old equipment is removed totally, the new equipment may be supplied in a steel enclosure (cubicle). If it is simpler to keep old excitation cubicles and simply remove the old voltage regulation control components, a new system may be supplied as a collection of new parts ready for mounting and wiring, or the voltage regulation system components may be mounted and wired to a steel chassis able to be bolted in place inside existing excitation cubicles.

ELECTRICAL REQUIREMENTS

Sensing Requirements

The voltage regulation system must have a means of measuring generator stator voltage and current. In some cases, these quantities cannot be measured directly, so it may be necessary for transformers to step down the voltage and current to useful levels for connection to the voltage regulation system. These transformers are not normally a part of the regulation equipment.

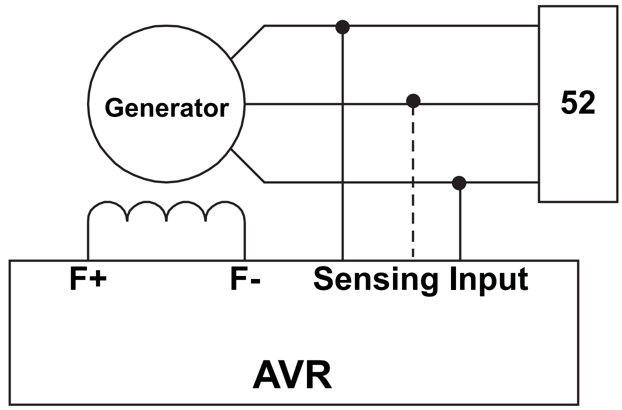


Figure 7: Sensing 1 or 3 phase

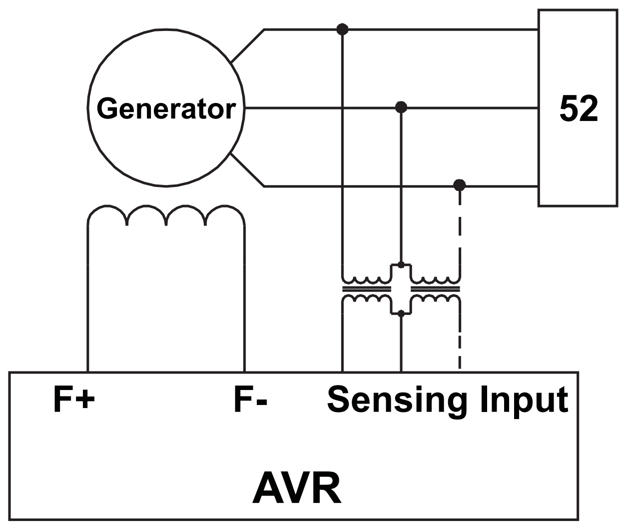


Figure 8: Sensing 2 or 3 phase, open delta

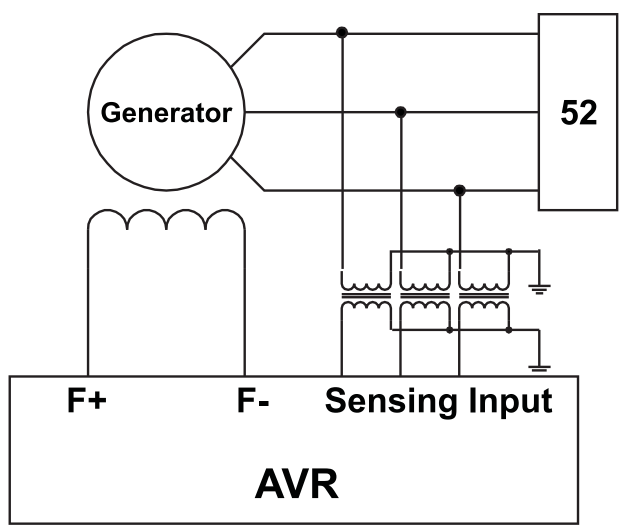


Figure 9: Sensing, 3 phase, wye-wye

Usually, they will be housed in switchgear or the generator connection boxes. Also, their secondary quantities may be used by other equipment in addition to the voltage regulation equipment. If the voltage regulation system is to have good performance, the quality of the measurement of voltage and current must be accurate. How accurate should the information be? IEEE/ANSI C57.13 is the U.S. standard for rating Potential Transformer (PT) and Current Transformer (CT) accuracy into various loads, called burdens. Using metering accuracy ratings, a rating of 1.2 for a PT or CT means that at some stated burden (load) on the transformer, the secondary ratio correction factor must not exceed 1.2 percent. PT burdens are given letters of the alphabet, such as Y, indicating a burden of 75 volt-amperes at 0.85 power factor. At burdens less than rated, the transformer is assumed to be more accurate. Thus, one can evaluate the ability of a PT or CT to perform within its necessary specifications by knowing the burden to be connected to it and the minimum acceptable accuracy for the application.

The maximum allowable error of a transformer for voltage or current sensing in an excitation system must be less than 1% of rated voltage and current.

Ordinarily, the replacement of legacy voltage control with modern voltage regulation equipment may make use of existing PTs and CTs without much concern for accuracy, because burden demands in modern solid state and digital excitation controls are generally less than the legacy equipment. Accuracy of measurement should be improved by the reduction of burden.

Field Power Requirements

A good starting point for the design of an excitation system is the decision to excite the generator's revolving field (static exciter) or to use the existing rotary exciter and provide excitation to the exciter field, Figure 11. This decision will impact the size and cost of the excitation system, because exciter field power will be much smaller than the requirement of the generator field. Once this decision is made, the required voltage and current to operate the generator at rated load must be determined based on nameplate data or documentation from the generator manufacturer. The resistance of the field may be determined from manufacturer's data or it may be measured.

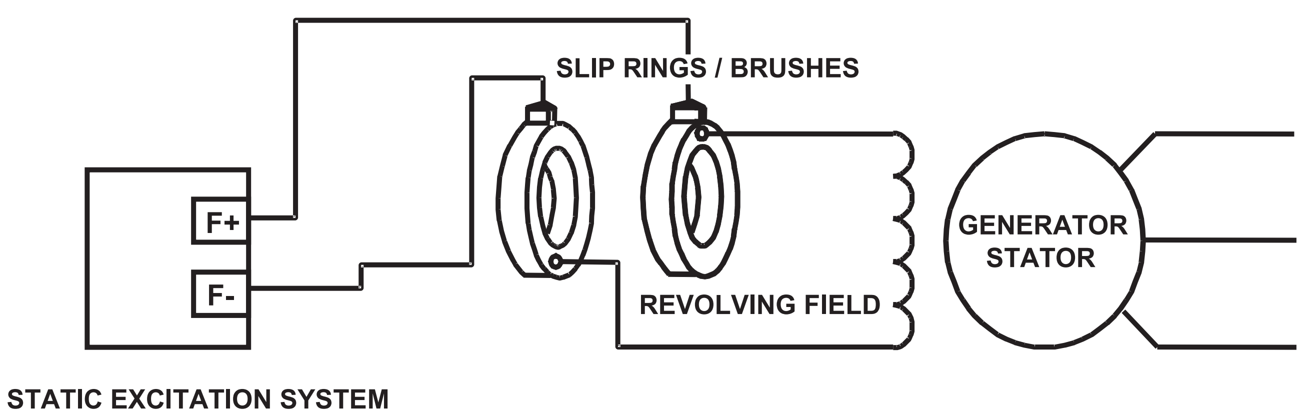


Figure 10: Voltage Regulator Connected to the Generator Field

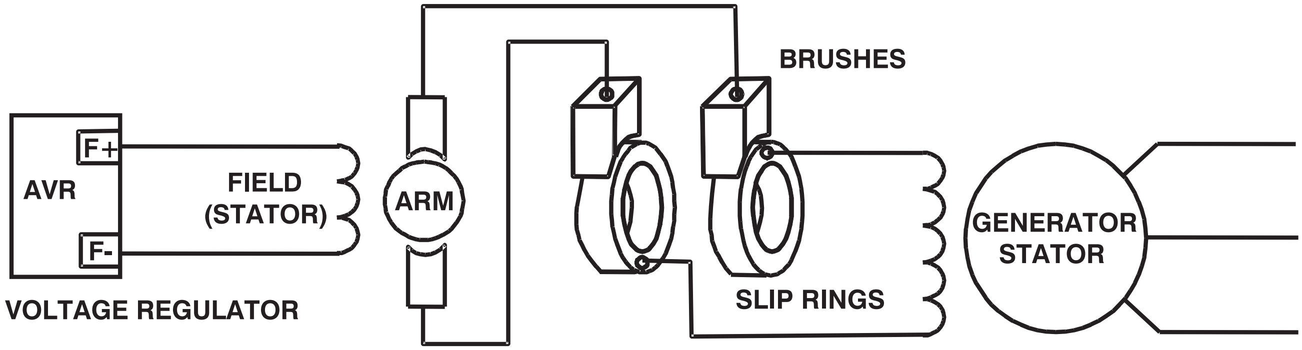


Figure 11: Voltage Regulator Connected to the Exciter Field

One complication may arise if the project to update the generating system includes improvements that increase the power capacity of the unit. In this case, the excitation parameters may be estimated, but until testing of the completed unit is performed to verify the results of the improvements, it is best to make sure the excitation power is sufficient to cover any possible outcome of the test results. This kind of testing normally is performed during the commissioning process after the improvements to the unit are complete.

	Exciter Field	**Generator Field**
Resistance	5.8 Ohms@25°C	0.71 Ohms@25°C
Rated Load Voltage	98 Volts dc	213 Volts dc
Rated Load Amps	15.8 Amps	270 Amps
Calculated Field Hot	6.2 Ohms	0.79 Ohms

Table1: Example of Values for Exciter and Generator Excitation

Because of the resistance of wire connections from the excitation control to the field, it is important to size the conductors to keep wire resistance low compared to the field. In static exciter applications, the field resistance may be on the order of 0.25 to 1.0 Ohms. Wiring from the static exciter to the brushes and slip rings must be very low to prevent the field current from being limited by the resistance of the cables. If power for the excitation system comes from a separate excitation transformer, the ac power leads are also subject to this same need to keep the voltage drop at a minimum.

Power to the excitation equipment

Some choices are available for providing ac power to the voltage regulation system. A common choice is to take power from the generator stator (shunt powered). Since power plant generators are normally medium voltage (5 or 15 kV or higher), a step-down transformer will be used to reduce voltage to the value needed by the voltage regulation system. For rotary exciters, this power may be small enough to be taken single phase, or it may require a 3 phase source, depending on the voltage regulator manufacturer’s recommendation. For static exciters, the power is usually 3 phase.

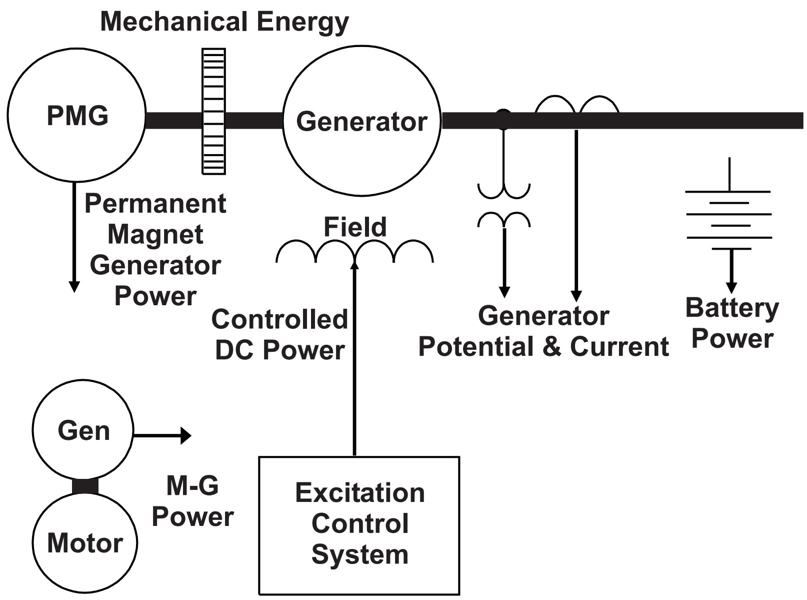


Figure 12: Power Sources for Excitation

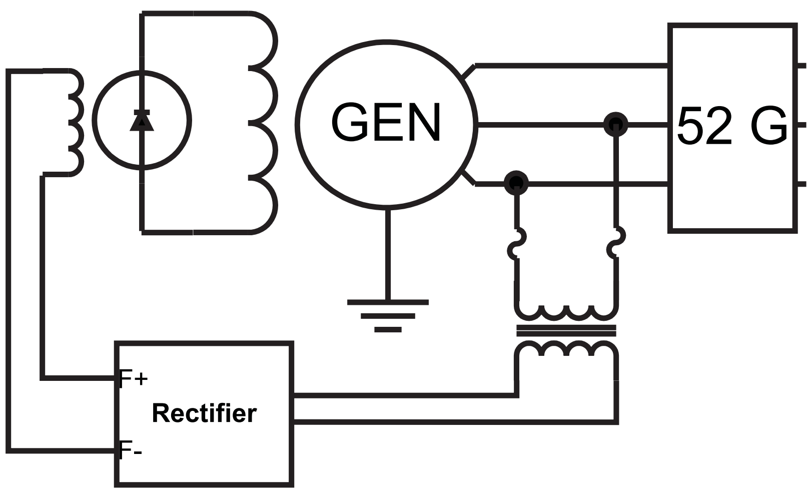


Figure 13: Shunt-Powered Excitation System

Primary Voltage Nominal	BIL Minimum	Winding-Winding Winding-GND High Potential Test
2.4KV	20KV	10KV
4.16KV	30KV	12KV
13.8KV	60KV	31KV
23KV	110KV	37KV

Table 2: Transformer Insulation Ratings

The transformer is normally designed to meet IEEE/ANSI specifications for dry-type transformers, C57.12.01. This spec includes high potential test requirements and Basic Impulse Level (BIL) test requirements for 5 kV and 15 kV class transformers. See Table 2. Often, higher ratings are specified based on the standards for the metal clad switchgear. The transformer may be supplied as an item to be installed in an appropriate location, or it may be installed in an enclosure by the excitation transformer manufacturer.

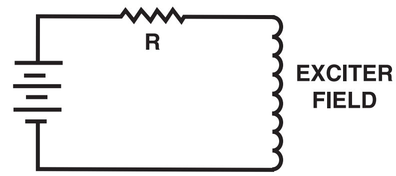


Figure 14: Basic Field Flashing

When the generator stator is used (shunt powered - See Figure 13), especially for a static exciter, low residual voltage may deem it necessary for the unit to receive a source of dc to the field for a short duration. The DC allows the generator terminal voltage to build to a level at which the voltage regulator will have sufficient power to operate. This is called field flashing. This source normally uses the station battery for flashing power, and control of field flashing can be built in to the excitation control as an automatic function. Normally, field flashing is initiated by an excitation start signal from the control room and terminated when the generator voltage builds up to a satisfactory level.

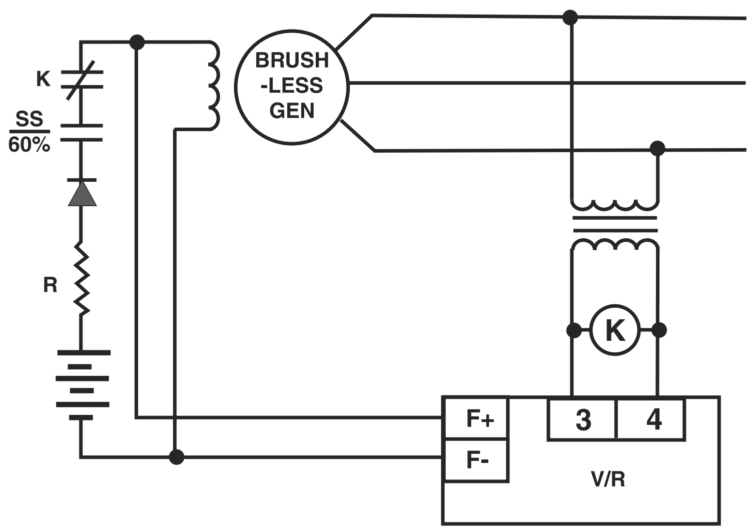


Figure 15: Automatic Field Flashing

A second source of excitation power is the bus or line side of the generator breaker. See Figure 16. Using this source will allow a start of the excitation without any dependence on the flashing of the generator from the station battery. The bus, or line side, source must be hot in order to excite the generator. This method may be used if the plant will only be running when the bus or line side source is available.

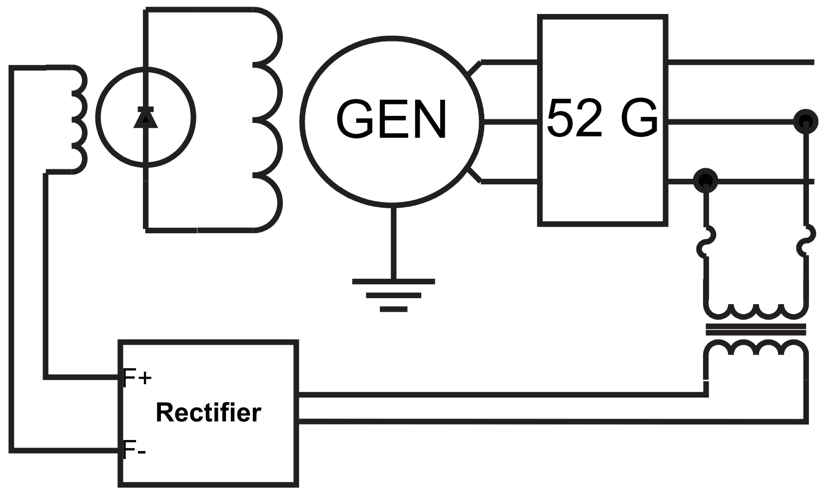


Figure 16: Bus-powered excitation system

A third source of excitation power, used only with rotating exciters, is the Permanent Magnet Generator (PMG). See Figure 17. Although it is possible to install a PMG on an existing generator, usually the PMG already is mounted to the generator shaft and was used for excitation power with the legacy system.

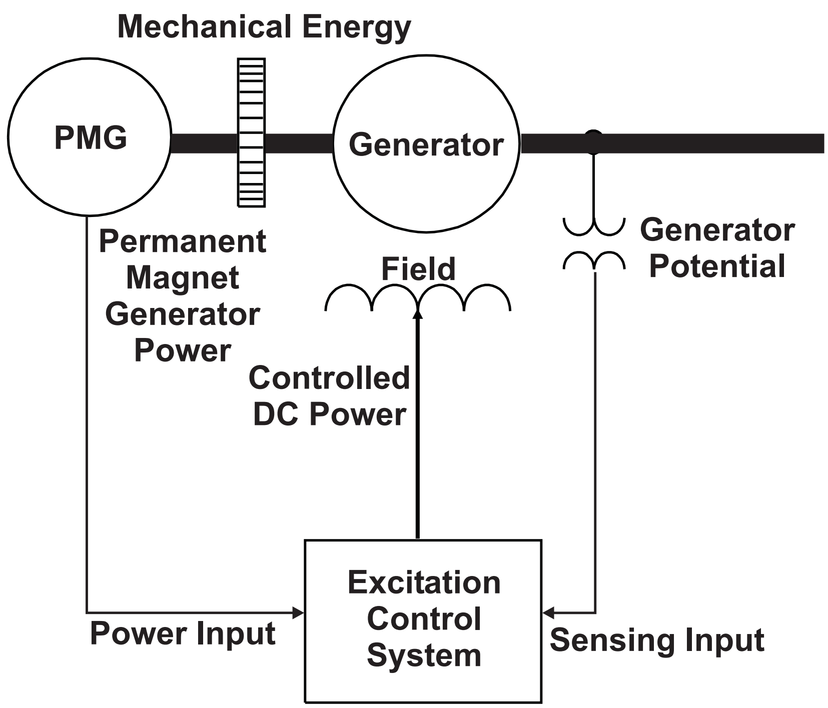


Figure 17: PMG power for excitation

A fourth source of excitation power is a low voltage plant bus (Station Service Bus). See Figure 18. If this source has a greater capacity when compared to the exciter power demand, for example 5 to 10 times more capacity, there is not likely to be any problem using this source. The usual reasons for using station power are to save on the cost of an excitation transformer, eliminate the need for field flashing provisions, and inherently provide excitation support. The reason for being careful of the power capacity of the source is to keep the harmonic content of the plant bus from causing problems with other loads on the plant bus. The voltage regulation system may utilize techniques in switching to control power to the field, like the SCR, which potentially can cause harmonic distortion severe enough to create problems with other equipment powered from the plant bus. Use this source with caution.

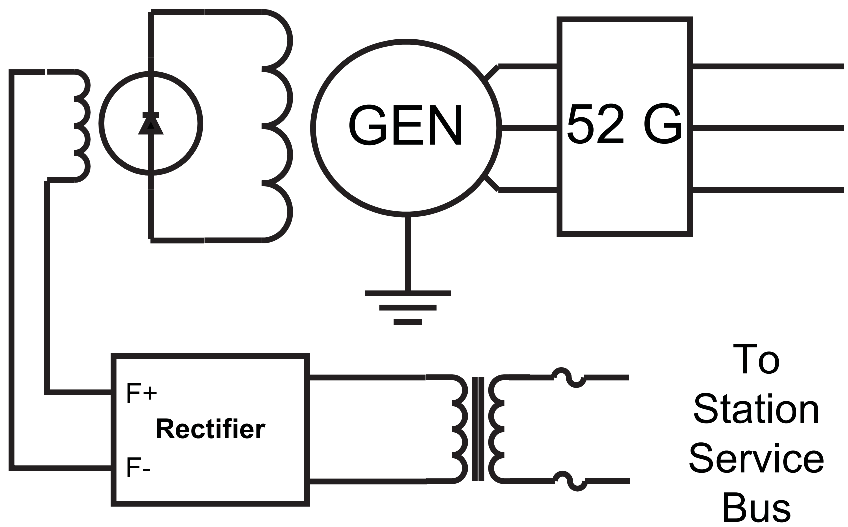


Figure 18: Station service-powered excitation system

The final source of excitation power is a current boost scheme. See Figure 19. This idea has already been discussed in a previous paper, and the ideas behind this kind of excitation control are the same with a prime power application, except the current can be much higher, the operating voltage for the current transformer normally is higher, and the scheme often incorporates current transformers in three phases instead of single phase. The idea behind current boost with prime power normally is focused on fault current support for the operation of protective relays. Protection engineers normally will be involved in the decision to equip a generator with fault current support. Current boost systems have been designed for rotary and for static exciter systems.

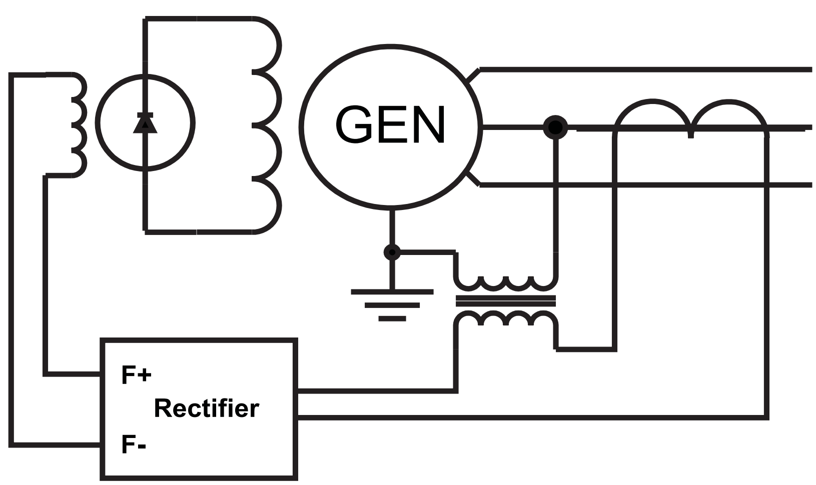


Figure 19: Compound Excitation System

Modes of Operation
In a replacement voltage regulation system, the normal operating modes supplied for controlling generator voltage are automatic voltage regulation (AVR), and field current regulation (FCR) or manual voltage control (MVC). All of these functions will be found in modern voltage regulation control systems for both rotating and static exciter systems. The manual control may be a more sophisticated control than the old rheostat used with many legacy excitation systems. For example, it might be a regulated field current supply (FCR Mode). In any case, a modern manual control must be able to back up the AVR function in case of AVR problems. The AVR normally would be equipped with means of voltage droop compensation to give the operator control of generator reactive load during parallel operation with a grid or with other generators.

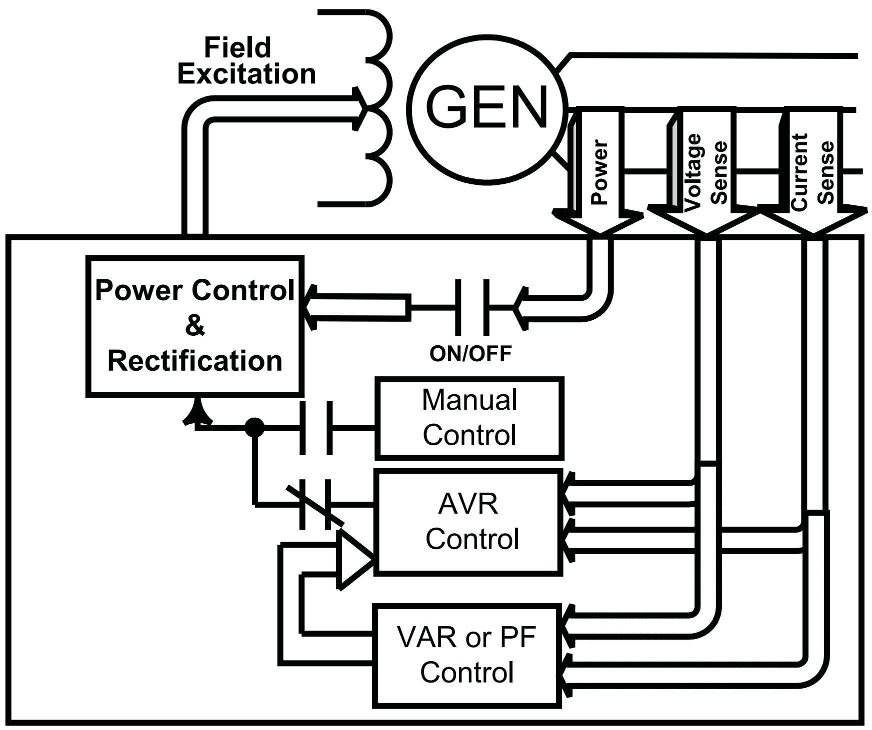


Figure 20: Excitation Modes of Operation

For units operating in parallel with utility grids, reactive power regulation in the form of VAR Control or power factor control may be provided. In this mode of operation, the generator voltage will follow the grid voltage. For small units with too little capacity to have any effect on grid voltage, one of these two modes of operation may be permissible.

With large units, however, such operation is usually discouraged because the unit operating in VAR or PF control will not help support the grid voltage. Under high or low voltage conditions, the need of the grid is for all generating units to be working to assist in restoring voltage to normal value.

Limiters
As a protective means against generator operation outside its limits, a modern voltage regulation system will be equipped with over and under excitation limiters. Such protection

becomes necessary with connection of the generator to a grid, where grid conditions can drive the generator beyond its ratings in its effort to maintain grid voltage.

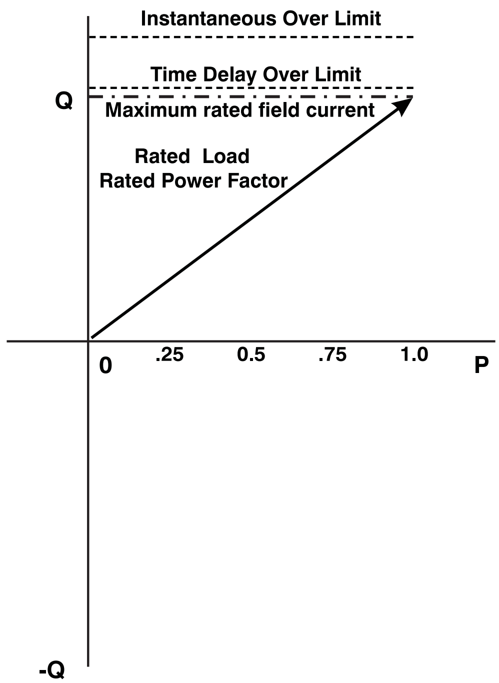


Figure 21: Overexcitation Limits of Safe Generator Operation

Excitation of a generator is limited by the heating effect of rotor field current on the field windings. Therefore, over excitation limiting monitors field excitation current. The heating of the field winding is not instantaneous. The maximum continuous rating of the field is much less than the maximum 1-second or 10-second rating. If the field thermal characteristics are well known, it is possible to maximize use of the machine capacity using a multilevel field current limiter. For example, a limiter may be equipped with two or three different levels of current limiting. The highest level acts without any time delay to set the maximum value of field current under any operating condition. If current reaches the high limit and stays at this limit for some time, the first delayed limit can reduce the field current from the instantaneous level. If field current remains at the first delayed limit for another adjustable time limit, the second delayed limit can reduce the field current to a still lower value, usually a level the field can sustain continuously without damage.

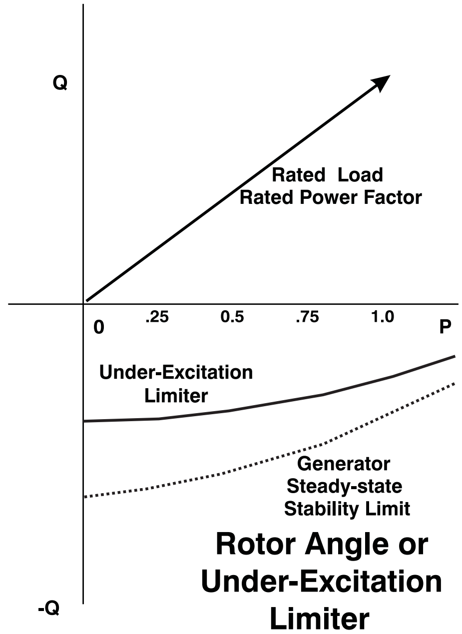


Figure 22: Underexcitation Limits of Generator Operation

The under excitation limit is used to keep a minimum amount of excitation to the generator to prevent loss of synchronism. Synchronism of the rotor to the stator frequency is dependent on the magnetic attraction of the rotor to the stator rotating magnetic field. In operation in parallel with a grid, reducing excitation reduces lagging reactive power. Further reduction of excitation will cause the generator's reactive power to decrease to zero, and the unit will begin to absorb reactive power (leading power factor). This reduction causes weakening of the field magnetic attraction to the stator. A generator has some capacity for absorbing reactive power before the unit is susceptible to slipping poles. But pushed too far, it is possible for the machine to fall out of step and begin to slip poles. Operating the generator out of step will quickly cause damage to the generator and must be avoided, if at all possible. By monitoring the machine real and reactive power load, an under excitation limiter will override the reduction in excitation current and prevent the unit from moving too far into the leading zone of operation.

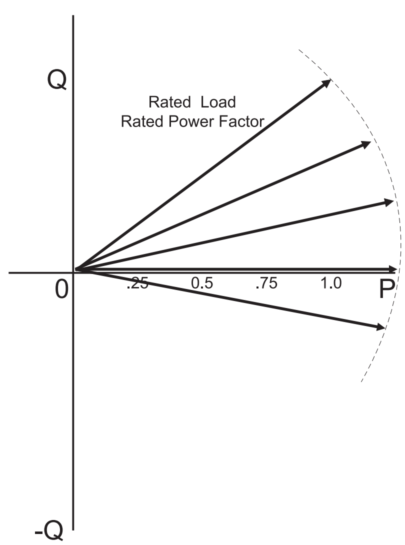


Figure 23: Stator Current Limit

A third type of limiter may be required in some applications. This limiter is the Stator Current Limiter. When the stator limiter sees stator current exceed the set point, excitation is reduced to hold the stator current at the maximum set point. This type of limiter may be used to keep stator current within limits only by reducing lagging reactive current through control of the excitation system.

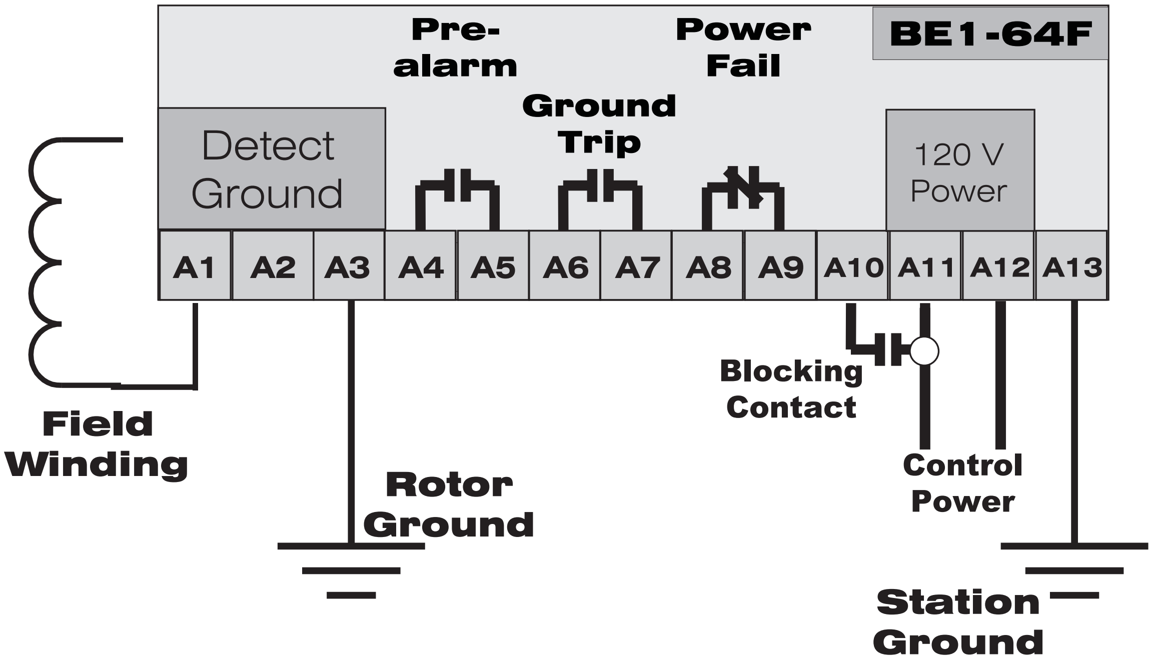


Figure 24: Field Ground Relay

Protection for the excitation system

Certain protection functions have become commonplace as components of the voltage regulation control system instead of being incorporated in the generator switchgear.

The field ground relay is an example of an excitation related relay. See Figure 24. Several operating ideas have been used for this relay, but a simple example is the connection of a low voltage source between one side of the field and ground. The field is supposed to be insulated from ground, so the voltage source should not cause any current to flow. For insulation resistance less than 20 kilohms, a prealarm contact is closed. For insulation resistance less than 5 kilohms, a trip contact is closed and the relay target will be set. The available current from the relay is very low, so there is no damage as a result of the relay's small current flow through the insulation fault. It is imperative to fix the field ground before a second field ground occurs, at which time the damage to the field is likely to be extensive and expensive. But it is common practice to alarm the first field ground and make repairs at the next available shutdown.

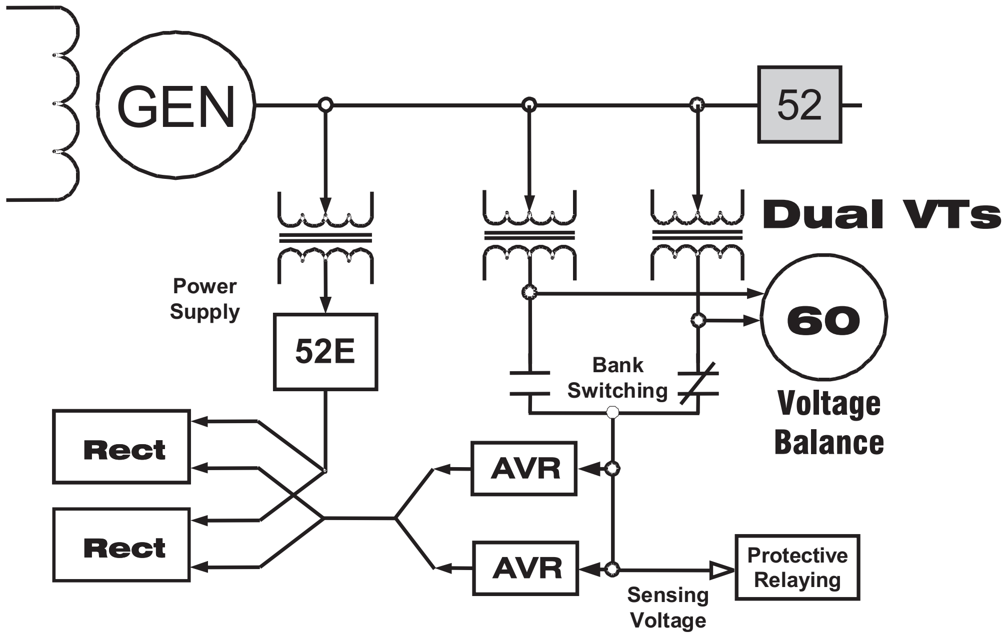


Figure 25: Dual Potential Voltage Transformers and Voltage Balance Relay

The sensing voltage to the AVR is very critical, because the loss of one of the PT fuses will result in a major over excitation event. Some units are equipped with dual PT banks, using a voltage balance relay (Device 60) to detect loss of a fuse. Since relaying and metering also depend on the PT voltage, the balance relay is sometimes used to move loads from the failed PT to the operating PT.

In voltage control, loss of PT signal is often used to automatically transfer mode from AVR to manual control. Since manual control is not dependent on the feedback of generator terminal voltage, it is a safe action to switch to manual control until the problem with the PT signals can be resolved. If the excitation control also incorporates automatic tracking between operating modes, and if some time delay in the tracking prevents the manual from quickly following an incorrect AVR output, the manual control will be able to take over at the same operating point that the AVR was using prior to the loss of the PT signal.

If only one PT bank is available, it is recommended to use a voltage balance and under voltage relay function to initiate a transfer from AVR to manual control in place of the voltage balance relay. Excitation limiters also act to prevent the AVR from driving the excitation too high, but normally the limiter setting is too high to keep generator voltage under control and not used to transfer from AVR mode.

Over excitation relaying in the form of a Volts-per-Hertz (V/Hz) relay (Device 24) is usually provided as part of the switchgear generator protection package, but within the excitation system, a field over current relay and/or a field over voltage relay function may be provided. Field current is usually preferred, because extreme field voltage variations are normal for short periods of time, so the relay needs a time delay to ride through the short term voltage variations. Field current is not quite so volatile because of the action of the field inductance that resists sudden changes in field current. It is still necessary to allow high field current to flow for short times, however, so the field current relay also incorporates some time delay.

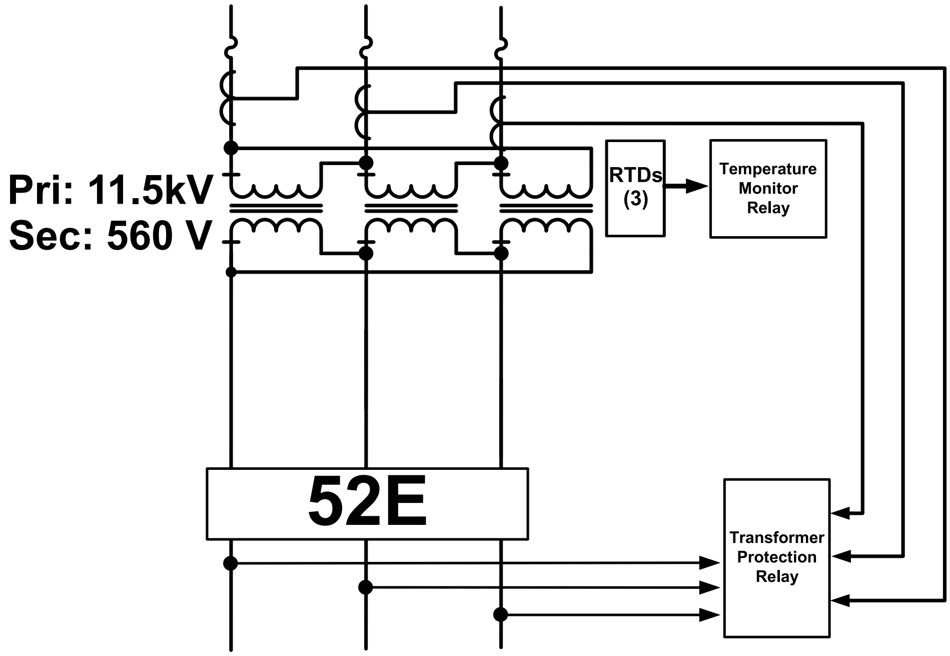


Figure 26: Power Potential Transformer

Protection of the excitation power transformer should also be considered. The transformer protection may include several items, such as thermal switches installed in the windings, resistance temperature detectors (RTDs) in the windings, fused disconnect switch for primary disconnection and fusing, and transformer differential or over current protection. See Figure 26.

At a minimum, the primary of the transformer normally will be fused for safety reasons. This fusing may be included in the exciter equipment or it may be supplied by the power plant. This type of transformer normally is designed with a shield between primary and secondary windings, and the shield must be grounded. By grounding the shield, a failure of the insulation on the medium voltage side of the transformer will result in a fault to ground. This will cause the fuse to blow on the primary and protect the low voltage winding and any personnel who might come near the low voltage wiring.

In modern multifunction voltage regulation systems, several non-traditional protection functions are available to be used, if needed. Generator over and under voltage and field over temperature relays are examples of functions normally supplied as part of the generator protection package, when required. These extra functions are advantages of the multifunction technology in excitation systems.

Engineering Requirements

There are three major design tasks to be considered in the replacement of an existing voltage regulation system. Each of these tasks must be tended to if the installation is to be successful. Part of organizing a replacement program is the task of assigning these three design tasks to the right people to get the project completed smoothly and with desirable results.

The first is the on-site design task. This task can be performed by outside or inside people, and it is essential to convey to the voltage regulation system supplier your needs for control, metering, and alarms in the new equipment. This task must look at the site for locating the new equipment. The site of the new equipment will dictate the environmental requirements to be placed on the new excitation system. Size constraints must be determined. A study of the removal process of old equipment, retention of reusable equipment, and the methods to bring in the new equipment and get it installed, wired and commissioned must be examined. If the equipment change must be accomplished within some time "window", coordination of this change will need a lot of planning. A complete specification is required to give the supplier of the equipment as much guidance as possible.

The second is the voltage regulation system design task. Although it is possible to give enough data to the manufacturer to design, build, and ship equipment from the information in the exciter specification, a more satisfactory result is obtained if one or two intermediate reviews are held. The in-house people are given an opportunity to review the plans for the equipment, ask questions, and verify the equipment will operate as required. By selecting a manufacturer with experience in the field of excitation control, the design will benefit from the experience of the manufacturer in putting together a system that will do the necessary job.

The third task is the commissioning task. Getting the installed equipment up and running, eliminating errors in wiring, and seeing the new equipment operating for the first time should involve more than just the manufacturer's commissioning engineer. First, the job of determining settings for all of the functions of operation and protection will need input from the people who must live with the equipment. Second, the logic used to put together the design may not have been totally detailed in the specs, leaving the exciter designer some decisions to be made. Observation during the commissioning is the first opportunity for the plant people to see how the equipment is working. There will often be some changes needed to get the excitation equipment to operate as expected by the plant personnel. So, involvement from the plant people is necessary to have a successful start-up, proper calibration and settings, and proper choices of operating logic. After everything is running, it is time to consider training of the technicians and operators on the new equipment.

With all three of the design tasks successfully completed, the result will be a plant operating at peak performance.

Metering, Control and Alarms

As part of the design task, specifying the interfaces with plant personnel is of great importance. A starting point for making these decisions is to look at the existing equipment access. If the control room is the only place where metering, controls, and alarms are provided with the legacy equipment, is this adequate, or do technicians who need to work on the voltage regulation system benefit if they have some access to metering or control or annunciation? If local control is provided in addition to remote control, is some kind of switching required to lock out remote control if local control is being used? Is there a need to operate the unit or some of its functions from a central control office using System Control and Data Acquisition (SCADA) equipment? Be sure to include your needs in the specification.

Install metering, control switches, and annunciation to make a unit “friendly” to operate. Ask operators about problems with existing equipment that could be corrected in the new equipment. Detail for them the kind of interface you expect to receive with the new equipment. List all switches (real or computer CRT), meters, new Annunciator labels, so operators can get an idea what to expect. Talk with technicians to determine what they can offer for suggestions to make the equipment easy to work with.

This is an exercise in human engineering to work out the interface requirements. This interface can be 100% operator-oriented or it can become more automated. As an example, if the generator synchronizing has been performed by the operator in the past, is it time to look at automatic synchronizing? There is no cookbook solution for this part of the process.

Control of the Excitation System

Most plants will try to keep the controls of a unit looking very familiar to the operator. There is always a need to balance new technology and old habits to find the best blend. New voltage regulation equipment is being designed using microprocessor-based technology, but attempts are being made to keep controls compatible with operation practices. For example, the traditional operator control for excitation has been a Raise-Off-Lower control switch, spring return to off. To adjust AVR set point, a quick movement of the switch handle to “raise” and back to center is used to nudge the set point higher. For large changes in voltage, the operator may move the switch to the raise position and hold it there while watching the metering until the desired operating point is reached. With today’s technology, the switch may be replaced by a CRT display with a touch-screen or a mouse. Still, the operator wants to be able to nudge or make continuous adjustment depending on his needs. This area of controlling the excitation can be specified to keep a traditional “switches and meters” approach or a totally digital approach may be installed as in a Distributed Control System (DCS). The control of some parameters may be available to a central control operator able to observe the operation of many units and control them from a location miles from the generating station.

Figure 27: Common Remote or Local Controls

Control functions may be connected from the control room to the voltage regulation system using traditional wiring techniques. Wiring also may be reduced by taking advantage of serial digital communications, which reduces the wiring to two wires connecting communicating devices to a computer. Using Graphical Interface software, screens may be created to display a graphic of the power plant with metering and alarms displayed on a CRT screen. Control of the unit can be implemented by screen “pushbuttons” to perform mode changes, reset alarms, raise and lower set point. Almost any arrangement you can imagine can be implemented using this new technology, made possible by microprocessor-based excitation and protection products.

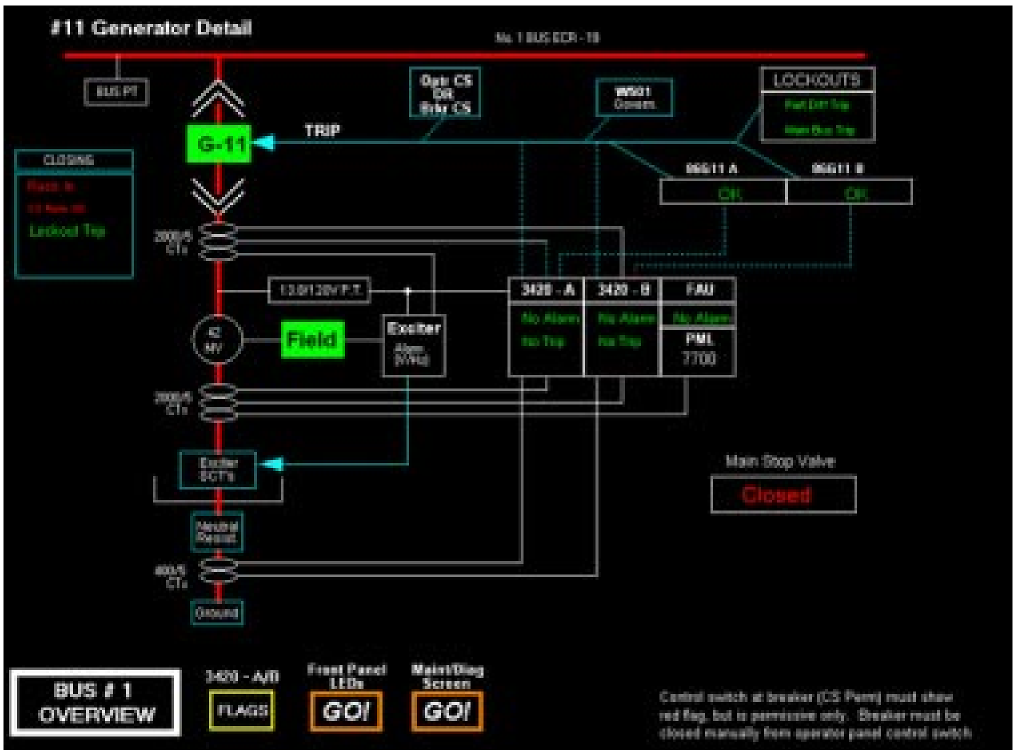


Figure 28: Sample Small Hydro Generator Control System

Several decisions must be made to define the voltage regulation system control methods. A brief list of these decisions should get you thinking.

- Will excitation be controlled locally, remotely, or both?
- Will excitation be controllable from off site?
- Will control be by multi-conductor wiring or by digital communications?
- How much metering locally and remotely?
- How to annunciate status and alarms?

Getting these decisions made will allow the system specification to be prepared and guide the supplier of the excitation control system in the design.

Communications

In your design of a voltage regulation system, don’t overlook the benefits to be gained by using the digital communication capability of today’s voltage control equipment. A computer connected to the RS-485 serial or Ethernet port of a communicating device can query for all operating modes, metering data, alarms, and contact status. The computer may also be used to control the operation of the voltage regulation system. The computer may be in the control room or 1000 miles away, if need be. A voltage regulation system may be connected via the serial link to other communicating devices, and each with its own address may be queried or controlled. This area of expertise may be explored using outside resources if the capability is not available in house. Explore the possibility offered by digital technology. One example is a remote display accessory available for the DECS-400 using just a small cable with conductors to transfer all metering, status and alarm conditions to the control room, replacing many conductors required if older technology were used.

Redundancy and Fault Tolerance

As the generator's rating gets higher, the value of power generated becomes high, and the design of the voltage regulation system leans in the direction of being able to lose a part of the voltage regulation equipment and still maintain the generator on line delivering load. This redundancy has many forms. Some common examples will be given here.

Voltage regulation system electronics and control relays make use of some source of control power. It is imperative that the loss of a control power source does not disable the regulation system. To achieve this goal, use is often made of dual sources of supply with no-break switching from two active supplies to one active supply if a failure of either should occur. The plant battery bus is normally one of the two sources. The second source is often a plant ac power supply from an uninterruptible power supply (UPS) or some other ac source with reliability as high as possible. This feature can be specified, but it has become standard practice in modern equipment.

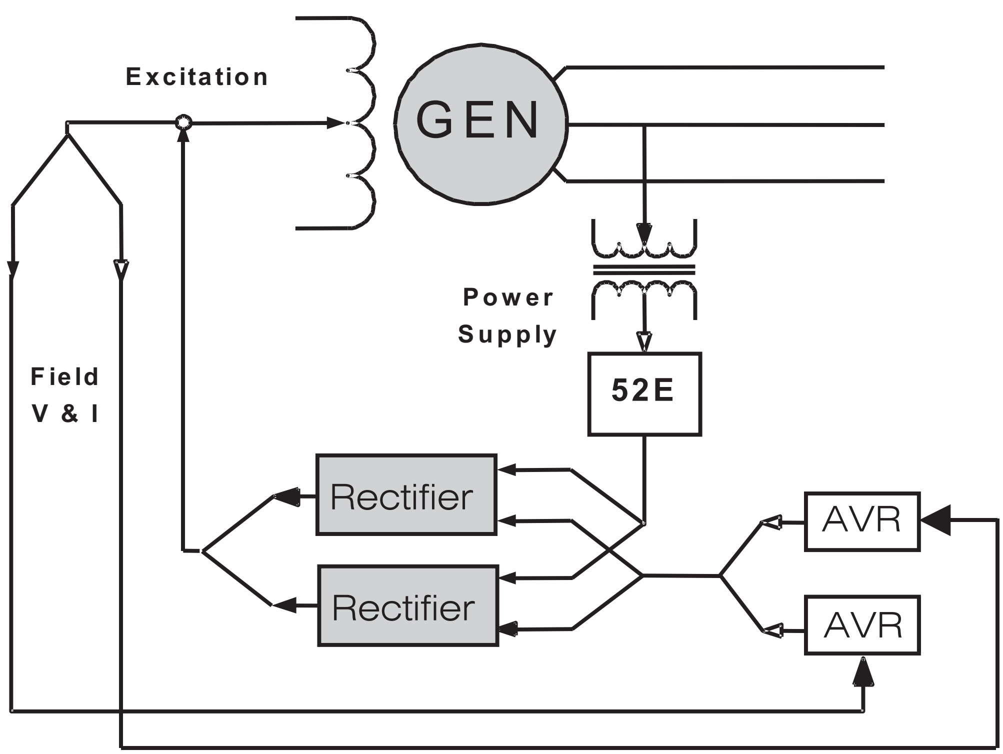


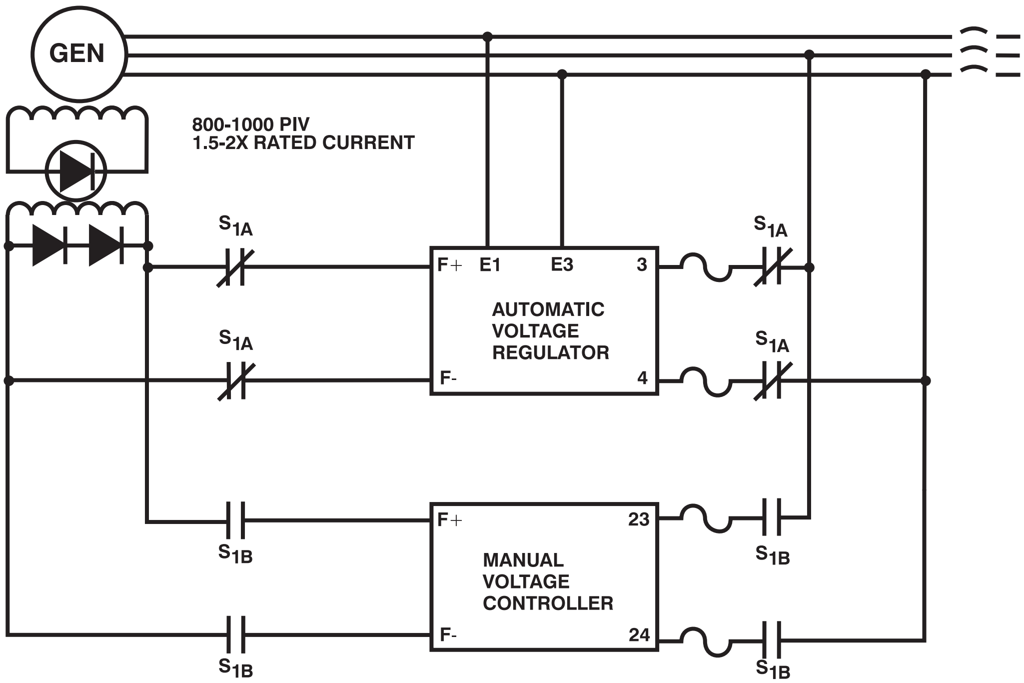
Figure 29: Redundant excitation system

Individual experiences with voltage regulation systems and their failure modes will usually drive the redundancy decision, but most people looking for high availability from the voltage regulator will specify redundancy in the field current control system. Some examples are:

- Over-rating of three phase rectifier bridge current to allow loss of one phase and continue to supply full field current
- Dual fully rated rectifier bridges
  - Both bridges hot, disable defective bridge
  - One bridge not connected, in reserve until failure occurs
  - Transfer switches to allow isolation of a defective bridge on line
- Three or more rectifier bridges, able to supply full field current with one out of service
  - All bridges hot, disable defective bridge
  - One bridge not connected, in reserve until failure occurs
  - Isolation switches to allow bridge service on line
- Redundant firing circuits with redundant bridges
  - Bridge and firing circuit are a pair
  - Either firing circuit may fire either bridge
- Dual Control Channels
  - Automatic Voltage Regulator for normal operation
  - Manual control of excitation for backup to AVR
  - Dual Automatic voltage regulators
  - Dual AVRs with manual backup

There are several methods of redundancy for the AVR as listed above. We have already seen how the manual control adds to the fault tolerance by giving the unit an alternate means of controlling the excitation, but manual control is not a desirable mode of operation, because there is no contribution to the maintenance of grid stability. Consequently, the next area of redundancy is the redundant AVR. Several examples of redundant schemes will be reviewed next, topped off by a redundant scheme implemented with microprocessor-based excitation control design that allows the backup channel to track the operation of the primary channel, ready to take over at a moment's notice.

The first example illustrates the conventional AVR with manual excitation control in Figure 30. The operation of this example switches power from the AVR to manual control and switches field connections at the same time. This kind of operation is easy to implement in rotary exciter systems, because the switching currents are reasonable, and the functions of AVR and manual can be found as separate black boxes. Note the use of the two series connected flyback diodes to allow the switches in the field circuit to safely switch the field current.



S_1	AUTO	OFF	MANUAL
S_{1A}	X		
S_{1B}			X

Figure 30: Typical Backup System Schematic

Figure 31 shows the use of a nullmeter to allow the operator to balance the manual excitation to the AVR excitation. Bumpless transfer from AVR to manual control is possible if the operator adjusts the nullmeter to zero difference between the two channels. This arrangement allows transfer even while operating on line at full load. To implement this scheme requires power to be applied to both manual and AVR channels. In addition, a loading resistor is often required to keep the output of the channel not connected to the field at the correct measured voltage. Next, the negative outputs of the two channels are tied together without any switch contacts, and the nullmeter is connected across the positive outputs of the two channels. The nullmeter indicates the difference in voltage between to the two channels. This arrangement provides manual tracking between channels. Figure 31 shows a typical nullmeter used in switchboards.

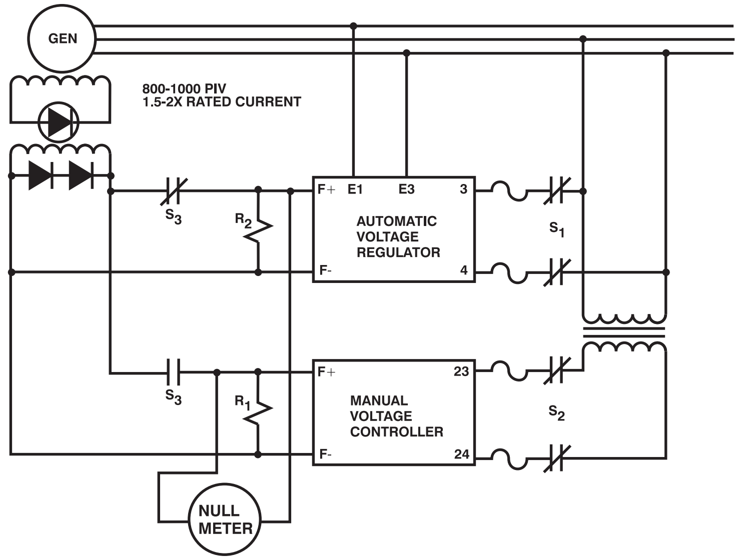


Figure 31: Auto to Manual Bumpless Transfer

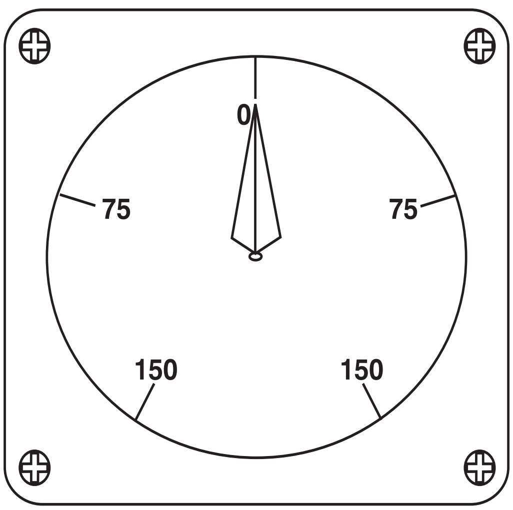


Figure 32: Nullmeter

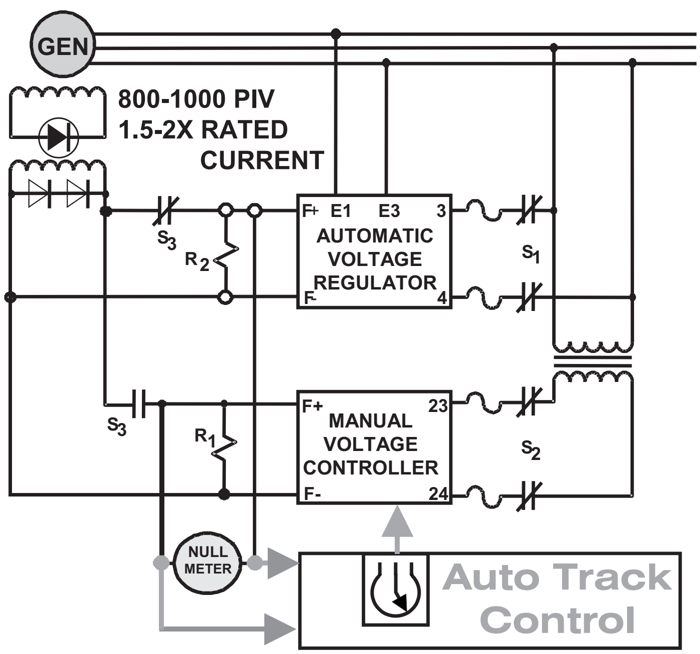


Figure 33: Bumpless Transfer using AutoTracking

If an operator can manually null the channels, can we devise a way to automatically track one channel against another? Figure 33 shows a scheme using a special “black box” designed to monitor the voltages from the two channels and to control the manual channel and balance it against the AVR channel. By looking at the same signal as the nullmeter, the device develops an error signal and controls the setting of a pot. The three wires from the Reference Adjuster to the Manual Voltage Control set the output of the MVC to some output voltage. The Raise and Lower contacts to the right of the Reference Adjuster are used to change the manual control setting when the generator excitation is supplied from the manual control. One very important feature of this kind of Automatic Tracking is the use of a time delay before the manual control follows the AVR. With a short delay, for example 1 second, we could allow a protective relay to trip the AVR and transfer to manual control. The time delay gives the manual control a short waiting time before it follows, to allow protective relays to trigger a transfer before the manual control starts following an erroneous AVR output.

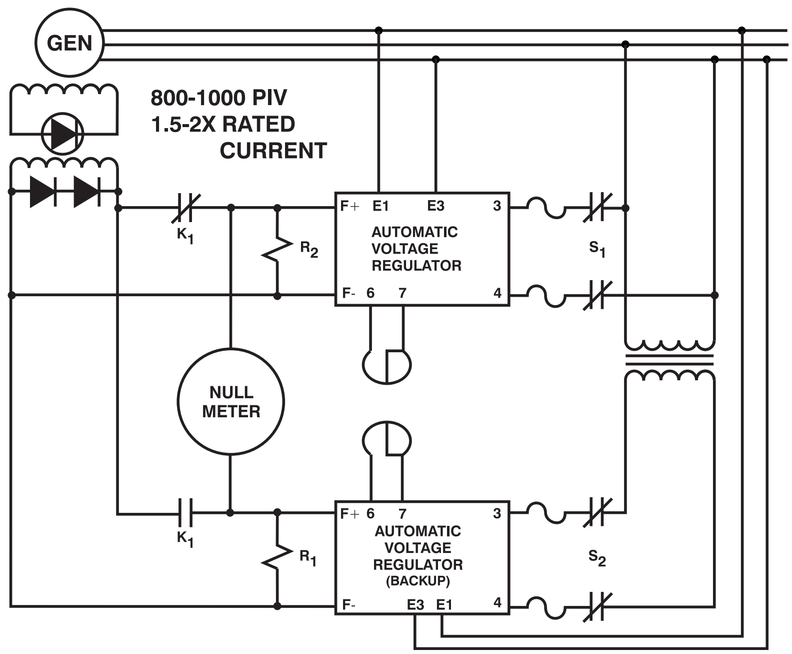


Figure 34: Bumpless Auto-to-Auto Transfer

Although many other schemes have been devised along these lines, let’s jump into using dual AVR channels instead of an AVR with a manual channel. In Figure 34, two independent AVRs are connected in a scheme to allow switching to the backup AVR by operating Relay K1. Each AVR has a loading resistor to give the nullmeter good signals to monitor. An operator could manually balance the nullmeter between the two channels and prepare to transfer to the backup channel with no bump in unit operation. Both S1 and S2 normally would be closed and would only be opened if one channel was suspected to be malfunctioning. This arrangement gives full control capability in the backup mode to support the grid stability, so no performance of the unit is sacrificed if the backup channel is needed.

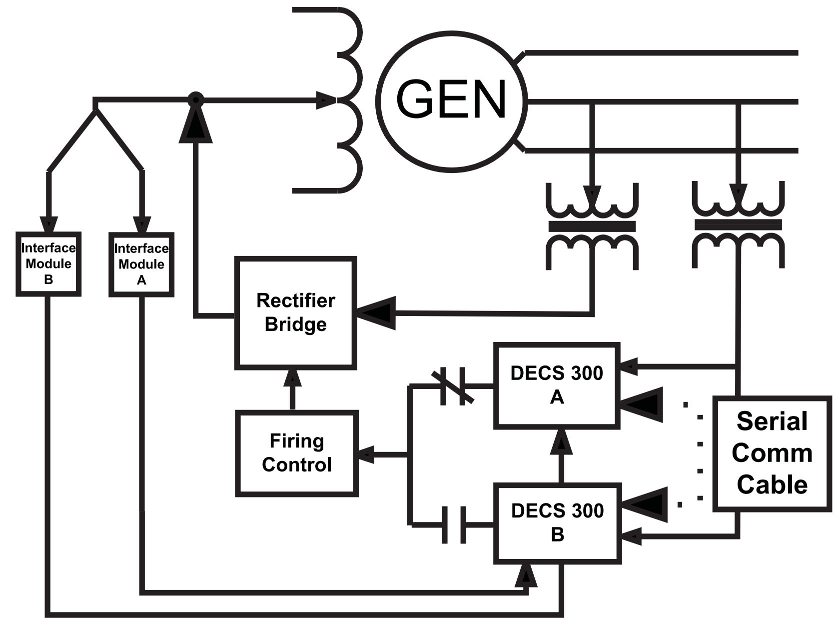


Figure 35: Dual Excitation Tracking Control

To fully automate this scheme, it would be interesting to be able to cause the backup AVR to track the set point of the primary AVR. It would also be interesting to transfer seamlessly from primary channel to backup channel without regard for operating conditions of the generator. And it would be good to have the tracking time delayed to allow external protection to detect possible malfunction of the primary channel and rapidly initiate transfer to the backup channel still set to operate at the excitation current of 1 second ago, before the primary channel was exhibiting a problem.

All of this and more can be provided using microprocessor-based multifunction excitation controls such as the Basler DECS-200, DECS-200N, DECS-300, DECS-400, and ECS2100 (see Fig 35). In addition, each channel has its own manual control, fully implemented limiters and protective functions. With all of these capabilities, a voltage regulation control system can be devised for either rotating or static exciter systems with very high levels of redundancy and unit availability.

Power System Stabilization

Look for a lot more on this subject in a later talk, but just a brief mention is given here to consider the need for adding the power system stabilizer function to the voltage regulation system specification. Power system stability has become an increasingly important subject as demands for reliable power to meet system requirements continue to be of concern. Poor stability can cause a generator to be power-limited or lose synchronism in a system disturbance. Power System Stabilizers may be integrated into the voltage regulation system to dampen the low frequency power system oscillations.

Conclusion

While we cannot hope to cover all possible topics important to this subject, we hope this overview will give you a good start on your next voltage regulation system design project.

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