

Power topic #6008 | Technical information from Cummins Power Generation

A Comparison of Generator Excitation Systems

■ White Paper

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Generator set manufacturers offer different options for providing power to the automatic voltage regulator (AVR), and selection of the proper option is important to ensure correct operation of the generator set. While there are multiple options available for excitation systems, each has its own unique features that provide benefits for different applications. This is generally driven by the electrical characteristics of the loads and the short circuit performance requirements. This paper discusses four methods of excitation, the advantages and disadvantages of each method, and recommendations for selecting the right method, based on the requirements of the application.

Four Generator Excitation Methods

Excitation methods include:

- Self-Excited (Shunt)
- Excitation Boost System (EBS)
- Permanent Magnet Generator (PMG)
- Auxiliary Winding (AUX)

Each method has its advantages. This paper describes each method including the construction, operation and the appropriate types of applications for each.

The process flow for the alternator and AVR goes as follows:

- AVR voltage sense lines are connected to the main stator and are used to control the field strength of the alternator to maintain a constant voltage on the output of the generator set under varying conditions by the AVR
- Input power to the AVR is received through one of the many methods described in the paper
- The input power is used by the AVR to supply a DC output to the exciter stator and the voltage level sensing is used to determine the level at which the AVR induces an AC signal on the exciter rotor

- The exciter rotor AC output is then rectified to a DC output into the main rotor of the alternator and ultimately induced onto the main stator for load output

For this process to work, the AVR must have a strong power source that will allow for the appropriate amount of excitation current when needed, especially in a transient situation. Without a strong source of power the system may not be able to recover voltage during a motor start or fault condition. This could lead to the motor struggling to start causing potential damage or the system to shut down due to loss of field in the alternator.

AVRs can have different construction as well, which will impact their ability to provide appropriate excitation based on the voltage sensing and power input. Two types of construction we will discuss are Silicone-Control-Rectifier (SCR) and Field-Effect Transistor (FET). Each construction type can have an impact on system performance in conjunction with the excitation type.

Shunt

Shunt (self-excited) excitation uses the output of the main stator to derive power for the input to the AVR. This same output is used for sensing the alternator output to continue properly regulating the voltage required for the input of the exciter (see Figure 1). This is a very simple and cost effective approach to providing the necessary input power the AVR requires to properly excite the alternator. It requires no additional parts or wiring and can be easier when troubleshooting.

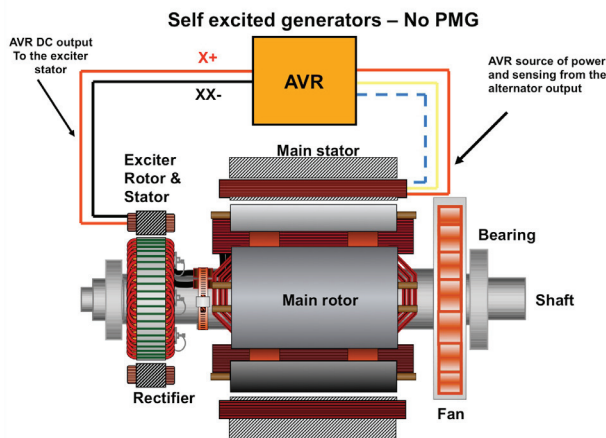
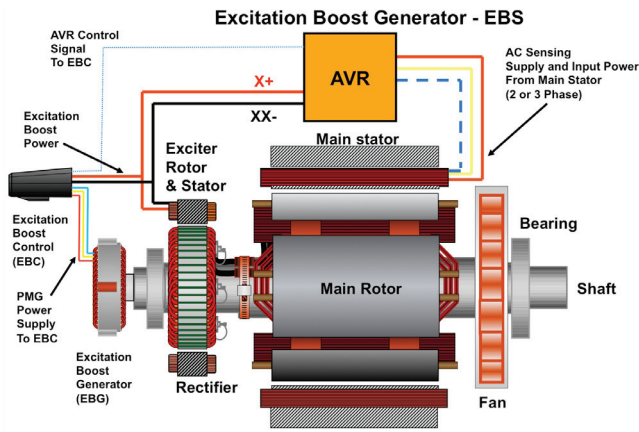


Figure 1: Shunt Excitation.

The simplicity of Shunt excitation also leads to its biggest drawback since the input power quality to the AVR is directly impacted by the loads the alternator is powering downstream. When a transient occurs due to a load connecting/starting or a fault appears downstream, the voltage and frequency will drop and the AVR must drive more excitation current to support the voltage. With reduced input voltage and frequency, powering the AVR can become a challenge especially in the case of a short circuit fault where the voltage collapses. In this case the AVR may not have the capability to support the voltage long enough to clear downstream faults as the main field in the alternator may collapse. Harmonics due to the powering of non-linear load can also be a challenge for a shunt excitation system. This is due to the power input variation which can limit the ability of the AVR to provide appropriate output power.

Excitation Boost System (EBS)

EBS is another form of excitation which provides a “boost” to the typical self-excited system. The construction of this system follows the same setup of the shunt excitation for voltage sensing and power input to the AVR and also includes an excitation boost control (EBC) module and small excitation boost generator (EBG) added to the non-drive end of the alternator shaft. This control module is connected to the AVR and gives the AVR the ability to engage varying levels of increased excitation current depending on the needs of the system. The additional power output from the EBG is in parallel with the typical AVR exciter output lines (see Figure 2) and is engaged by the AVR when needed through a command to the EBC. This power feeds the generator’s excitation system, supporting the load until a downstream breaker can remove a fault or enable the generator to pick up a motor and drive the voltage recovery. The EBG, while similar in appearance to a permanent magnet generator (PMG) excitation system, is not rated for continuous power output to the AVR and is intended for shorter output situations. During generator start-up, the EBS is switched off to prevent excessive voltage run-up. The EBG is producing a voltage potential at this time, but it is not providing excitation.



THE EBG PROVIDES A SEPARATE POWER SUPPLY TO BOOST EXCITATION WHEN NEEDED.

Figure 2: EBS Excitation.

The construction of the EBS system allows for a dynamic response in motor starting and short circuit situations. This is what makes EBS different from PMG. With the EBG being rated for non-continuous usage, it is a less expensive and smaller option that still meets the needs of providing 300% short circuit current and improved motor starting.

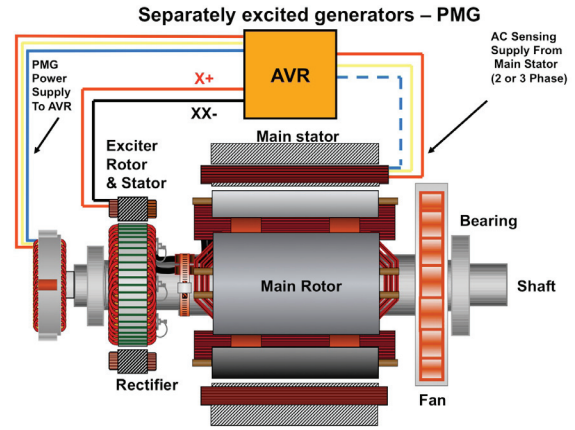
Permanent Magnet Generator (PMG)

One of the most well-known forms of excitation is the separately excited or PMG. This method actually places an additional small permanent magnet generator at the non-drive end of the alternator to produce power for the AVR (see Figure 3). This permanent magnet generator output is isolated from the disturbances on the main output from the alternator and produces a clean, uninterrupted 3 phase waveform as long as the alternator shaft is turning, thereby preventing any disturbances to the input power of the AVR. The PMG provides reliable isolated power input to the AVR where significant voltage waveform distortion may have been a problem in a self-excited system.

The PMG excitation system has a number of benefits for both motor starting and non-linear loading situations such as:

- Provides sustained short circuit (SSC) current during fault conditions which prevent the field from collapsing and allows for faults downstream to clear.
- Non-linear loads have no impact on the ability to provide power to the exciter.
- Powerful voltage build up on initial start-up instead of relying on residual magnetism.

- Isolation from high transient conditions in motor starting situations which otherwise would limit the AVR in its ability to provide full excitation to recover voltage and ultimately torque for the motor to get up to speed quickly.



THE PMG GENERATOR PROVIDES A SEPARATE POWER SUPPLY FOR AVR

Figure 3: PMG Excitation.

Although PMG systems adds length, weight, and complexity as compared to the Shunt, EBS, and AUX systems, it is the most commonly used excitation system for applications with high performance requirements for motor starting, selective coordination and non-linear loads.

Auxiliary Winding (AUX)

The auxiliary winding (AUX) is a different form of excitation that has been used for many years on many types of applications including marine and industrial. While it is a less commonly used type of excitation, it is not a new technology and becomes more practical in larger installations. The construction of the AUX uses the main field to generate power for the AVR through a separate winding on the stator. The winding is a separate single-phase winding which is inserted into the main stator alongside the main output winding. This eliminates the need for a separate PMG on the end of the alternator and avoids the issues Shunt can have with sustainable power output and harmonics due to non-linear loads.

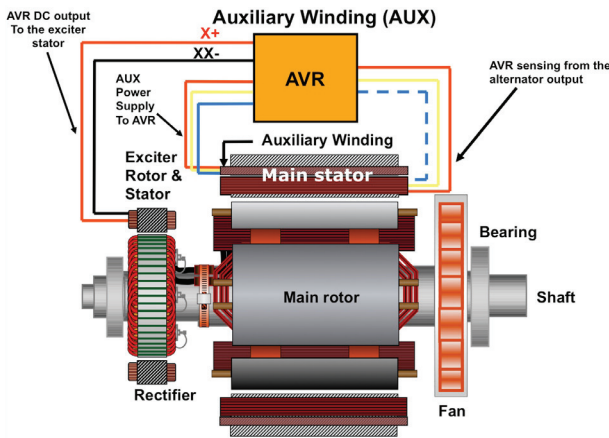


Figure 4: Auxiliary Winding.

The Cummins Power Generation construction involves three coils with all the coils being connected in series (shown in Figure 4). Under normal operations (no load to full load) the unit will use the first field harmonic to generate power for the AVR. However, under motor starting and SSC conditions, the rapidly increasing 3rd field harmonic becomes the dominant source for power from the AUX winding. This balanced usage of the two harmonics allows for a strong response during motor starting and SSC conditions, beyond what is needed to provide 300% current for 10 seconds.

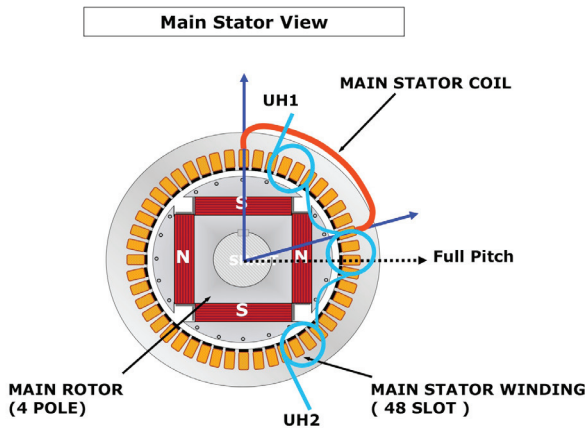


Figure 5: AUX Winding Excitation.

Some benefits of the AUX winding are that it results in a shorter axial length of the generator set and reduced production costs, as there is less equipment to install when compared with PMG systems. While its voltage input to the AVR can be affected to a certain extent by the power

being generated, it has a negligible impact on the performance of the set. It also provides a very robust solution with low incidents of failure. By design, the mutual inductance with the main winding is minimized and due to this the waveform distortions in the main winding from non-linear loads will not affect AVR performance. Both PMG and the AUX winding are suitable options for demanding applications.

AVR Construction

The type of AVR construction can have a significant impact on the ability of each of these types of excitation circuits. We will discuss two types of AVR construction: SCR type and FET type. Both systems have independent input power and voltage sense circuits. In all four excitation systems the voltage sense lines are pulled from the main stator which can result in a distorted voltage feedback signal from harmonics caused by customer connected loads. It is how the two systems deal with the power circuit and voltage sense lines that is important to the performance of the generator set.

SCR AVR

The SCR type system senses the voltage level on the output of the alternator and uses this level to time the firing of the SCR. It must determine both when the switch is to be turned on and when it will be turned off. The voltage level is used as a feedback loop to determine when the switch should be turned on and the switch will turn off based on when the voltage waveform reaches zero, otherwise called the zero-crossing. The length of time the switch is on determines the amount of power being sent to the exciter (shown in Figure 6). It also uses the zero-crossings on these lines to determine the system frequency when a magnetic pickup is not used. This impacts the timing of the SCR firing and may be also be used to adjust the electronic governor. This can be especially troubling with non-linear loads as the harmonic distortion and induced “notches” (shown in Figure 7) can cause additional zero-crossing points which cause the system to struggle in delivering the appropriate amount of excitation. It can also cause improper frequency sensing and drive a false over-speed fault condition. (For more information please reference Power Topic #6014 on power.cummins.com.)

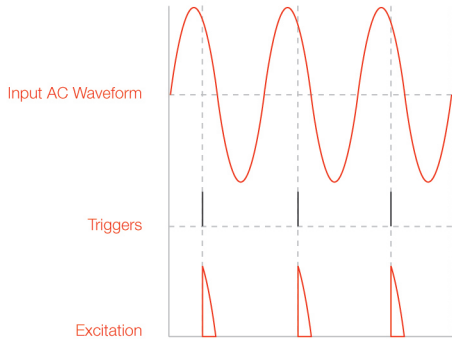


Figure 6. SCR-Controlled Excitation System. Note that a single trigger input “turns on” the excitation power, and the AC voltage crossing turns it off. When that regulator is applied with non-linear loads, the waveform notching causes the SCR in the AVR to switch off at the incorrect time, so the exciter does not get the proper level of energy to maintain generator output voltage level.

For these reasons an SCR type AVR is not recommended for large amounts of non-linear load with Shunt or EBS excitation systems. The rule of thumb for these two systems when powering non-linear loads is that the system can handle about 25% of the base rating of the alternator being non-linear before the distortion becomes excessive. The use of PMG or AUX will be an improvement due to cleaner input power so there will be no improper zero-crossings causing the SCR to shut off early, but the voltage sense lines will still be problematic with a distorted voltage as the zero-crossings will still drive improper excitation and inaccurate frequency readings (if no mag pick-up is used).

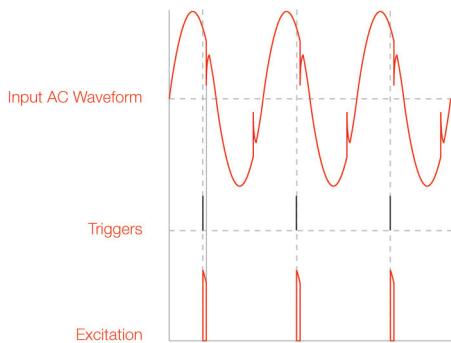


Figure 7. Sub-Controlled Excitation System with Distorted Input Voltage Waveform. Note that the single trigger turns on at the correct time, but waveform notching causes the AVR to “switch off” power to the exciter too soon.

FET AVR

The FET type AVR system has many advantages that are suited for all four excitation systems for improved performance when relating to non-linear loads and potential distortion. In the case of the FET AVR, the voltage sense lines are measured and translated to drive a pulse width modulated (PWM) circuit for the excitation output. The translated signal dictates the duty cycle of the PWM signal and ultimately the amount of excitation being applied (shown in Figure 8). This method prevents zero-crossings from dictating a single event or notch from impacting the amount of excitation by constantly pulsing and adjusting the duty cycle. The power input waveform is only used for excitation output and is filtered and rectified to a DC signal. This prevents the power quality from having an impact on the excitation capability of the system. The FET type AVR also uses a magnetic pick-up for engine speed and derives the frequency from this signal only, preventing false frequency information due to non-linear loads.

The effect of using a FET type AVR with each of the different AVRs discussed is significant. With a Shunt or EBS excitation system, the concerns for harmonics due to non-linear loads are mostly eliminated, and with the PMG or AUX systems the few limitations on SCR type systems were completely eliminated.

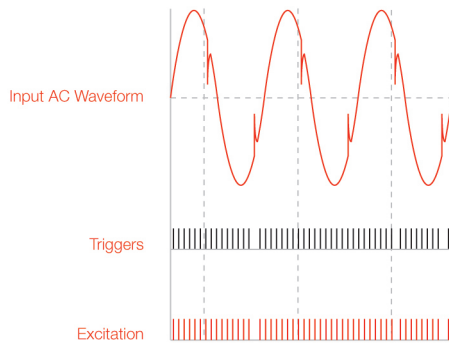


Figure 8. Pulse Width Modulated (PWM) Excitation System. Multiple triggers and pulsed output provide proper levels of excitation regardless of level of waveform distortion.



About the author

Greg LaLiberte is a graduate of the University of Minnesota, with a bachelor's degree in electrical engineering. He has been with Cummins Power Generation since 2011 and currently leads the Sales Application Engineering group for North America. His previous experience included high-horsepower generator set design. In his

current position, Greg's primary focus is assisting clients and distributors with technical guidance on application-specific issues. He is actively engaged in the Power Seminar customer training program, and he provided technical training content to support distribution teams in the United States, Canada and Caribbean.

Summary

While there are multiple options available for excitation systems each has unique features that provide benefits for different applications. For simple applications requiring a low cost solution with few motors or non-linear loads, Shunt excitation may be the appropriate choice. This will typically be more suitable for smaller generators as the applications are less demanding. Once the application dictates the need to start multiple motors, to have improved motor starting, and/or to meet requirements for sustained short circuit capability for selective coordination, the EBS excitation system will provide the level of excitation needed in this slightly more demanding situation, and at a lower cost than PMG.

For the most demanding applications requiring large motor starting, improved motor starting capability, non-linear load demands and sustained short-circuit capability during large faults, the PMG and AUX winding excitation systems should be evaluated to meet the application's needs. The use of a permanent magnet generator isolates the AVR power source from the alternator output and provides constant power output. The AUX winding takes advantage of the inherent harmonics within the generator to reduce the size of the set while still providing strong motor starting and sustained short circuit capability.

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