AVOIDING LOSS OF VOLTAGE SENSING RUNAWAY FOR GENERATOR EXCITATION SYSTEMS

Dale Buscher
Member, IEEE
Basler Electric
12570 State Route 143
Highland, IL 62249
USA

Abstract - **The excitation system, synchronous generator and connected loads of an electrical power system can incur serious damage if a generator's sensing voltage input to the automatic voltage regulator (AVR) is lost. There are various conditions that may cause loss of sensing voltage to the excitation system, such as blown Potential Transformer (PT) fuses, failed PTs, mechanical connection problems, and sometimes even human error. The design and features of a voltage regulator/excitation system will define how the excitation system will react to a Loss of Sensing Voltage condition. Normal voltage regulation operation requires that if the Automatic Voltage Regulator's sensed generator voltage is lower than the AVR's regulation set point, the AVR will respond by increasing field current until the sensed generator voltage satisfies the AVR. Without additional excitation limiters or protective functions to detect a problem, an AVR operating without generator sensing voltage will produce maximum available field current and potentially cause damage to some element of the electrical power system. This paper addresses the protective safeguards commonly built into excitation systems to manage Loss of Voltage Sensing events and prevent power system equipment damage.**

Index Terms – Overvoltage, Loss of Sensing, AVR, Voltage Regulator, Positive Sequence Voltage, Negative Sequence Voltage, Excitation Limiter.

I. INTRODUCTION

Many paper mills and other industrial plants generate electricity using steam turbine driven ac generators to take advantage of excess steam used in the manufacturing process. These on site generators, when paralleled and co-generating with the infinite electric grid, provide a substantial reduction to electricity costs for mill operations. Depending on the size of the generator and the plant load, they could also potentially allow the plant to operate independently from the utility grid in an islanded condition if a power disturbance trips open the utility tie breaker. The generators can provide the reliability desired to keep the plant in operation in the event of utility power loss.

Not limited to industrial co-generation facilities though, a loss of sensing voltage event is a serious concern to any and all synchronous generators with an automatic voltage regulator controlling the generator voltage. The vast majority of these utility-scale generators are operated in an automatic voltage regulator mode. They rarely are operated in a manual voltage control mode unless perhaps there is a failure of the automatic voltage regulator or for some other maintenance or testing reason. In fact, the North American Electric Reliability Council (NERC) Planning Standard III C S1 states "All synchronous generators connected to the interconnected transmission systems shall be operated with their excitation system in the automatic voltage control mode unless approved otherwise by the transmission system operator." Therefore, it should be noted that the manual mode of operation is not meant to be a long term operating mode, but rather a commissioning and troubleshooting tool and in a lost voltage sensing condition, an operating mode preferred over a generator trip and load rejection.

Operating in the manual mode makes the generator a voltage follower and does not provide voltage support to the power system. During a lost sensing voltage event, it would be best to design a system that would avoid transferring to a manual mode and remain in an automatic voltage regulation mode. Accomplishing that would retain the automatic voltage regulation benefits such as improved motor starting and fault clearing capability. Because of the costs often associated with interrupted manufacturing processes, keeping the generator on line is paramount.

II. AUTOMATIC VOLTAGE REGULATOR OPERATION

All synchronous generators need an excitation source providing dc current to the generator field (rotor) to produce stator ac voltage. This excitation source can either be provided by a brushed type or brushless rotating exciter or by a static exciter working directly into brush rigging/slip rings. An automatic voltage regulator will regulate the exciter field current or be inherent to a static exciter controlling main generator field current.

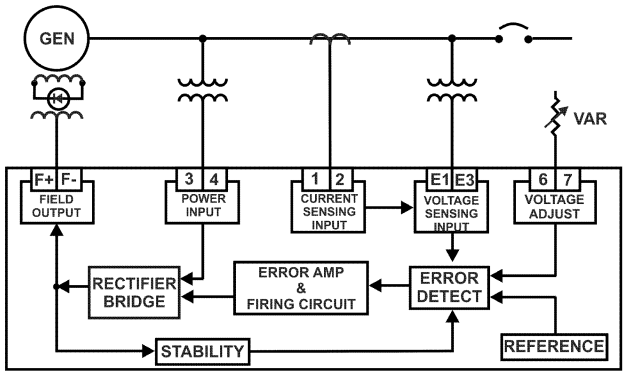


Fig. 1: Simplified Voltage Regulator Block Diagram

In the simplest sense, an automatic voltage regulator for a synchronous generator is a closed loop control system, as shown in Fig. 1, which regulates the field current to maintain a voltage set point for the generator's output. To effectively accomplish this closed loop control, the automatic voltage regulator (AVR) needs an input signal which is an accurate representation of the generator's output voltage. The input signal is then compared to an internal reference which represents the AVR's operating setpoint. If the sensed generator voltage is higher than the AVR's set point, it reduces field current to decrease the generator voltage. If the generator voltage is lower than the AVR's set point, field current is increased to raise the generator voltage.

The intent of this paper is to address protecting the AVR, generator and connected loads in the event that the sensed generator voltage is inadvertently lost. During such an event of lost sensing voltage, which incidentally causes an open loop state, the AVR should dutifully increase field current to its maximum capability. This full excitation current output reaction, however, will be a futile attempt to bring the generator voltage to its set point as seen by the regulator. The consequence of the full output reaction, without safeguards in place, can cause catastrophic failure of the AVR, heating damage to the generator field windings, and over-voltage and/or over-fluxing of the generator. Connected loads including motors and transformers are also subjected to damage from over-voltage and over-fluxing.

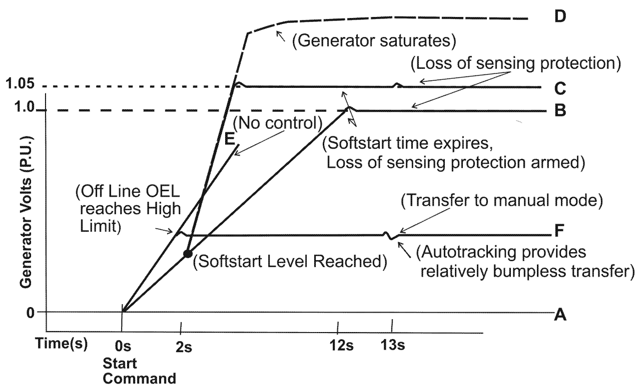
Generators for large power output applications normally have high voltage ratings that require a metering class step-down transformer or transformers to provide the voltage regulator a scaled-down input signal. The transformer will typically provide a 120 volt phase to phase voltage. The sensing voltage provided to the AVR is usually a three phase signal, either open delta or wye, yet single phase line to line signals are not unusual. Normally, the secondary voltage is 120VAC line to line.

Commonly, the high voltage potential transformers (PTs) will be fused on the primary side. While this serves an important purpose, it also can provide the opportunity for a lost voltage sensing event in case the fuses blow. When components of the power system age and are also subjected to vibration, they become more susceptible to failing. Fuses aren't immune to this. Vibration can also cause loose hardware connections. A lightning strike to the power system increases the potential to cause blown fuses and failed PTs. Sometimes these PTs are configured in switchgear so that they can be racked out. There have been occasions where PTs have been racked out for maintenance purposes and inadvertently forgotten to be racked in before restarting the generator, causing a generator overvoltage trip. Failure to make proper physical connection when racking in these types of PTs has been another source of lost voltage sensing to AVRs.

III. METHODS FOR DEALING WITH A LOST VOLTAGE SENSING EVENT

In lieu of some method for detecting that voltage sensing to the regulator has been lost, the best safeguard for such an event is to utilize an Excitation Limiter [1][2]. The limiter is usually an integral function of a modern digital type voltage regulator. In older analog regulators, it may have been an external device providing a control signal to an auxiliary input to the voltage regulator which would clamp the field current to safe levels. To be effective during a lost sensing voltage event though, the limiter needs to have high gain which usually wasn't the case with analog devices.

Depending on the AVR manufacturer, this function is commonly labeled an Over Excitation Limiter (OEL) or a Maximum Excitation Limiter (MEL). This type of limiter compares the magnitude of the field current to a predetermined set point that is normally associated with either the amount of field current related to preventing generator overvoltage when operating off-line and unloaded or the amount of field current to prevent rotor overheating while on-line. It seems that the best solution to deal with the event is to first, be able to detect the situation, then second, take responsive action. In practice, the best responsive action is to transfer to a redundant set of PTs, if available, and the system stays in automatic mode. The less attractive responsive actions would be to either cause an automatic transfer to a manual excitation mode, if available, or lastly, trip the generator and shut down. Manual excitation mode in modern digital regulators is typically a closed loop operating mode based on either field voltage regulation or field current regulation, not dependent on generator voltage. Fig. 2 depicts anticipated generator voltage and field voltage levels during an event where sensing voltage is not present during a generator startup.



Legend:
A = Sensed generator terminal voltage due to racked out Vts or blown VT fuses
B = Desired actual generator voltage
C = Predicted generation voltage with Offline Overexcitation Limiter enabled with no ac sensing voltage
D = Predicted actual generator voltage without Offline OEL with no act sensing voltage
E = Predicted field current without Offline OEL enabled with no ac sensing voltage
F = Predicted field current with Offline OEL with no ac sensing voltage

Fig. 2: Generator Voltage Plots with a Digital Excitation System

Several methods for detecting complete or partial lost sensing voltage have been implemented with protective relays. The relays used have been based on undervoltage (ANSI/IEEE function 27), undervoltage/negative sequence voltage (47/27), voltage balance (60), or a combination of negative sequence voltage and current in a fuse loss scheme (designated 60FL) [3]. Prior to the advent of microprocessor-based voltage regulators, these protection schemes were implemented externally to the voltage regulator. An output contact from the protective relay is wired into a logic scheme to transfer the AVR to manual mode.

Generators that have single phase L-L PTs for AVR voltage sensing as shown in Fig. 3 would typically have a simple undervoltage relay for Loss of Sensing protection. If the generator voltage would decrease below a threshold that would not be reached in normal operation, the relay would cause a transfer to the manual mode of operation. Although it is prudent to allow a short time delay to prevent nuisance transfers, a time delay greater than 0.2 seconds would be too long considering today's high gain digital voltage regulators. During generator startup, the 27 output would be blocked for a period of time to allow generator voltage to build to nominal values. In digital regulators, loss of sensing protection is normally blocked by the software code written into it until a nominal generator voltage is reached.

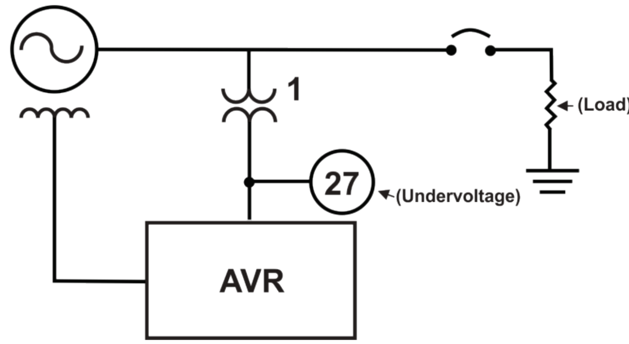


Fig. 3: Under Voltage Relay - 27

Generators having one set of PTs in a 3 phase L-L configuration could provide Loss of Sensing protection with a 47/27 configuration as shown in Fig. 4. While the 27 function operates for a balanced loss of voltage similar to the single phase PT referenced above, the negative sequence voltage 47 relay will detect unbalanced voltages. The 47 relay pickup will be set to trip on unbalanced voltages outside of the range normally anticipated in the power system. Again, the output of this relay will be wired (or programmed in software) to cause a transfer to the manual mode of operation while the relay output will be blocked during generator voltage buildup. Time delay to transfer should again be short to avoid generator overvoltage. One must always keep in mind the coordination of these settings with respect to main generator protective relays.

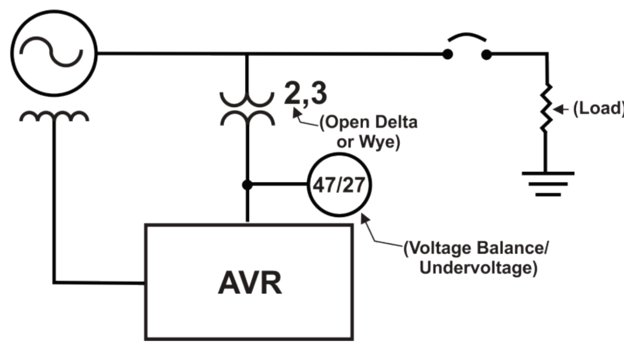


Fig. 4: Phase Sequence/Under Voltage Relay – 47/27

The 60FL fuse loss and loss of potential scheme shown in Fig. 5 uses a function found in a modern, numerical multifunctional relay. This function monitors positive and negative sequence voltage thresholds from a three phase PT. The positive sequence voltage detects when minimum voltage levels have been reached and normal voltage levels. Positive sequence voltage below a given threshold detects loss of three phase voltage. The relay also monitors current transformer inputs from the three phase generator output. Positive sequence amperes allow detection of minimum currents levels for arming the relay output and also normal current level. If a negative sequence voltage greater than a given threshold is detected, the relay compares the low phase voltage to the current in the corresponding phase. The premise is that if the negative sequence voltage is greater than the threshold and positive sequence current is in the normal range, the PT fuse must be blown. In such an event, the relay would cause a transfer to the manual mode of operation.

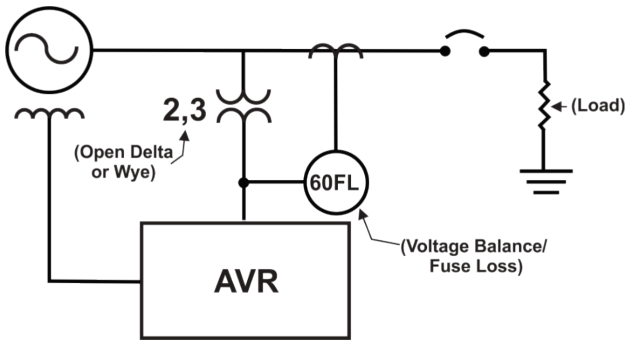


Fig. 5: Voltage Balance Fuse Loss – 60 FL

Where smaller generating plants have a tendency to have only one set of PTs available for AVR sensing, it is common practice in the industry for larger generators to have two sets of three phase PTs. One set is dedicated to AVR sensing voltage while the other set is used for metering and protection schemes. In this scenario, depicted in Fig. 6, a voltage balance (60) relay monitors the secondary voltages of both sets of PTs. Since the PT primaries are connected to the same source, the PT secondary voltages should always be as close to identical as PT accuracy permits. If the 60 relay detected an imbalance of voltages between identical phases, then through relays or contactors, the metering set of PTs would be switched to the AVR and an alarm would be annunciated for Loss of Sensing. In this way, the generator could stay on line continuing in the automatic mode of operation.

In such a scheme with redundant sets of PTs, if the backup set of PTs that would normally be connected to the generator main protective relays is detected to have lost a fuse, then transfer of those PTs to the AVR should be blocked. During such an event, one must also be mindful that main generator protective relays, which are sensitive to generator voltage such as 51/27C, 32, 40 etc., should also be blocked as they are likely to misoperate.

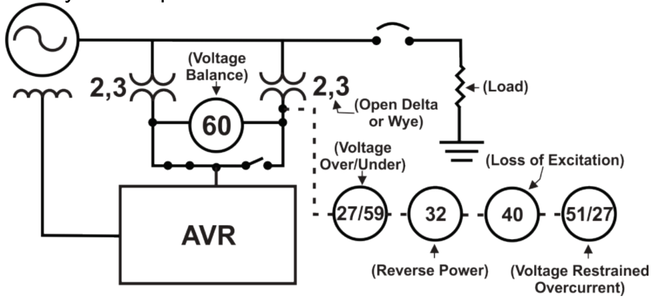


Fig. 6: Voltage Balance - 60

Most modern digital excitation systems have a loss of sensing voltage protective function built in. Thresholds are programmed for balanced and imbalanced voltage levels. Once the threshold is surpassed, a short time delay of less than 0.2 seconds is normally programmed to prevent spurious trips or transfers. Software programming normally allows for automatic transfer to a manual mode of operation and/or annunciation of the loss of sensing voltage event so that maintenance personnel can troubleshoot the root cause of the problem while the generator stays on line until an orderly shutdown can occur for repairs. For the larger generator plants that have redundant sets of PTs, the ultimate protection from lost sensing voltage is employed to first transfer to the redundant PTs with a 60 relay and then transfer to manual mode if sensing voltage is lost from both sources. Again, the preference is to stay in automatic mode.

IV. CONCLUSION

A loss of generator voltage sensing input to an automatic voltage regulator or static exciter can cause serious and costly equipment damage if protective functions are not put in place to mitigate the situation. When the appropriate protective functions are put in service, the choices of action during a loss of voltage sensing event are limited to transferring to a redundant set of PTs, transferring the excitation system to a manual mode of operation that is not dependent on the sensing voltage or tripping the generator.

We are especially fortunate because of the digital world we live in today. When vintage excitation systems are retrofitted, digital excitation systems commonly replace them. The inclusion of these protective functions into the digital products and the ease of software programmability simplify our tasks and enhance the capabilities of the equipment. We can then rest assured that if the dreaded event occurs, the event will be managed swiftly and automatically and will become nothing more than a minor inconvenience as opposed to a major catastrophe.

V. REFERENCES

[1] T.W. Eberly and R.C. Schaefer, “Minimum/Maximum Excitation Limiter Performance Goals for Small Generation,” *IEEE Trans. Energy Conversation*, vol. 10, pp. 714–721, Dec. 1995.

[2] R. Schaefer; D. Jansen; S. McMullen and P. Rao, “Coordination of Digital Excitation System Settings for Reliable Operation,” in *2009 IEEE Power & Energy Society General Meeting* (July 2009), pg. 1-7

[3] ANSI/IEEE C37.2, *Standard Electric Power System Device Function Numbers*, New York, NY: IEEE.

Basler Electric®

www.basler.com

Highland, Illinois USA
Tel: +1 618.654.2341
Fax: +1 618.654.2351
email: info@basler.com

Suzhou, P.R. China
Tel: +86 512.8227.2888
Fax: +86 512.8227.2887
email: chinainfo@basler.com