The Effect of Reactive Compensators and Coordination with Volts/Hertz Limiting

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***Abstract*--It is important to evaluate all of the variables necessary in the setup and commissioning of the generator excitation system to ensure predictable behavior of the synchronous machine during all conditions of operation. The digital voltage regulator has several programmable features that enable setup for proper operation. A few of the many controls include Reactive Droop compensation, Line Drop compensation, and Volts/Hertz limiting.**

Often, for reactive sharing, Reactive Droop compensation is utilized with either a small percentage of droop or no droop when connected to a large step-up transformer. Line Drop compensation regulates terminal voltage to a point beyond the generator terminals into a step-up transformer by using a small percentage of terminal voltage rise at the generator output. The benefit of Line Drop compensation is its greater reactive contribution from the generator during a disturbance.

Volts/Hertz limiting ensures safe operation of the synchronous machine for either underfrequency operation or generator overvoltage. Whereas the use of Reactive Droop compensation is fairly predictable with Volts/Hertz limiting, Line Drop compensation also needs to be coordinated with Volts/Hertz limiting. In this case, it is necessary to carefully examine the settings of the Line Drop compensator versus the setting of the Volts/Hertz limiter. If unchecked, the two settings may overlap unfavorably. For example, if the Volts/Hertz limiter set point were lower than the Line Drop compensation setting, there could be undesired reduction in excitation.

This paper discusses the two types of reactive compensators and Volts/Hertz Limiter to provide a better understanding of their effect on the generator excitation system.

***Index Terms*--Commissioning, Compensation, Coordination, Droop, Excitation, Generator, Limiting, Line Drop, Reactive, Synchronous**

I. REACTIVE COMPENSATION

A. Reactive Droop

Reactive compensation is important in any generation plant to minimize circulating current but still allow good reactive support to the utility system during a disturbance. Reactive Droop compensation simulates an impedance between the generator and the utility bus which creates a voltage regulating point at some location other than the terminals of the synchronous machine. With Reactive Droop, a small percentage of error is added to the input of the voltage regulator sensing circuit that results in a very small reduction in field voltage (perhaps up to 5% depending upon the % Droop programmed) and, hence, a reduction in generator terminal voltage. The generator instrument potential transformers and instrument current transformer are connected in quadature such that a 90 degree phase shift between the generator voltage and line current results at unity load. In Fig. 1, E_T is the generator terminal voltage, E_B is a voltage drop proportional to generator current, and E_S is the Automatic Voltage Regulator (AVR) sensing voltage. The angle between E_T and E_B increases with lagging power factor and decreases with leading power factor. It can be seen that the magnitude of E_S also changes accordingly. [1, 2]

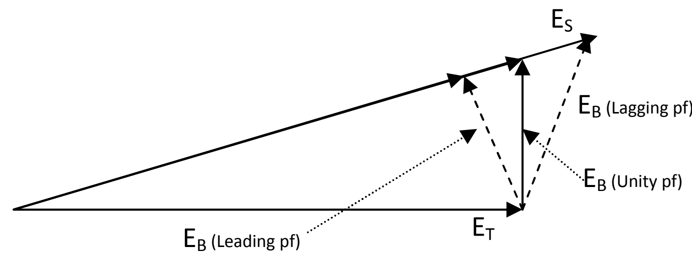

Fig. 1. AVR sensing voltage generation

In the utility system, often the Reactive Droop is abandoned, since the generator step-up transformer has at least 10% impedance. If 5% impedance contribution from the AVR is added, the voltage stiffness of the utility bus during a fault will be affected unfavorably. The greater the voltage drop across the step-up transformer, the lesser the contribution from the generator for reactive support during the fault. Therefore, the AVR Reactive Droop often is reduced to zero.

Fig. 2 shows terminal voltage versus reactive output based on 3% and 6% droop. The graph illustrates how, as droop increases, a larger per-unit change in terminal voltage is required to reach 100% reactive output.

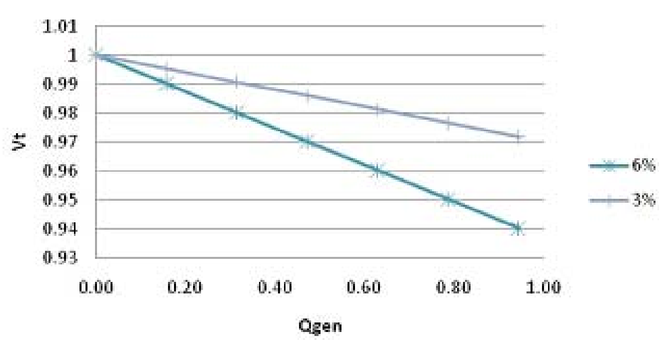

Fig. 2. 3% versus 6% reactive droop

B. Line Drop Compensation

Where Reactive Droop in the AVR essentially adds impedance to the generator system, Line Drop compensation removes some of the apparent impedance between the generator and the utility bus via the connected step-up transformer. Like Reactive Droop compensation, the approach utilizes the generator system instrument potential transformers and generator current transformer that are connected in quadradure. But instead of the result being subtractive from the field, it is additive. Here, the field voltage increases by a small percentage of the total field voltage being applied into the rotor, generally from 1 to 6%. Line Drop will cause the generator voltage to increase depending upon the amount of Line Drop compensation added to the voltage regulator compensation circuit. Hence, 5% compensation causes the generator terminal voltage to increase to 105%, resulting in significant voltage stiffness to the generator system. Fig. 3 illustrates 6% Line Drop compensation. Notice that, as terminal voltage increases, reactive output also increases compared to Fig. 3.

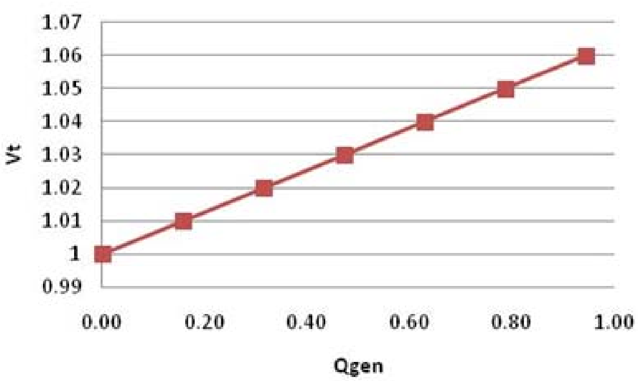

Fig. 3. 6% line drop compensation

C. Volts/Hertz Limiting

The Volts/ Hertz limiter measures generator voltage and frequency. Volts/Hertz limiting will limit the ratio of generator volts to generator frequency with an adjustment for changing the Volts/Hertz ratio accompanied by an inverse or definite timing characteristic. Generator flux density is proportional to the ratio of terminal voltage and frequency. Excessive magnetic flux can be caused by overvoltage or underfrequency, and that can result in core overheating or breakdown in insulation resistance between the core and laminations. This function maintains generator flux density at appropriate levels and limits the generator excitation when programmed values are exceeded.

II. MODEL AND SIMULATIONS

Fig. 4 represents the AVR model used for simulation, and Fig. 5 represents the system model where E_T is generator terminal voltage, X_T is the step-up transformer impedance, E_{HV} is the high side step-up transformer voltage, X_{L1} and X_{L2} represent transmission lines, and E_0 is an infinite bus. A change in E_{HV} is simulated by switching a line. [3]

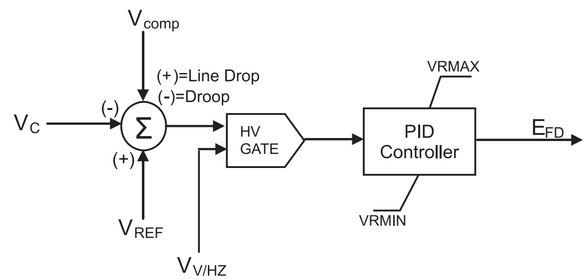

Fig. 4. AVR model with reactive droop and line drop compensation

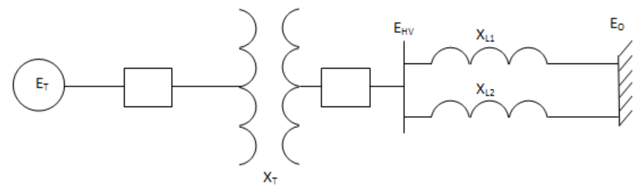

Fig. 5. System model

A series of graphs is shown to illustrate how Droop and Line Drop compensation affect the system response during a fault.

A. No Reactive Droop Simulation

Fig. 6 illustrates the result of a generator having no AVR Reactive Droop compensation and being connected to a 10% impedance generator step-up transformer during a disturbance. Notice that the generator terminal voltage dips to 0.98 per-unit (PU) and then recovers to 1 PU while, initially, reactive output reduces to 0.05 PU, before settling at 0.25 PU reactive output.

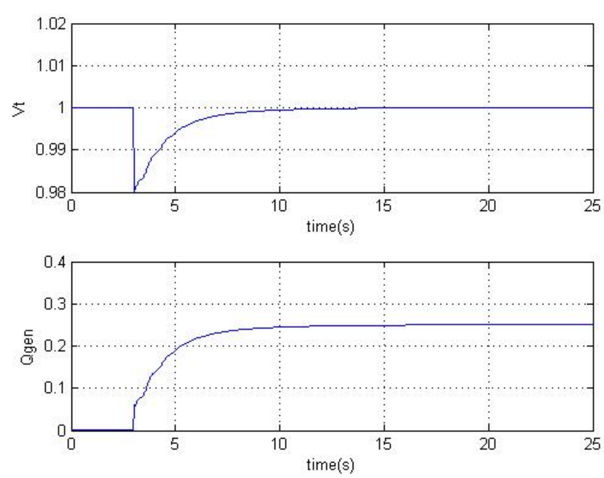

Fig. 6. AVR with no reactive droop compensation

B. 6% Reactive Droop Compensation

In Fig. 7, 6% Reactive Droop compensation has been programmed into the voltage regulator. The system is subjected to the same disturbance, resulting in an initial voltage dip of 0.98 PU. Reactive output again rises initially to 0.05 PU but, unlike the AVR that has no droop, 6% Reactive Droop compensation causes the generator terminal voltage to recover to 0.99 PU and total reactive output to increase only to

0.16 PU compared to 0.25 PU for a system having no droop. The lower reactive output demonstrates that the generator is contributing less reactive support during the disturbance.

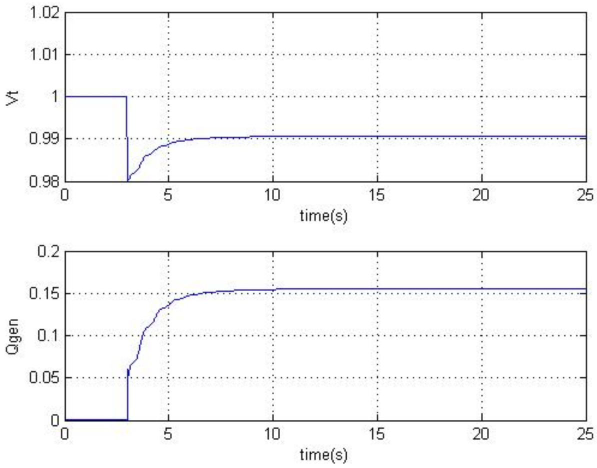

Fig. 7. AVR with 6% reactive droop compensation

C. 6% Line Drop Compensation

In Fig. 8, 6% Line Drop compensation has been programmed into the voltage regulator such that, instead of regulating the terminal voltage at the generator output, voltage regulation is in the generator step-up transformer at 6% causing a voltage rise at the generator output. When a disturbance occurs, the generator voltage drops to 0.98 PU and reactive power rises to 0.05 PU. After recovery, generator voltage moves to its new target of 1.04 PU, while the reactive output from the generator increases to 0.7 PU. Line Drop increases reactive contribution to the system during the disturbance, providing a more voltage-stiff system.

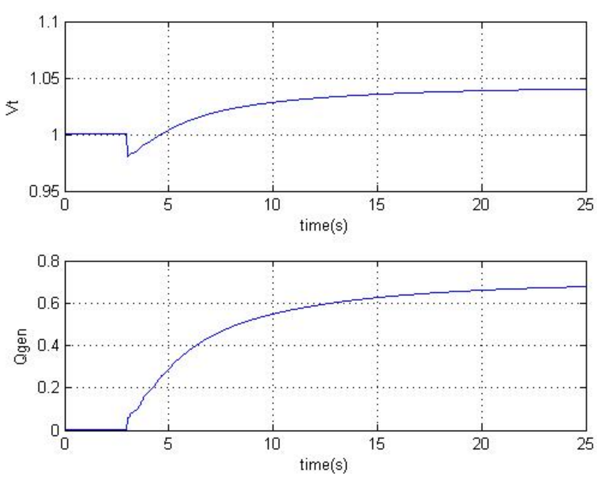

Fig. 8. AVR with 6% line drop compensation

Table I illustrates the results of three compensation settings.

TABLE I
REACTOR DROOP AND LINE DROP SETTINGS
VS. REACTIVE SUPPORT

	No Droop	Droop	Line Drop Compensation
Generator Voltage	1.0 PU	0.98 PU	1.04 PU
Reactive Support	0.25 PU	0.15 PU	0.7 PU

D. Line Drop Compensation and Volts/Hertz Limiting

Coordination of Line Drop compensation with Volts/Hertz limiting, as well as the Volts/Hertz protection, needs to be reviewed to ensure proper coordination among all functions. Fig. 9 illustrates coordination issues between the AVR Line Drop compensation and Volts/Hertz Limiter. While Line Drop compensation is set for 1.06 PU, Volts/Hertz limiting is set for 1.03 PU, resulting in an overlap that can cause consequences in the system.

After a system disturbance, recovery occurs, but the Volts/Hertz Limiter provides corrective action at 1.03 PU, reducing the generator voltage and limiting the generator reactive support that effectively overrides Line Drop compensation.

The solid line in Fig. 9 represents the system response with Volts/Hertz Limiting enabled. The dotted line represents the Line Drop characteristic unaffected by the Volts/Hertz Limiter.

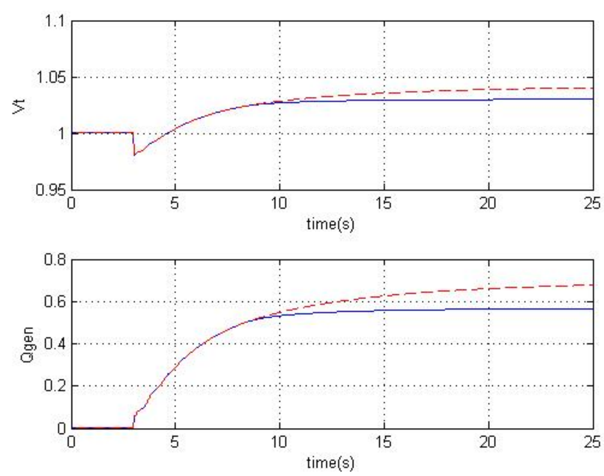

Fig. 9. 6% line drop compensation with V/Hertz limiting generator terminal voltage versus generator reactive output

III. SETTING CONSIDERATIONS

Careful examination needs to be made of the selected Line Drop compensation value. Too much Line Drop compensation may result in too little impedance between the generator step-up transformer and the connected generator, resulting in poor reactive sharing during steady-state operation. A generator step-up transformer that has 10% impedance with 8% Line Drop compensation may exhibit poor reactive sharing/support, causing the generator reactive power to drift over time and possibly become overexcited or underexcitated. Various amounts of Line Drop compensation versus reactive output are shown in Fig 10. As Line Drop Compensation increases, a greater change in terminal voltage occurs to provide the same reactive power output. [4]

Therefore, percentage of Line Drop compensation applied to the AVR should be reviewed carefully against the step-up transformer impedance.

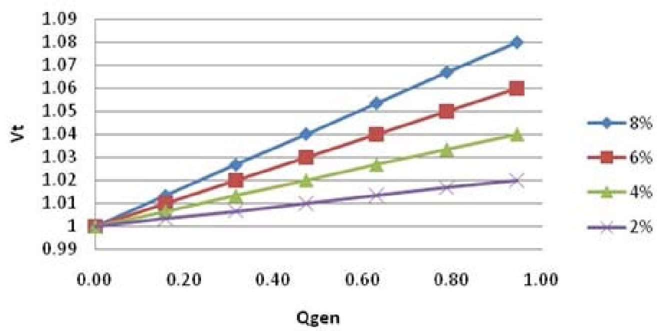

Fig. 10. Line drop compensation slopes

A. Line Drop/ Volts/Hertz Limiter Considerations

Several factors need to be considered when using Line Drop compensation:

1. Coordination of Line Drop with Volts/Hertz Limiter ensures no overlapping
2. Coordination of Line Drop with Volts/Hertz Protection
3. Volts/Hertz Limiter versus High Line Voltage condition using Line Drop compensation
4. Impedance of Generator Step-up Transformer. The greater the impedance, the greater the Line Drop that can be used.

IV. CONCLUSION

The use of reactive compensation benefits the system by ensuring stable behavior for all types of loads. Line Drop compensation improves the voltage stiffness of the system and provides greater reactive support than Droop. However, when using Line Drop compensation, it is important that the Line Drop, Volts/Hertz Limiting, and protection are all properly coordinated to ensure proper operation of all related devices.

V. REFERENCES

[1] *IEEE Guide for the Preparation of Excitation System Specifications*, IEEE Standard 421.4-1990.

[2] "Voltage Regulator and Parallel Operation", Basler Electric Power Control and Protection Conference, October, 2009.

[3] *IEEE Recommended Practice for Excitation System Models for Power System Stability Studies*, IEEE Standard 421.5-1992.

[4] *IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems,* IEEE Standard 421.2-1992.

VI. BIOGRAPHIES

Richard C. Schaefer, a Senior IEEE Member for 16 years, holds an AS degree in Engineering Technology. He is Senior Application Specialist in Excitation Systems for Basler Electric Company. Since 1975, Rich has been responsible for excitation product development, product application, and the commissioning of many plants. He has authored technical papers for numerous conferences including IEEE Power Engineering Society, IEEE IAS Pulp and Paper, EPRI, and IEEE Transactions on Energy Conversion and IEEE Transactions on Industry Applications publications. He has been involved with power plants for longer than 25 years.

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