DC-LINK CONTROL-LOOP DESIGN OF A SYNCHRONOUS GENERATOR WITH ELECTRONIC LOAD

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Abstract **– In this paper is present control-loop design and analysis of a system consisting of a variable-speed synchronous generator that supplies an active load (inverter) through a three-phase diode rectifier. It's present dc-link control-loop design responsible for stability and proper impedance matching between generator and load. The first attempt in compensator design was made, therefore, with a simple compensator P.I. For reasons which will be discussed in the this paper, the system's operation with that compensator was found to be unsatisfactory, and a more complex compensators, consisting of three-zeros and five pole, needed to be designed and implemented.**

Keywords: *variable-speed synchronous generator, electronic load, control-loop, stability, compensators.*

1. INTRODUCTION

In [1] it has already been stated two major advantages of the developed average generator/rectifier model consist in savings in transient simulation time and the possibility to perform frequency-domain analysis. In figure 1 is presented block diagram of the studied system in closed loop [1].

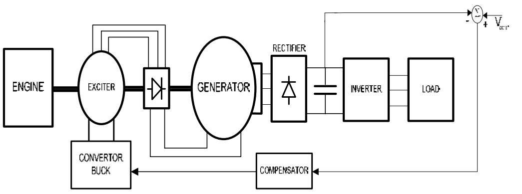

Figure 1. Block diagram of studied system in closed loop

This paper contains dc-link voltage, control-loop design procedure. It is based on the exciter's field voltage-to-dc-link voltage transfer functions obtained with model developed in [2]. A design procedure for a PI compensators is given, and transient simulation with resistive load at the dc-link are shown. Unstable operation of this compensator with an inverter load due to poor impedance matching between different parts of the system is discussed and the need for a higher-order dynamic compensator is found to be satisfactory. Validity of this compensator is verified through simulation with resistive load and inverter load at the dc-link.

In figure 2 is presented magnitude plot of control-to-output transfer function realized in [2].

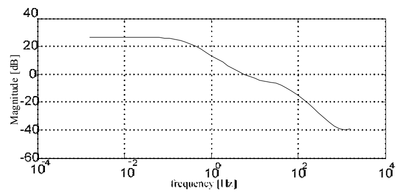

Figure 2. The exciters field voltage-dc-link voltage transfer function at 3340rot/min and 105kW current source load

Block diagram of the closed loop system drawn for small-signal analysis is shown in figure 3. In figure 3 *G(s)* represents the exciter's field voltage-to-dc-link voltage transfer function of [2], *p* represents the gain of dc-link voltage sensor, *H(s)* stands for dynamic compensator transfer function, *M* for modulator's gain, and V_g for input voltage of the buck converter dc-to-dc power supply use to provide the exciter's field voltage.

Regarding signal's notation $\tilde{v}_{efd}$ (the exciter's field voltage), $\tilde{v}_{adc}$ (dc-link voltage), $\tilde{v}_s$ stands for dc-link voltage sensed signal, $\tilde{v}_m$ for voltage signal input to the modulator and $\tilde{d}$ for the buck converter's duty cycles .

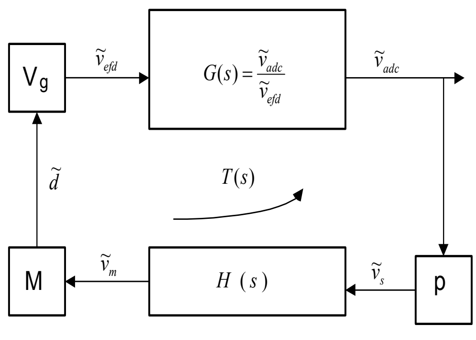

Figure 3. Small-signal block diagram of the closed-loop system

Stability and performance of the closed loop system can be expressed in terms of system's loop gain $T(s)$, which as indicated in figure 3, is product of all blocks forming the loop

$$T(s) = G(s) \cdot p \cdot H(s) \cdot M \cdot V_g. \quad (1)$$

In this paper sensor gain *p*, modulator gain *M*, and voltage V_g are constants, i.e. [1]

- *p*=0,005;
- *M*=0,56;
- V_g =48V.

With these parameters fixed, loop gain is shaped by selecting appropriate gain, poles and zeros of the compensator transfer functions *H(s)*.
Stability and performance criteria, such as phase margin and crossover frequency, can be read directly from Bode plots of the system loop gain.

2. DESIGN P.I. COMPENSATORS

The P.I. compensator is the simplest compensator that provides zero steady state error, due to its pole in the origin.
The compensator's transfer function is

$$H(s) = K\frac{1+\dfrac{s}{\omega_z}}{s}. \quad (2)$$

Standard analog realization of this transfer functions is shown in figure 4.

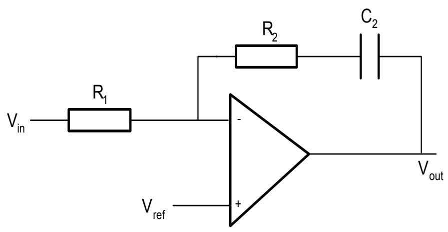

Figure 4. Analog realization of a P.I. compensator

After one component's value, say C_2, is chosen the either components

$$R_1 = \frac{1}{KC_2}, \quad (3)$$

$$R_2 = \frac{1}{\omega_z C_2}. \quad (4)$$

Zero at ω_z has the role of compensating for 90° phase leg introduced by the pole in the origin. It can see in figure 1 that the zero needs to be placed between 0,1 Hz and 1 Hz in order to have the desired phase-boosting effect.
Gain *K* can be adjusted in order to have stable system with the acceptable phase margin. With zero placed at 1 Hz, and the compensator's 1,5 the loop gain shown in figure 5 is obtained. It is characterized by a crossover frequency of approximately 2Hz and phase margin of approximately -70°. a higher phase margin would have been preferred, but the crossover frequency would have become unacceptable low in that case.

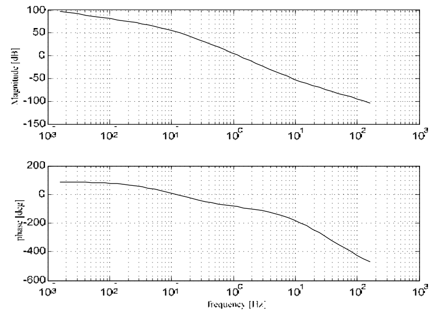

Figure 5. Loop gain with P.I. compensator (3340rot/min, 105kW current source load)

After several tatonation, it was found by trial-and-error that pole frequency of 150Hz, 150Hz, 250Hz and 500Hz, 0Hz and zeros at 1,5Hz, 2Hz and 10Hz, and gain of 116,8.
In figure 6 is presented Bode plots for compensators and in figure 7 is presented loop gain with multiple poles and zeros (three zeros and five poles).

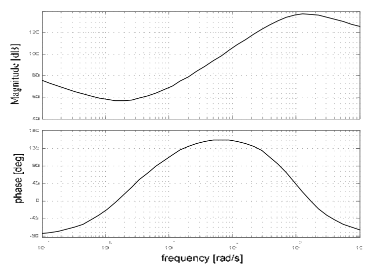

Figure 6. Bode plots for compensators (three zeros and five poles)

Using this compensator it observes in figure 7 the crossover frequency is 110Hz. An analog five-pole and three-zero compensator, having the transfer function

$$H(s) = K_a \frac{1+\dfrac{s}{\omega_{za}}}{\left(1+\dfrac{s}{\omega_{pa1}}\right)\left(1+\dfrac{s}{\omega_{pa2}}\right)} K_b \frac{\left(1+\dfrac{s}{\omega_{zb1}}\right)\left(1+\dfrac{s}{\omega_{zb2}}\right)}{\left(1+\dfrac{s}{\omega_{pb1}}\right)\left(1+\dfrac{s}{\omega_{pb2}}\right)} \cdot \frac{1}{s}, \quad (5)$$

was implemented with the circuit shown in figure 8 [1].

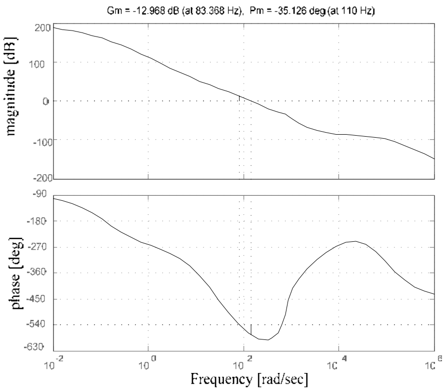

Figure 7. Loop gain with three-zeros and five poles compensators for 3340rot/min, 105kW current source load

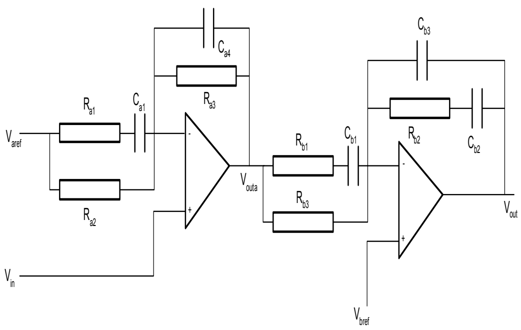

Figure 8. Analog realization of a five-pole and three zeros compensators

After one component value for each stage, say R_{a2} and R_{a1} is chosen arbitrarily others can be calculated from the transfer function's parameters follows

$$C_{a1} = \frac{1}{\omega_{za} R_{a2}}, \quad (6)$$

$$R_{a1} = \frac{1}{\omega_{pa1} C_{a1}}, \quad (7)$$

$$R_{a3} = K_a R_{a2}, \quad (8)$$

$$C_{a4} = \frac{1}{\omega_{pa2} R_{a3}}, \quad (9)$$

$$C_{b1} = \frac{1}{\omega_{pb2} R_{b1}}, \quad (10)$$

$$R_{b3} = \frac{1}{\omega_{zb2} C_{b1}}, \quad (11)$$

$$C_{b2} = \frac{1}{R_{b3} K_b}, \quad (12)$$

$$R_{b2} = \frac{1}{\omega_{zb1} C_{b2}}, \quad (13)$$

$$C_{b3} = \frac{1}{\omega_{pb1} R_{b2}}. \quad (14)$$

For the expression 9 to 14 to be valid, it need to be $C_{b2} >> C_{b3}$ and $R_{b3} >> R_{b1}$.

3. CONCLUSIONS

In this paper is presented design control-loop and analysis of a system consisting of a variable-speed synchronous generator that supplies an active load through a three-phase diode rectifier. Is design a high-order (five poles and three-zeros) dynamic compensator needs for stabilized the cascaded generator-rectifier-inverter system, affected by instability due to poor matching of output and input impedance of different parts of the system. In such a design, the system's dynamic response needs to be known, in a detailed manner, at frequencies much fighter than the frequency corresponding to be transfer function's dominant pole. The developed average generator/rectifier model represents a unique and indispensable means to study and solve this and similar problems.

References

[1]. Jadric I., Borojevic D., Jadric, M. *Modeling and control of a synchronous generator with an active dc load.* IEEE Trans., Power Electronics, vol. 15, no.2, march 2000.

[2]. Corcau J. *Sisteme evoluate de comanda si control al proceselor din instalatiile electrice ale avioanelor.* Teza de doctorat, Universitatea " Politehnica", Bucuresti, aprilie, 2006.

[3]. Corcau, J. *Three-phase synchronous generator modeling as subsystem of a PDS (Power Distribution System).* 7th International Conference of Applied and Theoretical Electricity ICATE 2004, 14-15 october, Baile Herculane, pp. 543-546.

[4]. Louganski, K.P. *Modeling and analysis of a DC power distribution system for in 21st century airlifters.* Doctoral dissertation, Virginia, 1990.

[5]. W.J. Bonwich, V. H. Jones. *Performance of a synchronous generator with a bridge rectifier.* Proceedings IEE, vol. 119, no.9, 1972, pp. 1338-1342.

[6]. Elbuluk, M. E., Kankam, M.D. *Potential starter/generator Technologies for Future Aerospace applications.* IEEE AES Magazine, vol.11, no.10, 1996, pp. 1724.