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Excitation Limiters for Small Synchronous Generators

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Original scientific paper

Small synchronous generators connected to electrical power system operate by following changes in the system voltage. Limiting of the generator excitation current enables generator operation within limits of the power chart diagram and increases the safety and availability of generator in the system. This paper includes algorithms for the determination of maximum and minimum excitation current limits and the implementation within digital control system of generator voltage. The performance of generator excitation current limits was experimentally verified on a laboratory model.

Key words: synchronous generator excitation system, maximum excitation limiters, minimum excitation limiters

1. INTRODUCTION

Small synchronous generators (< 10 MVA) connected to the electrical power system are susceptible to the changes of the system voltage. Generators remain synchronised to the system even in the extreme operating conditions (e.g. during considerable changes of the system voltage) and during that permissible load limits should not be exceeded. Exceeding of those limits activates the generator protection system that puts the generator out of operation.

Modern automatic voltage control systems should be equipped, besides voltage control circuit, with generator excitation current limiting functions. Limiting of minimum or maximum excitation current enables operation within whole generator power chart diagram and particularly in boundary areas. This increases safety of generator operation in the power system. Furthermore, inaccuracy in adjusting reference values of voltage or reactive power of generator may lead to the action of appropriate limit value, but not to the generator failure.

Limits are not able to replace generator protection system which acts upon exceeding permissible physical values of synchronous generator.

2. EXCITATION CURRENT LIMITING CRITERIONS

Generator automatic voltage control systems shall include voltage drop regulator circuit (Figure 1). Voltage drop regulator in voltage control system is usually adjusted within area of ±10 % of nominal voltage of the generator. Generator voltage control system will act on increasing or decreasing of excitation current in a way to achieve adjusted characteristic (Figure 1) while changing system voltage.

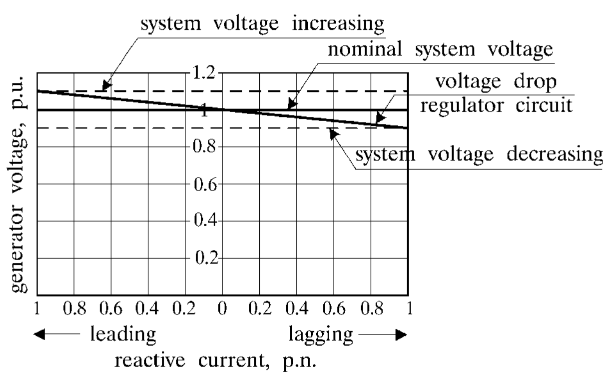


Fig. 1 Voltage drop regulator action as system voltage changes

Voltage control system maintains voltage on terminals of the generator, which operates within electrical power system, by changing reactive current or reactive power of the generator. The greater short circuit power of the system on the generator terminals comparing to the generator power and the greater changes of the system voltage cause greater changes of the generator reactive power. Considerable changes of the electrical power system voltage can cause generator to give in or take from the system reactive current (power) greater than nominal. Those cases can lead to overload of the stator, excitation or both generator windings. Also the generator may come out of synchronisation. Because of that it is necessary to construct generator voltage control systems with excitation limiting functions. It is usual to apply following limits in the generator voltage control systems:

- minimum excitation current
- maximum excitation current.

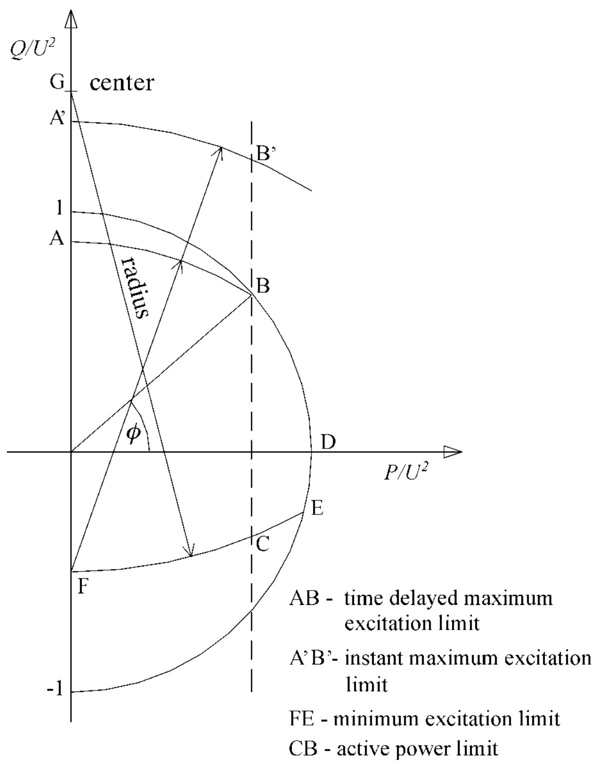


Fig. 2 Typical power chart diagram of synchronous generator

Excitation current limit within voltage control system put out basic operation of voltage control system i.e. voltage control and put on excitation limitation control according to adjusted curve.

Typical limitation curves are given on the generator power chart diagram (Figure 2) which is given in the form of conductance ($P/U^2 = 1/Z$, where Z is impedance). In this presentation of the generator power chart diagram, characteristics and adjustments are independent of generator voltage and they do not depend on temporary voltage changes. Limitation characteristics and their adjustments depend on size and purpose of the plant, generator parameters and system reactance.

3. MINIMUM EXCITATION CURRENT LIMIT

Minimum excitation current limit acts instantly and does not allow generator to get out of synchronisation. In addition, minimum excitation current limit protects generator stator and rotor against local overheating. Generator operation with minimum excitation or underexcited operating mode is more often in systems with long and lightly loaded transmission lines, in bigger cable networks, during putting in operation of long transmission lines and when control systems of regulating transformers are not acting in correspondence [2].

Limit characteristic of the minimum excitation current is shown in generator power chart diagram (Figure 2) with the part of circle ECF. Limit characteristic in form of the part of circle is chosen in a way to approximately represent real static stability curve of the generator.

4. MAXIMUM EXCITATION CURRENT LIMIT

Generator voltage control systems are also equipped with functions of instant and time delayed limit of the maximum excitation current. Instant limit of the maximum excitation current limits excitation current to the value of forcing current (Figure 3). Value of the forcing current depends on requirements of the power system. In Croatia, it is usual to chose curve according to Figure 3a with the for-

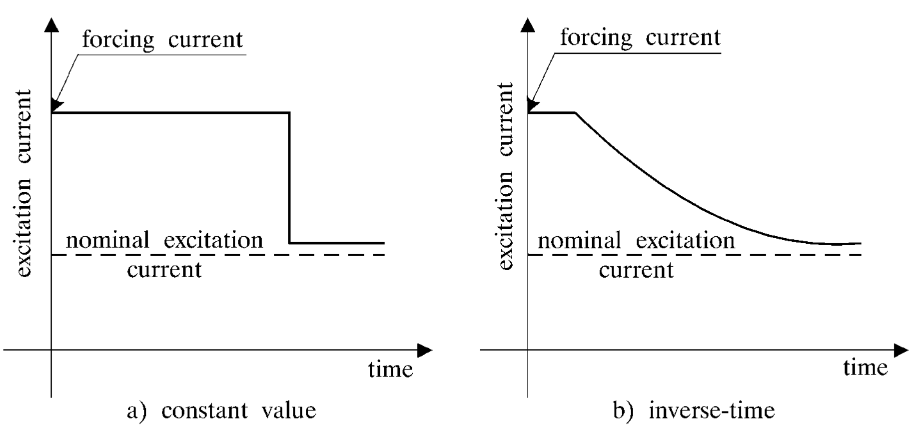


Fig. 3 Maximum excitation current limit characteristics

cing current up to 2 times greater than nominal and time delay 10 to 20 seconds. Limit of the maximum excitation current shall be, according to ANSI (C50.13-1977) [1], inverse-time characteristic (Figure 3b). After time delay excitation current is limited to the value of 110 % of nominal excitation current. In this way transient stability of generator and system is improved during peak loads and short circuits in system. Voltage control system is acting during short circuit in a way to force excitation current. Synchronising torque of the generator is increasing and possibility of getting out of synchronisation is decreased. If the short circuit is not switched off after determined time period, time delayed limits of excitation current are beginning to act and reduce armature and excitation current to the permanently permitted values.

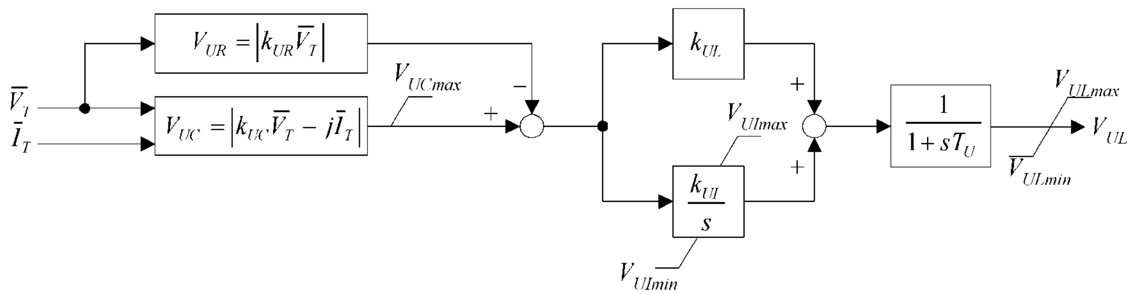
Instant limit of the maximum excitation current is presented by curve A′B′ and limit with time delay by curve AB in generator power chart diagram (Fi-gure 2).

5. LIMITING DEVICES AND IMPLEMENTATION IN THE BRUSHLESS EXCITATION SYSTEM

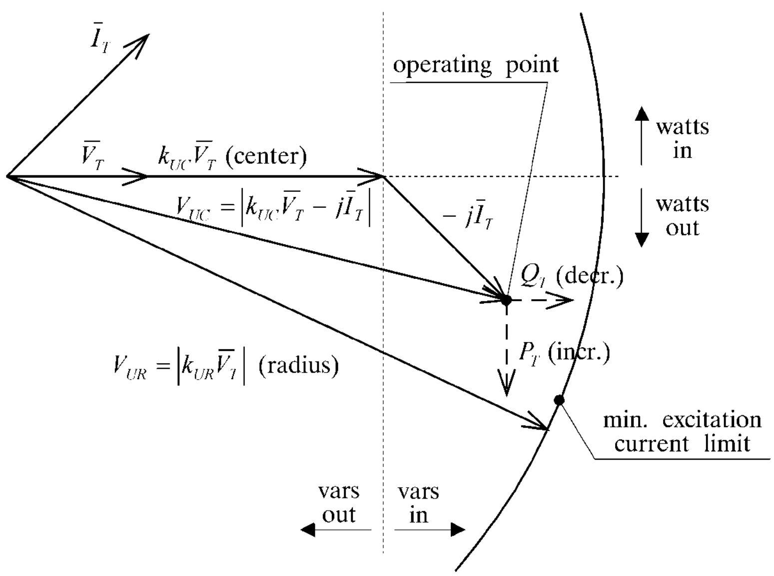
Today even small generators are equipped with digital voltage control systems. Digital voltage control systems enables, at the same time, realisation of the basic voltage control function and realisation of the most complex control structures.

Design and implementation of control algorithms in digital voltage control systems is performed through graphic programming environment by using standard function elements. In those systems it is possible to realise most complex limitation curves of minimum and maximum excitation current according to real generator parameters.

Algorithm of minimum excitation current limit (circular form) and phasor diagram are shown in the Figure 4. Circular form of minimum excitation current limit with radius V_{UR} is formed based on input values of generator voltage $\bar{V}_T$ and generator



a) block diagram of minimum excitation current limit algorithm



b) phasor diagram of minimum excitation current limit

Fig. 4 Block diagram and phasor diagram of minimum excitation current limit current $\bar{I}_T$. When signal $V_{UC} = \left| k_{UC}\bar{V}_T - j\bar{I}_T \right|$ became greater than signal $V_{UR} = \left| k_{UR}\bar{V}_T \right|$ minimum excitation current limit is starting to act. Depending on structure of the voltage control system, minimum excitation current limit can be realised by acting through voltage control or through the minimum excitation current limit control circle.

Parameters k_{UR} and k_{UC} determine position of the circle shaped curve of limit in the generator power chart diagram (P_T, Q_T). The circle shaped curve of minimum limit can be realised by means of active power (P_T) and reactive power (Q_T) signals according to equation:

$$\left(\frac{Q_T}{V_T^2} - CENTER \right)^2 + \left(\frac{P_T}{V_T^2} \right)^2 = RADIUS^2 .$$

Limitation of the maximum excitation current can be realised according to the algorithm shown in block diagram on Figure 5. Input signal is generator excitation current I_F or exciter excitation current I_{FE} in brushless systems.

Acting of the limit of the maximum excitation current is adjusted by means of signal I_{TFPU}. When the excitation current I_F (or I_{FE}) exceeds adjusted value I_{TFPU}, output signal of the integrator T_{LIM} starts increasing linearly and when it exceeds adjusted value T_{FCL}, reference value I_{FREF} starts decreasing linearly from the value I_{FINST} to the value I_{FLIM}. Rate of linear decreasing of the output maximum excitation current limit signal is determined by parameter k_{RD}. When $I_F < I_{TFPU}$ and $T_{LIM} < T_{FCL}$, reference signal I_{FREF} and output signal of maximum excitation current limit are increasing with rate determined by parameter k_{RU}.

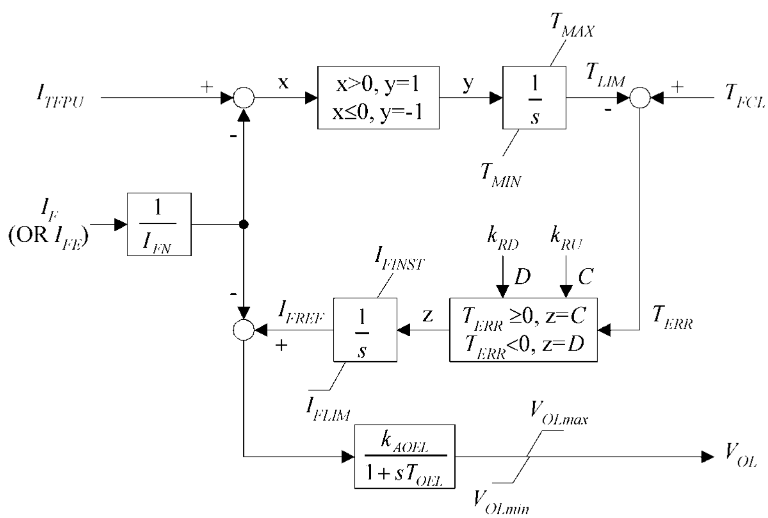


Fig. 5 Block diagram of maximum excitation current limit

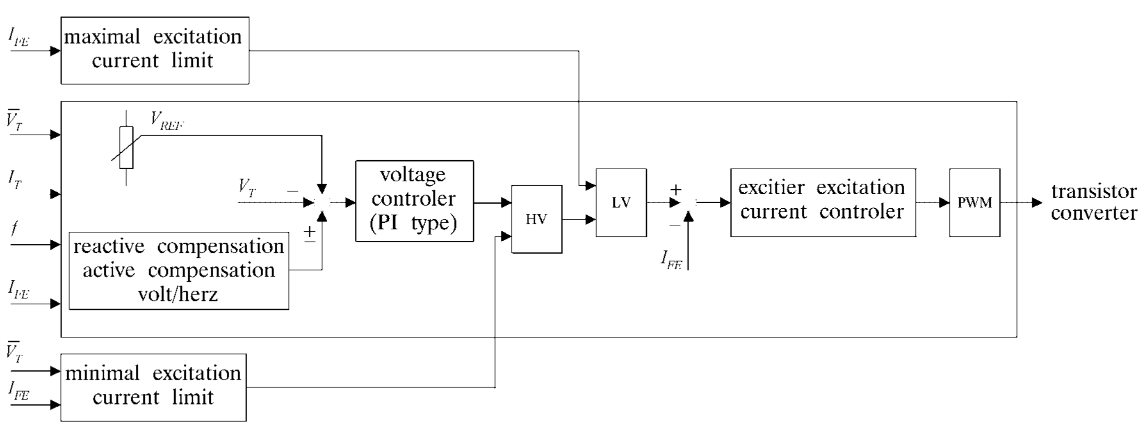


Fig. 6 Block diagram of digital voltage control system of brushless synchronous generator with minimum and maximum excitation current limits

By choosing parameters of maximum excitation current limit it is possible to obtain requested characteristics concerning role of the generator in the power system.

Minimum (Figure 4) and maximum (Figure 5) generator excitation current limits are implemented in digital voltage control system of brushless synchronous generator (Figure 6). Excitation of generator exciter is fed by transistor converter controlled by pulse width modulator. Excitation voltage control system has two feedbacks. Besides basic, generator voltage feedback, it has additional inner feedback of exciter excitation current. Inner feedback, besides for increasing system stability, is used for linearization of the subsystem within this control loop and for improving the transient process of exciter excitation.

Minimum excitation current limit is to be verifyed in two steps. Generator minimum excitation current characteristics already implemented in the system is verifyed in the first step. It can be done by reducing generator excitation current till it exceed minimum excitation current limit for different amounts of generator loads.

Dynamic characteristics of minimum excitation current limit are adjusted in the second step. It is usual to test dynamic behaviour of minimum excitation current limit experimentally, applying step signal of generator voltage reference for different operating points within power chart diagram. Limit shall not initiate action of generator underexcitation protection system during the transient process.

Generators are working under very different operating conditions in the electrical power system. Generator voltage control system structure is varying according to these conditions. Algorithm and adjusted parameters of generator voltage control system shall ensure changing of structure of voltage control system with smooth transitions without oscillations of generator current and reactive power.

6. LABORATORY MODEL OF DIGITAL VOLTAGE (EXCITATION) CONTROL SYSTEM AND EXPERIMENTAL RESULTS

Multiprocessor control system is developed at Faculty of Electrical Engineering and Computing, Department of Electrical Machines, Drives and Automation, Zagreb. System hardware is based on DSP (AMDC 300, Analogue Devices). Beside system software this system also include library of function modules (350) and application software. Application software is easy to be made by linking different function modules for specific application within graphic, user friendly, environment. System enables realisation of most complex control algorithms with maximum sampling frequency of 10 kHz. It is very suitable for fast drives and processes.

Performance of excitation current limit was tested on brushless generator 54 kVA (400 V, 78 A, 50 Hz) connected to the electrical power system.

Within laboratory model of generator voltage control system are implemented limits of maximum excitation current according to characteristics (Figure 3.a) and minimum excitation current according to characteristics (Figure 4.).

Response of minimum excitation limit loop to step decreasing reference signal is shown in Figure 8. Response of maximum excitation limit loop to step increasing reference signal is shown in Figure 9.

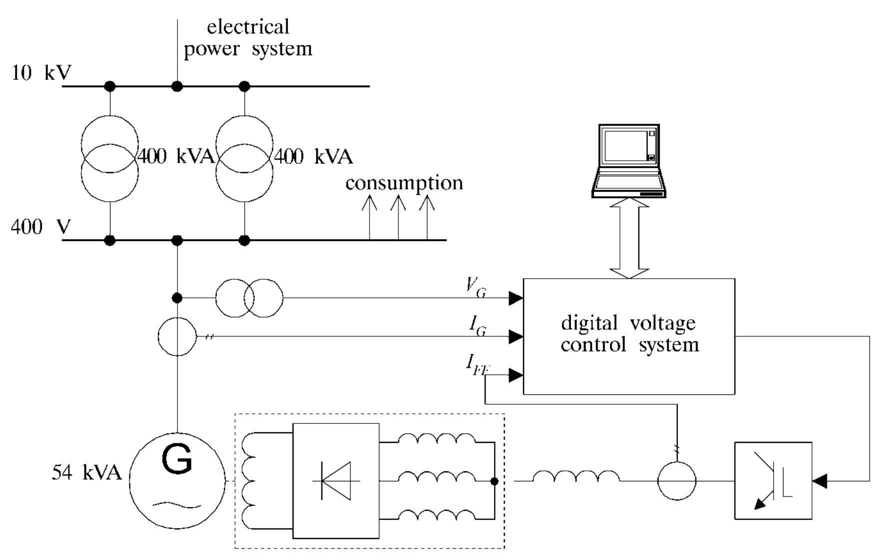


Fig. 7 Laboratory model of generator voltage control system

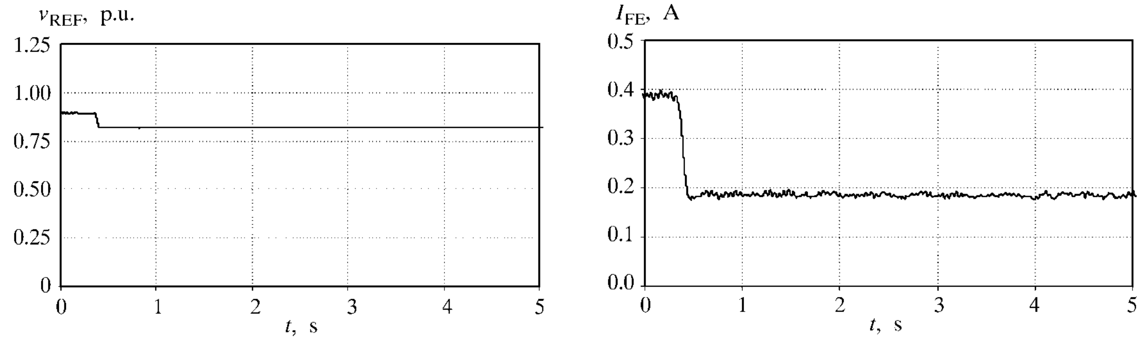


Fig. 8 Response of minimum excitation limit

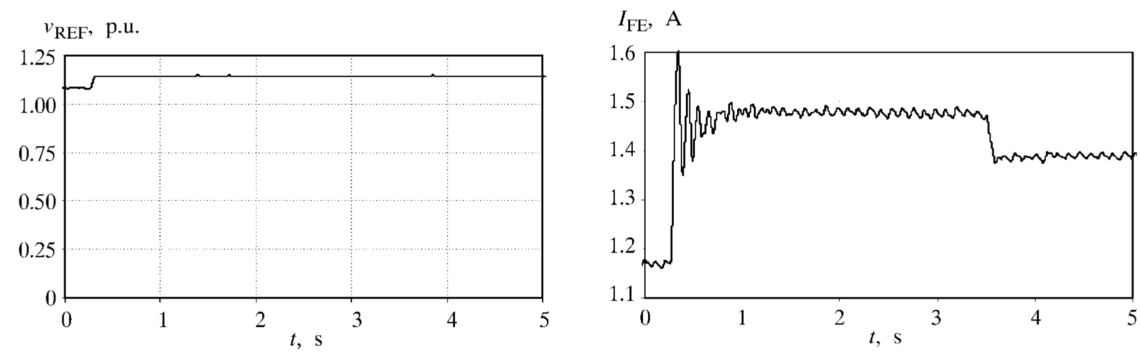


Fig. 9 Response of maximum excitation limit

7. CONCLUSION

Today even a small synchronous generators, permanently or occasionally connected to the electrical power system, shall be equipped with digital voltage control systems which include minimum and maximum excitation current limiting functions. Operating reliability of the generator will be significantly increased with excitation current limiting functions, especially during transient disturbances in electrical power system. Besides that, digital voltage control systems enable simple implementation of complex limiting functions of excitation current in accordance with generator parameters and electrical power system requirements.

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APPENDIX – NOMENCLATURE

- V_T – generator voltage signal
- V_{UL} – output signal
- I_T – generator current signal
- k_{UR} – radius of minimum excitation current limit
- k_{UC} – center of minimum excitation current limit
- k_{UL} – proportional gain
- k_{UI} – integrator gain
- T_U – filter time constant
- P_T – generator active power
- Q_T – generator reactive power
- I_{TFPU} – pickup level

I_{FREF} – reference
I_F – field current
I_{FN} – rated field current for scaling
I_{FINST} – instantaneous current limit
I_{FLIM} – timed current limit
T_{LIM} – timing signal
T_{MAX} – timer maximum limit
T_{MIN} – timer minimum limit
T_{FCL} – timer setpoint
T_{ERR} – timing error signal
k_{RU} – ramp up gain
k_{RD} – ramp down gain
k_{AUEL} – controller gain
T_{OEL} – controller time constant
HV – high value gate
LV – low value gate

Limiteri uzbude malih sinkronih generatora. Mali sinkroni generatori pri radu u elektroenergetskom sustavu slijede promjene napona sustava. Limitiranje uzbudne struje generatora omogućava rad generatora unutar granica pogonske karte te povećava sigurnost i raspoloživost generatora u sustavu. Ovaj članak sadrži algoritme za određivanje limita maksimalne i minimalne uzbudne struje te za implementaciju u digitalnom sustavu regulacije napona generatora. Ponašanje limitera uzbudne struje generatora eksperimentalno je potvrđeno na laboratorijskom modelu.

Ključne riječi: uzbudni sustav sinkronog generatora, limiter maksimalne uzbude, limiter minimalne uzbude

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