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POWER SYSTEM STABILITY IMPROVING BY USING OF POWER SYSTEM STABILIZERS AND ADAPTIVE STATIC COMPENSATORS

Abstract

In the suggested paper a different system devices for improving power system stability are examined and compared. A power system stabilizer for synchronous generator (PSS) and adaptive static var compensator (ASVC) are used. Using the conventional PSS tend to vastly improving of power system stability due to interpolation additional components of damping torque, which compensate phase lag of automatic voltage regulator, exciter and generator. The controlling system of ASVC is identify in real time on the basis of estimated parameters and variables of identification model and after that is create a controlling signal which control system device. Thanks to these controls the power system damping is largely increased, like all transient processes performances are improved.

INTRODUCTION

The incensement of electric power consumption put requirements for better control of power systems, lower price of electric power into decentralized competitive circle. In this way the power system could be easy reaches to maximal limit loading in compare with the past. These reasons could be bring to system instability and poor damping of oscillations.

Improving of oscillation performances of power system could be done by improving of damping action of automatic regulators for excitation (ARE) of generators or/and automatic speed regulators (ASR). The choice of adjustment of ARE/ASR usually is performed in terms of ensuring of static stability.

In recent years another method of approach is imposed based of development and introducing of separated devices. These devices realize additional feed back by signals from different variables of operating mode. This additional feed back stabilizes the transient processes in power systems. These devices are known as system stabilizers and mainly are used for damping of subsynchronous resonance in range between 0,2 to 2,5 Hz. Those disturbances could appear between large power systems when frequency of one power systems relatively swings in relation of another power system frequency which systems are interconnected by transmission line for exchange of electrical power.

In last years are wide using conventional power system stabilizers. In most cases is better to know that the parameters of synchronous machine are changing by loading of machine. That allows to different behavior of synchronous machine at different operating modes. Therefore the power system stabilizers could ensure robustness in some degree at alternation of system parameters or configuration. Wide used system stabilizer is from type which modulates exciting of generators by addition of signal to reference voltage (set point). The basic requirements to system stabilizer is to ensure proper phase shifting in frequency range from frequency oscillations in range from 0.2 to 2.5 Hz. Usually the input signals are rotating speed of generator rotor, active power, network frequency and all local measured signals from generator.

The advantages of modern power electronics allow development off flexible alternating current transmission systems (FACTS). The basic function of these system devices is capability for damping improvement of system as a whole.

Introducing of shunt compensation mainly is used for improving of natural electrical characteristics of transmission line, for control of line voltage and for increase of transmission power in steady state mode. As static shunt compensators is used static var compensator (SVC) or static synchronous compensator (STATCOM). Mainly they represent shunt connected static controlled generator or absorber which can adjust it’s output for exchange of capacitive or inductive current. In this way is regulating and keeping power systems parameters in given range.

Combination of system stabilizers together with FACTS systems allows to improvement parameters of systems as s whole [1, 2]. In this paper is investigating common operation of these system devices as is using original adaptive method for control of shunt var compensator.

I. INVESTIGATION SYSTEM

On fig.1 is shown the diagram of the examinated scheme. The system is consisting from synchronous generator (*SG*) with automatic voltage control system (*AVC*), automatic speed controller (*ASC*), conventional power system stabilizer (*CPSS*) and primary mover – turbine (*T*). The synchronous generator is connected to infinity buses by transmission line with resistance Z_L. On the generator’s buses is connected active-inductive static load with resistance Z_T, adaptive static var compensator (*ASVC*). This adaptive compensator represents shunt connected condenser *C* and thyristors controlled reactor *L*. The control of thyristors is performing by adaptive regulator (*AR*) creating controlling signal which is proportional to conductivity of reactor B_L. This signal is transforming from thyristors control module (*TCM*) into firing angle for thyristors α. The thyristors controlled reactor continuously regulates reactive energy by regulation magnitude of reactors current. This regulation is performs by control of firing angle of thyristors as is regulating inductivity of shunt connected reactor. Each three-phase bank and thyristors controlled reactor are connected in delta so that, during normal balanced operation, the zero-sequence tripplen harmonics (3rd, 9th...) remain trapped inside the delta, thus reducing harmonic injection into the power system.

II. MATHEMATICAL MODEL OF THE INVESTEGATED SYSTEM

Synchronous generator

Equations of the generator are written of own coordinate system, which is fixed for its rotor. In this manner a variable coefficients are ignored.

Equations of the other elements (static load, transmission line, ASVC) are written in synchronous rotating coordinate system. At creation of equations for connections the current equations of generator are transformed into *d,q,0* axes.

The synchronous generator is modeled by its complete model in the *d,q,0* frame is used, written in Cauchy form [3]:

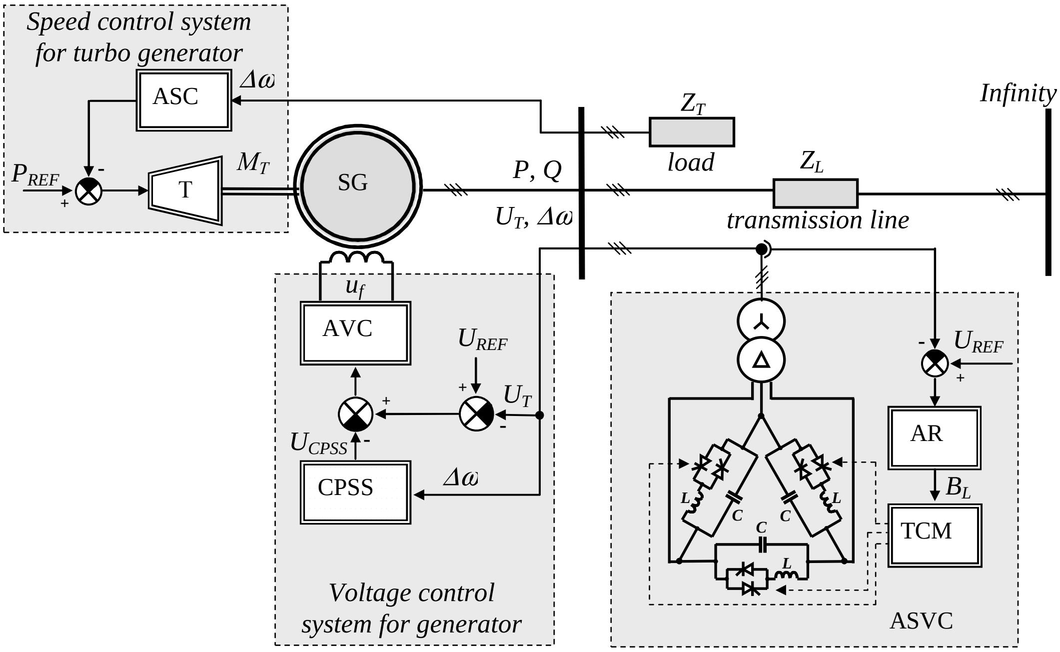

Fig.1. Examinated system diagram.

$$\frac{d}{dt}\begin{bmatrix} \mathbf{I_s} \\ \mathbf{I_r} \end{bmatrix} = \begin{bmatrix} \mathbf{H_s} \\ \mathbf{H_r} \end{bmatrix} + \begin{bmatrix} \mathbf{B_{ss}} & \mathbf{B_{sr}} \\ \mathbf{B_{rs}} & \mathbf{B_{rr}} \end{bmatrix} . \begin{bmatrix} \mathbf{U_s} \\ u_f \end{bmatrix};$$
$$\frac{d}{dt}\omega_k = \frac{1}{T_m}\left(M_T - M_{SG}\right); \qquad (1)$$

where subscript s refers to the stator parameters and variables, and subscript r - rotor; the elements of matrices and vectors $\mathbf{H}$ and $\mathbf{B}$ are in function of the stator and rotor resistance and inductive impedance and the rotor angular speed (axes $d,q,0$) - ω_k; M_T- turbine torque; M_{SG}- the generator electromagnetic torque; T_m- the turbine and generator mechanical time constant; u_f - field voltage; generator parameters in $p.u.$:

$$\mathbf{I_{SG}} = \mathbf{I_s} = \left[i_d, i_q\right]^t; \quad \mathbf{I_r} = \left[i_f, i_g, i_h\right]^t; \quad \mathbf{U_T} = \mathbf{U_s} = \left[u_d, u_q\right]^t$$

Since the equations of power system are written in axes $d,q,0$, which are rotating synchronous, the stator matrix and vectors are transformed in same coordinate system with the help of next expressions:

$$\mathbf{B^t_{ss}} = \mathbf{T_{tb}} \mathbf{B^b_{ss}}; \quad \mathbf{H^t_s} = \mathbf{T_{tb}} \mathbf{H^b_s}; \quad \mathbf{I^t_s} = \mathbf{T_{tb}} \mathbf{I^b_s};$$
$$T_{tb} = \begin{bmatrix} \cos\delta_{tb}; & \sin\delta_{tb} \\ -\sin\delta_{tb}; & \cos\delta_{ij} \end{bmatrix}; \qquad (2)$$

Static active-inductive load

$$\frac{d}{dt}\mathbf{I_T} = \mathbf{H_T} + \mathbf{B_T} . \mathbf{U_T} \qquad (3)$$

Where: the elements of vector $\mathbf{H_T}$ and matrix $\mathbf{B_T}$ are functions of load parameters;

Transmission line

$$\frac{d}{dt}\mathbf{I_L} = \mathbf{H_L} + \mathbf{B_L} . \left(\mathbf{U_T} - \mathbf{U_b}\right)$$

Where: the elements of vector $\mathbf{H_L}$ and matrix $\mathbf{B_L}$ are functions of transmission line parameters;
$\mathbf{U_b}$ - voltage vector of infinity buses.

Reactor from adaptive static var compensator (ASVC)

$$\frac{d}{dt}\mathbf{I_{L.ASVC}} = \mathbf{H_{L.ASVC}} + \mathbf{B_{L.ASVC}} . \mathbf{U_T} \qquad (4)$$

Where: the elements of vector $\mathbf{H_{L.ASVC}}$ and matrix $\mathbf{B_{L.ASVC}}$ are functions of reactor parameters of ASVC.

Equations of connection:

$$\frac{d}{dt}\mathbf{U_T} = \mathbf{A_{C.ASVC}} \cdot \mathbf{I_{C.ASVC}} + \mathbf{U_T} \qquad (5)$$

$$\mathbf{I_{C.ASVC}} = -\left(\mathbf{I_{SG}} + \mathbf{I_T} + \mathbf{I_{L.ASVC}} + \mathbf{I_L}\right) \qquad (6)$$

Where: the elements of vector $\mathbf{A_{C.ASVC}}$ are functions from condenser parameters of ASVC.

III. SYSTEM ADAPTIVE CONTROL

Automatic system for synchronous generator voltage control and speed control

As primary mover for the investigated system is used turbo-generator. For keeping of frequency and regulating of active power is used automatic speed controller (ASC) [2].

The conventional exciting system for generator (IEEE Std. 421.5) is used [4].

The conventional power system stabilizer *CPSS* is consisting of two lead-lag blocks, washout block and gain block [5]. As input signal is use a generator rotor speed deviation - $\Delta\omega$.

Reactor control of adaptive static var compensator (ASVC)

The basic idea of stabilizer is, that the control object can be continuously estimate by linear model of low order and create additional control signal.

In the investigation scheme is used single-input single output (SISO) adaptive singular observer. On the observer inputs is feed discrete parts from compensator voltage U_{MEA} and output of resulting inductivity B_L.

On the fig. 2 is presented block-diagram of controller for *ASVC*. The diagram is consisting from classical *PI* - regulator, group for determination of desired characteristic's slope, OSA observer, limiter for output signal. The OSA observer calculates estimation of parameters and variables of model and is creating additional controlling signal $B_{AO,}$ which is adds to main signal from *PI* -

regulator. In this way is improving the control in whole controlling range.

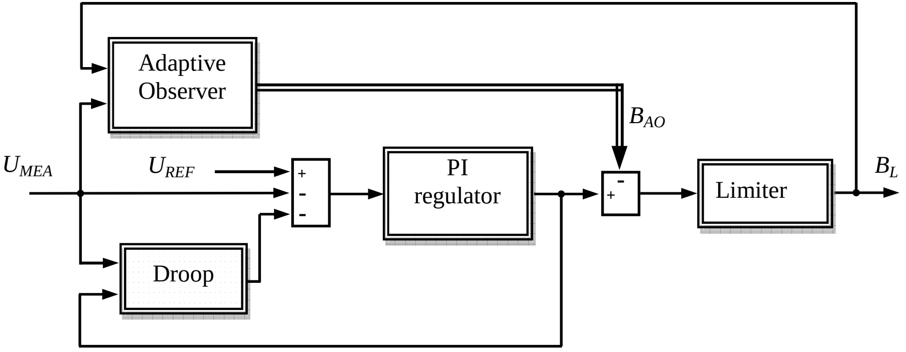

Fig.2. Block diagram of controller for ASVC

The observed system might be present by a following type of a linear model in the state space describing from following differential equations:

$$\boldsymbol{x}(k+1)=A.\boldsymbol{x}(k)+b.\boldsymbol{v}(k), \tag{7}$$

$$\boldsymbol{y}(k)=\boldsymbol{c}^{\boldsymbol{t}}.\boldsymbol{x}(k), \tag{8}$$

$$v(k)=u(k)+z(k), \ \boldsymbol{x}(0)=\boldsymbol{x}_0,\ k=0,1,2,\ldots.;$$

where: $\boldsymbol{x}(k)$, $\boldsymbol{x}(k+1)$ are an unknown current state vector in two neighbour moments of discretization; $\boldsymbol{x}(0)$ is an unknown initial state vector; $\boldsymbol{u}(k)$ is an input signal; $z(k)$ is a limited input sequence for identification.

On the equations (7) and (8) corresponds following difference equation *''input-output"*

$$\begin{aligned}&y(k+n)-a_n.y(k+n-1)-a_{n-1}.y(k+n-2)-\ldots.\\&-a_2.y(k+1)-a_1.y(k)=\\&=h_1.u(k+n-1)+h_2.u(k+n-2)+\ldots. \qquad (9)\\&+h_{n-1}.u(k+1)+h_n.u(k).\\&k=0,1,2,\ldots.,\end{aligned}$$

The investigation [6] shows that for reactor control regulator could be used minimal models from 2-nd order, which ensures high rapidity and sufficient accuracy.

A, ***b*** and ***c*** are unknown matrices and vectors of the following type:

$$\boldsymbol{A}=\begin{bmatrix}\boldsymbol{0} & \boldsymbol{1}\\ \hline & \boldsymbol{a}^{\boldsymbol{t}} & \end{bmatrix}=\begin{bmatrix}0 & 1\\ a_1 & a_2\end{bmatrix};\boldsymbol{b}=\begin{bmatrix}0\\1\end{bmatrix};\boldsymbol{c}=\begin{bmatrix}1\\0\end{bmatrix} \tag{10}$$

The input/output data are shaped in following matrices and vectors.

$$\boldsymbol{Y_1}=\begin{bmatrix}y(0)\\y(1)\end{bmatrix};\boldsymbol{Y_2}=\begin{bmatrix}y(2)\\y(3)\end{bmatrix};\boldsymbol{V_1}=\begin{bmatrix}v(0)\\v(1)\end{bmatrix};\ \boldsymbol{Y_{12}}=\begin{bmatrix}y(0) & y(1)\\y(1) & y(2)\end{bmatrix}$$

The vector estimate $\hat{\boldsymbol{a}}$ is calculate by following expression:

$$\boldsymbol{Y_{12}}.\hat{\boldsymbol{a}}=\boldsymbol{Y_2}-\boldsymbol{V_1} \tag{11}$$

The initial steady state vector $\hat{x}(0)$ estimation is calculated by the optimal estimator of following type:

$$\hat{\boldsymbol{x}}(\boldsymbol{0})=\boldsymbol{Y_1} \tag{12}$$

The current steady state vector is estimates by the degenerate OSA observer:

$$\hat{\boldsymbol{x}}(k+1)=\hat{\boldsymbol{A}}.\hat{\boldsymbol{x}}(k)+\boldsymbol{b}.\boldsymbol{v}(k) \quad \hat{\boldsymbol{x}}(0)=\hat{\boldsymbol{x}}_0$$

$$k=0,\ 1,\ 2,\ \ldots, \tag{13}$$

The determination of formulate problem with the help of suggested algorithm exist only if matrix $\boldsymbol{Y_{12}}$ is singular

$$det\,\boldsymbol{Y_{12}}\neq 0$$

The additional stabilizing signal $\boldsymbol{B_{AO}}$ will be calculated by estimated steady state vector and parameters of model:

$$B_{AO}(p)=-\widehat{\boldsymbol{a}}^{\Sigma}.\widehat{\boldsymbol{x}}(p)=-\widehat{a}_1.\widehat{x}_1-\widehat{a}_2.\widehat{x}_2 \tag{14}$$

After determination of control signal for SVC reactors B_L follow transformation of specific values of B_L into values of firing angle α for thyristors in degrees. This transformation is performed by next expression:

$$B_{Lpu}=(2-2\alpha/\pi+sin(2\alpha)/\pi).B_{Lnom} \tag{15}$$

where: B_{Lpu} - values of B_L converted into real system in per units (*p.u.*); B_{Lnom} – nominal value of B_L.

Thyristor control

The thyristor is a semiconductor device that can be turned on via a gate signal. The thyristor model is simulated as resistor, inductor and DC voltage source representing the forward voltage, connected in series with a switch. The switch is controlled by a logical signal depending on the thyristor's voltage and current and also the gate signal [**7**].

IV. EXPERIMENTAL DATA

For proving correctness and effectiveness of the investigated system was created computer model in *Matlab* space. Different disturbances causing transient processes have been simulated. The simulated transient processes are: three-phase earth short circuit and it's disconnection from circuit breaker, connection/disconnection of powerful static load. The obtained simulations are compared with system of identical parameters with compensator from fixed capacitor and reactor. The parameters of that fixed compensator are same as investigated compensator in steady state mode. It was exanimate cases with CPSS and without CPSS, with ASVC and without ASVC as the results are compared with system with identical parameters with compensator created from fixed capacitor and inductor.

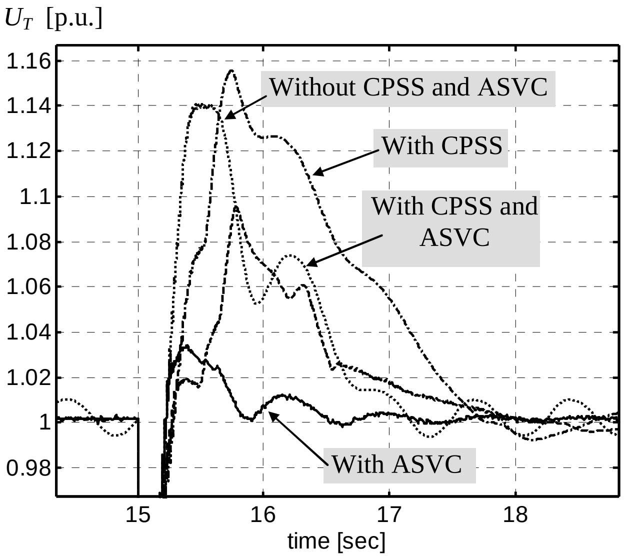

Fig.3. Terminal voltage at three-phase short cut in generator terminals

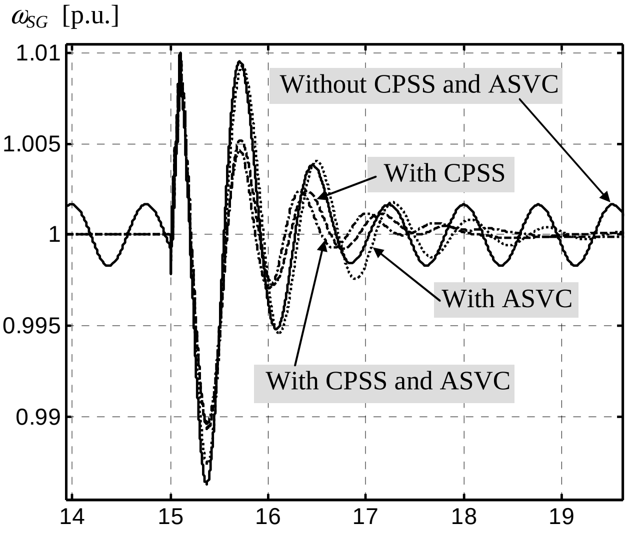

Fig.4. Angular speed of generator at three-phase short cut in generator terminals

V. CONCLUSION

Using the proposed mathematical model investigated the work of power system containing static variable compensator and generator equipped with a conventional system stabilizer. Performed simulations and comparison of results show the effectiveness of damping of low frequency oscillations with different stabilizing devices, as well as in their common work.

Analysis of experimental results shows that the system stabilizer influenced to a greater degree of damping of angular speed oscillation and static variable compensator - a voltage deviation.

Their common works improves damping of both regime parameters.

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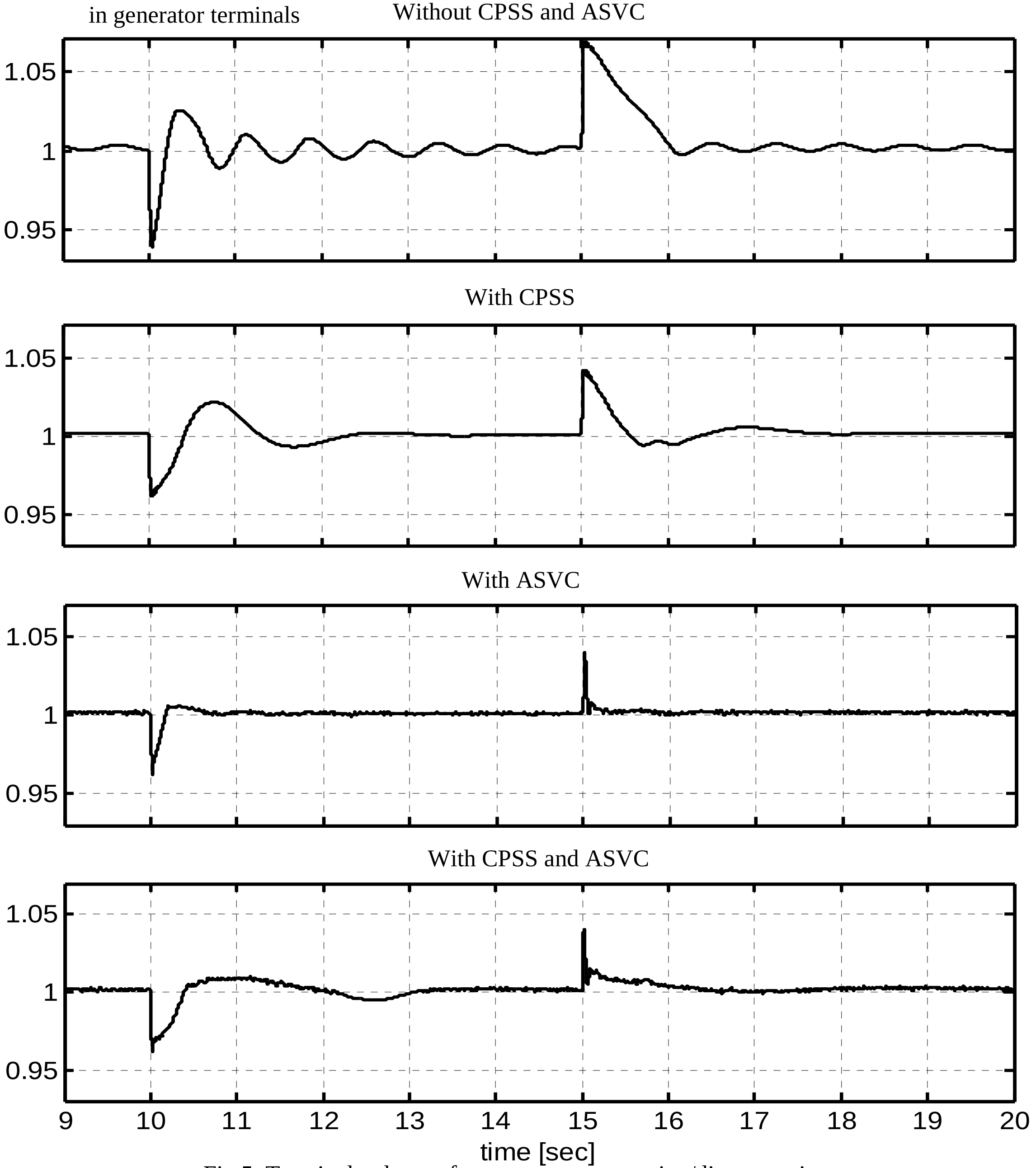

Fig.5. Terminal voltage of generator at connecting/disconnecting of powerful static active-inductive load.

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