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Monitoring Stability Reserve of Power Systems on the Base of the Identifications of the Generator Admittance Matrix for Electro Mutiveforce (EMF)

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KEYWORDS

Steady state operating conditions, transient conditions, post emergency conditions, steady-state stability, simulation condition of power systems, monitoring of stability.

1 INTRODUCTION

The subject of the development is the technology of monitoring of steady-state stability of power systems (PS), founded on the use synchronized measurements of regime parameters in the electric network nodes.

As amount PMU in power system is increasing the quantity of regime parameters being got as a result of synchronized measurements find the all greater using under deciding of the different problems: verification of the digital models of the power systems [1]; increasing quality of the state estimation; monitoring of the transient conditions and participations of the generation set for regulation and others.

This work is dedicated to study the possibilities and particularities of the real-time monitoring limitation of powers given and stability power station reserve in the frame of PS.

Synchronized measurements (the registrations of the transients) of the regime parameters, including vectors of the voltage in the network nodes, create the technical possibility of realization of the technologies for the checking of regime admissibility of PS [2]. The information residing in transient conditions of the mutual moving of synchronous machines rotors allows to form the model for determination of the stability restrictions of the regime PS, take into account the current condition and the actual electric network topology without their observation, and use the model for the supervisor and the automatic control PS.

2 MODEL FOR CHECKING THE STEADY-STATE STABILITY RESTRICTIONS OF THE PS REGIME

PS may be presented as a linear passive multi pole with active nodes, which are the EMF nodes of generators. The load may be presented as a linear transverse element and be included in the linear passive multi pole. This linear passive multi pole (network) may be presented as the square matrix of self-admittances and mutual admittances (SMA) EMF of generators ($\mathbf{Y}$). The equations system (1) describes the regime of n generators [3]:

$$\underline{\mathbf{S}} = \text{diag}\{\dot{\mathbf{E}}\} \cdot \underline{\mathbf{Y}}^* \cdot \dot{\mathbf{E}}^* \quad (1)$$

where $\mathbf{S}$ – matrix of the generators power in points of EMF;

$\underline{E}$ – column matrix of EMF of generators.

Regime each of n generators is defined by expression

$$\underline{S}_i = \dot{E}_i \sum_{j=1}^n \underline{Y}_{ij}^* \dot{E}_j \quad (i=1, 2, \dots, n) \quad (2)$$

where i and j – an indexes, which indicate the number of generator in scheme;

S_i – internal power of the generator i ;

$\dot{E}_i, Y_{ij}$ and $\underline{Y}_{ij}$ – an elements of the matrixes $\underline{E}, \underline{Y}$.

The equation (2) may be presented as:

$$\underline{S}_i = \dot{E}_i \cdot (\dot{\underline{E}}^*)^T \cdot \underline{y}^{(i)*} \quad (3)$$

where $\underline{y}^{(i)}$ – matrix-column (the vector) SMA of generator i , which is identical to row i of the matrix $\underline{Y}$.

The equations (3) for $n-1$ generators form the linear independent equations system for calculation of vector SMA of generators $\underline{y}$, which is got from vectors $\underline{y}^{(i)}$:

$$\underline{S} = \underline{A} \cdot \underline{y}^* \quad (4)$$

$\underline{Y}$ is the symmetrical matrix ($Y_{ij} = Y_{ji}$) so the vector of SMA $\underline{y}$ has dimensionality $(n^2 + n)/2$ or $(n^2 + n - 2)/2$, if one of the generations nodes is taken as the bus of endless power (BEP).

In PS with n generators the quantity of unknown variables of the SMA vector is more the quantity of the independent equations (4), with the exclusion of event of the functioning (working) of the generator without own load on BEP. The system of the equations (4) may be determined by addition of the equations of the power of generators, using the measurements for different moments of the time in the transient conditions.

Unlike of detailed digital model PS, usually used at calculation at steady state operating conditions and transient conditions, matrix SMA EMF of generators has a smaller order, at her identifications is excluded the influence such factors, as mistakes of the telemechanics facilities and of the database of equipment PS. The order of the matrix (the structure of identified models) and inaccuracy of the determination of her parameters depend from nature and intensities of the mutual moving of generators rotors, because for generators with the in phase moving rotors the identification of mutual admittances is impossible on account of $\square\square\square\square \rightarrow 0$.

The Identification of model of the PS regime on base of the matrix of SMA EMF of generators is concluded in decision of the system of the equations (4) with determination $\underline{y}$. EMF of generators for each moment of time are calculate on the base of process recording of the power and voltage on the bus of generator with taking into account the falls of the voltage on the generators impedance.

"Window of identifications" - interval of the time, for which is typical the stability of identifications of variables of the matrix SMA, as a rule have 1-3 s in the electro mechanics transient conditions. The choice of the optimum interval for identifications and the smoothing the results allows to provide the stability and to increase the accuracy of identifications.

It is possible to create the conditions for determination the SMA on the base of one of the principles:

- may be using the processes recording which arise as the result of the sporadic disturbance of the normal regime of PS. In this case, the application of considered models of PS - a checking of admissibility of emergency conditions and after emergency conditions (AEC).
- may be using the processes recording which arise as the result of the artificial influence on the regime of PS, for instance, by the special pulse for unloads of the turbines. In this case provide the checking of the normal regime admissibility.

3 MONITORING OF ADMISSIBILITY OF THE PS REGIME

3.1 Research on mathematical models

The simulation was conducted for PS submitted on the fig. 1.

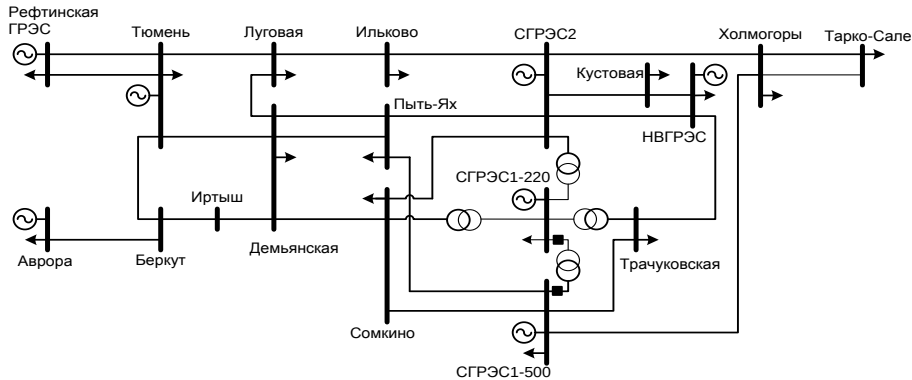


Fig. 1: Scheme of the power system

The calculations of the transient conditions was carried out in program "Mustang" with receiving of the processes recording on the buses of power stations with use of the different models of the load and generator (uncontrolled PS, model of the generator $E = \text{const}$; uncontrolled PS, model of the generator - simplified equations of Park-Gorev; controlled PS with ACV of proportional action; controlled PS with ACV of strong action).

Processing of the transient conditions recordings, procedure of the identifications of the matrix SMA, checking of maximum powers and the restrictions of the steady-state stability AEC were produced in special program, which was written in "Mathcad".

Identification of the actual matrix SMA were executed on result of the calculation of the transient conditions for 3 node equivalent PS, calculation to limiting power one of the generator with provision for change the powers others, using analytical expressions for angular features of the powers generator:

$$P_i = E_i^2 g_{ii} + \sum_{\substack{j=1 \\ j \neq i}}^n (E_i E_j b_{ij} \sin(\delta_i - \delta_j) - E_i E_j g_{ij} \cos(\delta_i - \delta_j)) \quad (5)$$

where P_i – an active power of the generator;

E_i – a module of the vector EDP generator;

g_{ii} and g_{ij} , b_{ij} – accordingly active and reactive forming SMA generator;

δ_i and δ_j – a corners vector EMF generators for vector of the voltage BELP.

On fig. 2 brought graphs of the change given active powers generator and limiting power of the first generator in transient conditions in comparison with result of the making heavier the regime, got on program "Mustang". Making heavier is executed by increase to powers one of the generators under constant powers others, corresponding to their boot in steady state PEC. The Limiting power of the generator in transient conditions was defined at condition constancy corners rest.

The value of transient EDP equal its current importance was taken at each moment of time. Averaged importance's SMA is used in calculation on interval, corresponding to window to identifications. The disturbance was chosen limiting on condition of the conservation to dynamic stability to fix the maximum of the angular feature to active power of the generator in transient conditions.

Identification of the matrix SMA were executed on the results of the calculation of the transient conditions for the equivalent of PS, which contained 3 generators, calculation of the maximum power for one of the generators was carried out with taking into consideration of the changes of others, with using analytical expressions for angular powers of the generator:

$$E_i = \sqrt{\left(U_{\Gamma i} + \frac{Q_{\Gamma i} \cdot x_{\Gamma i}}{U_{\Gamma i}} \right)^2 + \left(\frac{P_{\Gamma i} \cdot x_{\Gamma i}}{U_{\Gamma i}} \right)^2} \quad (6)$$

As is visible on a fig. 2 the ultimate output of the generator is a variable, the change of which in transient depends from the several factors: changes of transient EMF of the generator, the influence of becalming moment, the activity of ACV and complementarily of ultimate outputs of generators. After becalming of electromechanical transient and termination of activity of control systems the ultimate outputs of generators should be established to values, which correspond to conditions of constant voltage on buses of generators or ultimate reactive powers, i.e. to those values, that are retrieved by loading a regime by a traditional method.

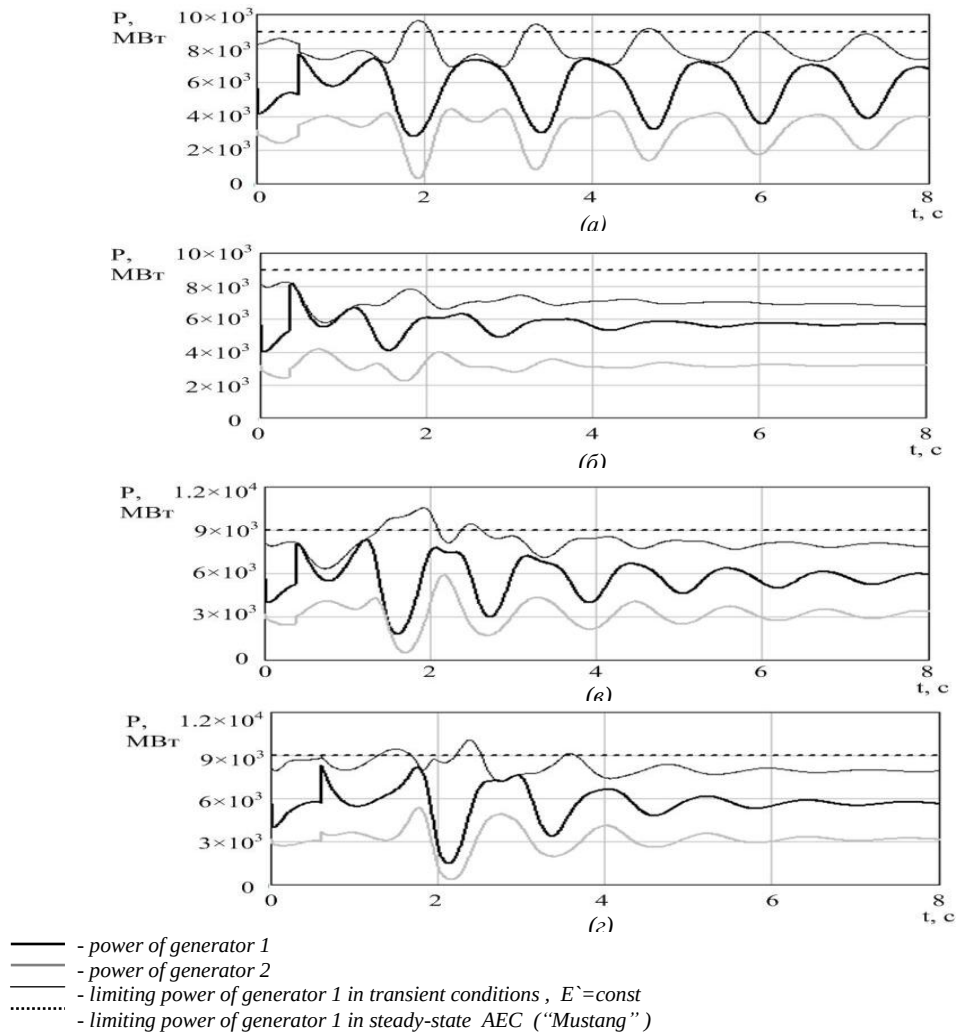


Fig. 2: Comparison of the ultimate output of the generators in transient conditions and of the steady-state stability ultimate output of the generators in AEC for the equivalent of PS, which contained 3 generators, of the scheme (a) - uncontrolled PS, model of the generator - E'=const; (b) - uncontrolled PS, model of the generator - simplified equations Park-Gorev; (c) - with ACV proportional action, (d) - with ACV strong action.

In table 1 for comparison are submitted the ultimate outputs as a result of loading of the generators with taking into account activities ACV and limitations on a reactive power as a result of application of model of regime PS on base of matrix of SMA, and the ultimate outputs of generators as a result of calculation in the program « Mustang». Besides ultimate outputs in the tables is presented the miscalculation of calculation of a limit in relation to the ultimate outputs as a result of loading of generators in the program «Mustang».

Generator	Ultimates output of the generators, got as a result of loading in program Mustang, MW		Limits, got as a result of loading, on the base of identification of the matrix SMA EMF of generators, (MW), and the appraisal of relative inaccuracy of the determination of the limits, %			
	At condition Ug=const	At condition Ug=const with taking into account of restrictions on Qg	At condition Ug=const		At condition Ug=const with taking into account of restrictions on Qg	
			Interval of calculation of average value SMA - 2 c	Interval of calculation of average value SMA - 6 c	Interval of calculation of average value SMA - 2 c	Interval of calculation of average value SMA - 6 c
1	11005	8981	<u>11154</u> 1.35	<u>11024</u> 0.17	<u>9048</u> 0.74	<u>8964</u> 0.19
2	8507	6503	<u>8663</u> 1.84	<u>8549</u> 0.50	<u>6572</u> 1.06	<u>6453</u> 0.77

Table 1: Comparison limit on steady-state stability in steady-state PEC

The source of inaccuracy of the determination of the limit on base of the matrix SMA - a linear model of the load, which is taken into account in matrix SMA as a constant conductivity. The Influence of models of the load on accuracy of the calculation of the limit appreciably in regimes with lowered by voltage.

The Interval of calculation of average value SMA EMF of generators also influence on inaccuracy of the determination of the limits: with increase of this interval, at condition of the stability of matrix SMA, increase the accuracy of the calculation of limits. In the table 1 is visible, with the increase of the interval of calculation of average value SMA to 6 s the inaccuracy of estimation of the limits is decreasing (does not exceed 1%).

The Model for checking for the steady-state stability restrictions of the regime PS on base of the matrix SMA can be adapted to different phases of transient condition of PS [4]. The results of the monitoring of transient conditions admissibility and AEC can be used for adjustment of controlling in real time of the process with the taking into account of the current conditions and the disturbance.

Monitoring of admissibility of regime PS propose the monitoring of a spare of steady-state stability in coordinates of power of generators, which has a following advantages:

- independence from the structure of the network, because is absent the need of monitoring sections of the scheme;
- information saturation, because the structure of the matrix SMA allows to discover the generators with in phase moving, in respect to which exists the threat of the breach of stability, and to define the vector of loading of regime;
- universality - a possibility of monitoring of stability as in transmission network, so in network with distributing of generation; possibility of the use in sidebar of control power generator (for instance, for determination level and rate under long unload of the turbines);
- is absent the need to accommodate measuring in all PS, it is enough to install the recorders only on the buses of power stations .

Aside from monitoring of the restrictions of steady-state stability the monitoring of admissibility of regime PS also include checking of voltage in nodes of the load [5] and power flows in sections. For this it is necessary to execute the identification of relationship between appropriate parameters and EMF of generators. That require of installing of the recorders of SMPR on the substations, being of interest with standpoint of stability of the load, and with lines, being included in sections.

3.2 Research on physical model PS

Check of simulation veracity was conducted on physical models PS (NSTU (a), NIPT (b)) for schemes, which are submitted on fig. 3.

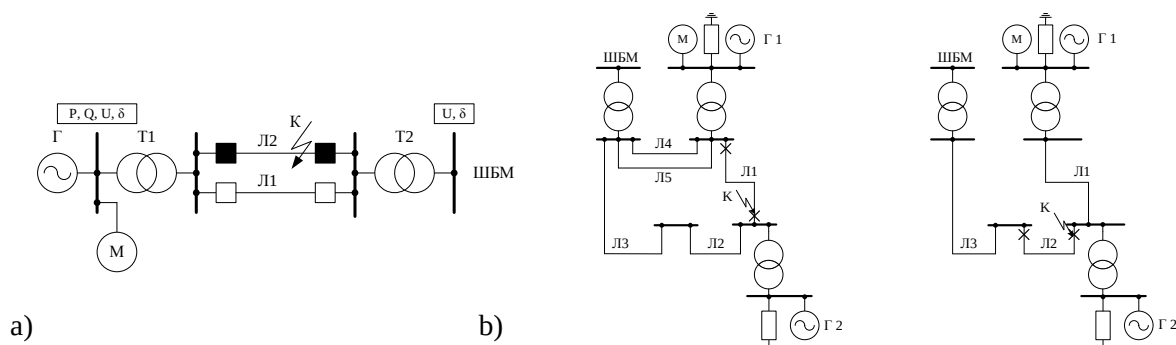


Fig. 3: Schemes of PS, which were used under experimental studies on physical model of PS

Recording of momentary currents and voltages were executed with frequency 2400 kHz. The calculation of active and reactive powers of generators, of effective values of the voltages and mutual corners was executed with step of 20 ms.

Changes of regime parameters in the transient conditions for the simplest scheme of PS (fig. 3(a)) after short circuit at the beginning of line (L2) are presented on fig. 4(a).

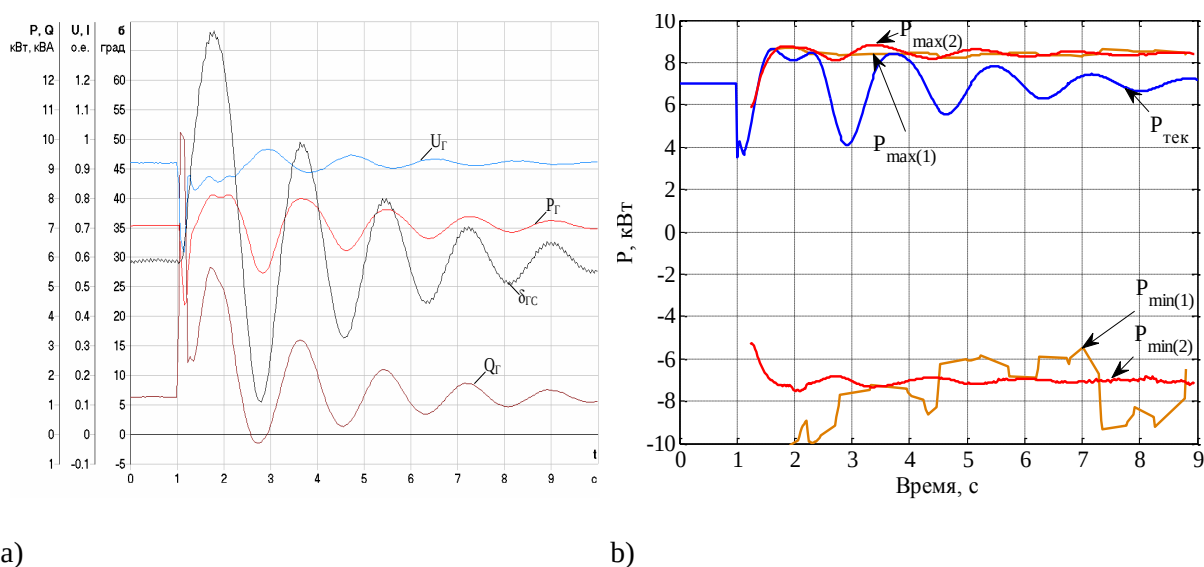


Fig. 4: Results of recording of process 4(a) and the monitoring of the limitings of regime of the generator 4(b) in scheme 3(b)

$P_{тек}$ - a current power of generator, (P_{max} , P_{min}) - an estimation of limits of giving and "consuming" power by the generator. (1) -recording of process is a result of calculation, (2) -recording of process is a result of experiment.

The results of the estimation of ultimate output of the generators, which are got by method of the loading on the base of the matrix SMA and in physical experiment for schemes (fig. 3(b)) with 2 generators, are presented in table 2.

	Method of the loading on the base of the matrix SMA	Physical experiment	
		1 event	2 event
Scheme fig 3(b) left, κW			
$P_{\max}$, κW	4,7	4,57	4,60
$P_{\min}$, κW	-	-0,60	-0,93
Scheme fig. 3(b) ruling, κW			
$P_{\max}$, κW	7,45	7,40	7,46
$P_{\min}$, κBт	1,82	1,63	1,32

Table 2: Ultimate output of the generators as a result of calculation and physical experiment (schemes are presented on fig. 3(b))

4 CONCLUSION

1. The identification of the matrix SMA EMF of generators on base of the measurements SMTC allows forming model of the regime of PS for monitoring of stability and regime admissibility of PS.
2. The results of experiment confirm the possibility of identifications of the matrix SMA and checking of stability in real conditions.
3. Making the system of the monitoring of regime admissibility of PS will allow realizing transition from the control of regime on principle "BEFORE" on the base of beforehand executed calculation of stability to principle "AFTER" the fact of the arising of disturbance.
4. The Results of the monitoring of regimes admissibility PS can be used for adjustment of the restrictions of regimes PS, of necessary influence of controlling in transient conditions.

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