I. INTRODUCTION

Predetermination of the synchronous machine behave our at the transient processes depends to a large measure on the validity of its electromagnetic quantities, among them the equivalent circuits or frequency response characteristics.

In accordance with the IEC Standard [1] the frequency response characteristics of synchronous machines, reflecting their generalized electromagnetic parameters, can be determined from the DC decay test in the stator winding or applied variable frequency voltage tests at standstill. The findings obtained can be used for synthesizing the equivalent circuits in d-axis of the rotor providing the time dependence of the field winding current was recorded in the test as well. However, in this case the contact pressure between the mechanically mated structural elements of the rotor corresponding to the nominal rotational speed is not ensured.

The test of sudden disconnection of the applied armature rated frequency low voltage at low slip [1] requiring the additional energy source and the manual control of the turbine torque is very laborious and is used for determining the synchronous and subtransient reactances. This method makes it possible to determine the frequency response characteristics of the input armature admittance if the linear conditions for the experiment are provided.

Meanwhile, the possibility of determining the electromagnetic quantities of the excitation winding and the damper system from the sudden disconnection of the synchronous machine at the rated voltage from the network had not been considered before. Implementation of the approach to be considered in the paper makes it possible to significantly reduce the labour costs and the time taking to the test.

By way of example the results of determining the parameters of the rotor equivalent circuits and the frequency response characteristic of the input armature admittance of the 889 MVA turbogenerator are given. In the paper the mathematical expressions for determining the rotor electromagnetic quantities by the use of voltage recovery test, impact excitation test with the stator winding open-circuited and field extinguishing test with the stator winding open circuited are exhibited. In contrast to the IEC Standard recommendations the tests are carried out under conditions with the variable saturation level on the path of the main magnetic flux of the SM during the transients.

II. TRANSIENT PHENOMENA EQUATIONS FOR THE TEST CONDITIONS

The analysis of transients in the test was carried out by the use of R.H. Park's differential equations written in theoperational form for the deviations from the steady-state conditions. The equivalent circuit of the rotor in the direct axis constructed in line with the operational equations, as it is seen from the Figure 1, includes the following unusual features: the mutual reactance between field winding and equivalent branches of the damper system on their mutual stray ways (x_{lfD}), the equivalent circuits of the field winding taking into account its skin-effect (r_{if}, x_{lif}) and the direct-axis operational impedance $x_{ad}(p)=Ca[x_{ad}(t)]$.

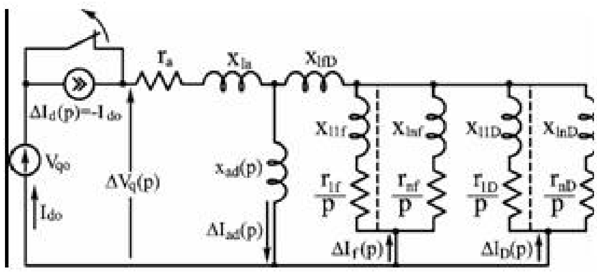

Figure 1. Equivalent circuits of a turbogenerator in d-axis

Neglecting the influence of the transformation EMF in the initial differential equations, and the changes in the rotor rotational speed, provided that the synchronous machine operates with the power factor being equal to zero and that a simultaneous non-arc disconnection of the stator phase windings takes place, we have (in the per-unit system).

III. IDENTIFICATION OF TURBOGENERATOR ROTOR QUANTITIES TAKING INTO ACCOUNT THE INFLUENCE OF SATURATION CHANGES

The mutual reactance between the armature phases and the referred rotor circuits in d-axis of the synchronous machine depends on the saturation level on the path of the main magnetic flux of the machine in d-axis during the transients. As the stator winding voltage changes from V_{qo} to $V_{q\infty}$, the $x_{ad}(t)$ dependence can be determined using $V_q(t)$ experimental dependence and the $x_{ad}(V_q)$ characteristic as it is shown in the Figure 2. The characteristic $x_{ad}(V_q)$ is calculated by application of the open-circuit and short- circuit curves (see Figure 3).

This makes it possible to use the operational method for experimental determination of the rotor parameters of the synchronous machine with variable saturation of its magnetic circuit.

The value of ΔV_f in the expression (3) may be assumed as being equal to zero if power is supplied to the excitation winding of a synchronous machine from the DC generator or the independent excitation system.

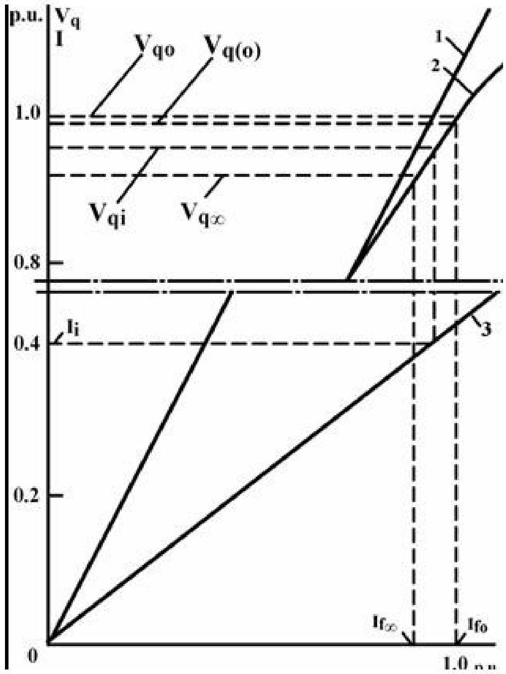

Figure 3. Characteristics of the TBB-800-2 type turbogenerator:
1 – linearized open-circuit curve; 2 – open-circuit curve;
3 – short-circuit curve.

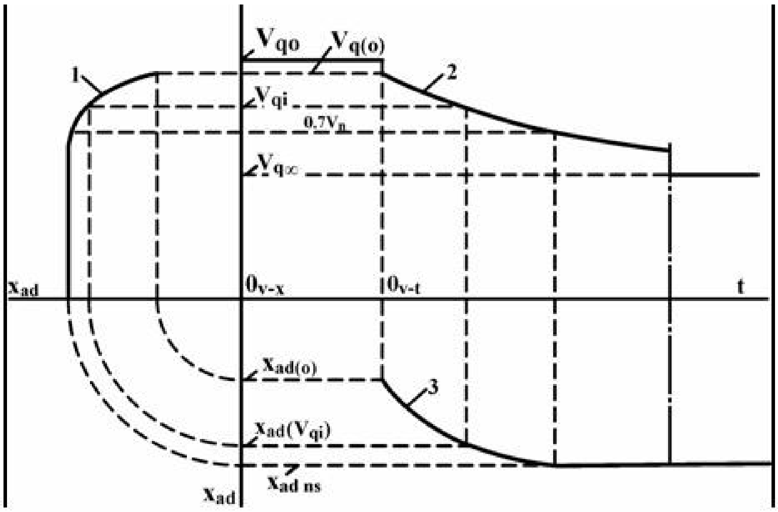

Figure 2. Characteristics of the turbogenerator at the sudden disconnection from the busbars of an electrical system (qualitative consideration): 1 – characteristic $x_{ad}(V_q)$; 2 – envelope of the instantaneous phase voltage values;

The above expressions follow from equating the operational admittances of the excitation winding and the damper system according to the expression (6) and the right-hand sides of equations determined by using the O.Heaviside's expansion theorem.

It should be noted that on physical grounds the experimental unit step functions of voltage $\Delta V(t)$ and current $\Delta I_f(t)$ should be approximated by components with equal damping factors ensuring $\alpha_{if} = \alpha_{iD}$.

IV. EXPERIMENTAL FINDINGS

The results of determining the parameters of the rotor equivalent circuits and frequency response characteristic of the input armature admittance of the TBB-800-2 turbogenerator (S_N = 889 MVA, V_{nom} = 24 kV, I_{nom} = 21.4 kA, cosφ = 0.85, 3000 r.p.m.) are given in the Appendix. At the test of disconnecting the applied operational range voltage the turbogenerator was connected through a transformer (S_{nom} = 1000 MVA) and the air circuit breaker to the busbars of the 330 kV network.

The frequency response characteristic of the input armature admittance of the turbogenerator obtained by the use of sudden disconnection from the busbars of an electrical system, shown in the Figure 4, was compared with the analogous one obtained from the test of DC decay in the armature winding at the motionless state of the generator.

Close inspection of the above mentioned characteristics shows that the difference between their current vectors in the wide range of the frequency ($0.35\cdot10^{-3} < s < 1.0$) is within 6%. It may be safety suggested, the discrepancy between the frequency responsecharacteristics, particularly in the range of relatively high frequency, is attributable to the action of the centrifugal forces due to weakening the end bells fit and increasing the contact resistance between the mechanical conjugations of the revolving edge elements of the rotor [2]. The better accuracy can be achieved by taking into account the mutual reactance between field winding and equivalent damper circuits on the stray ways of mentioned ones (x_{lfD}) busbars. The latter factor is of no essential significance.

V. DETERMINING THE ROTOR QUANTITIES BY THE USE OF A SYNCHRONOUS MACHINE TRANSIENTS ATTHE TESTS PROVIDED BY THE IEC STANDARD

The voltage recovery test, impact excitation test with the stator winding open-circuited and the field extinguishing test with stator winding open-circuited are considered in the Standard [1].

It is evident from analysis of the above tests that the changes of the mutual reactance at the sudden disconnection of the applied voltage and the field extinguishing test can be described by mathematical expressions of the same structure. The similar peculiarity is inherent in the case of voltage recovery test (see Figure 5) and the impact excitation test.

The operational expressions for the mutual reactances and the rotor admittances obtained by analytical consideration of the identification problem raised are given in the Table 1. Electromagnetic parameters of the excitation winding and the damper system can be determined in an analogous way as in the case of the sudden disconnection of the applied operative range voltage.

VI. CONCLUSION

The technique discussed in the paper can be used for analyzing the skin effect in the excitation winding and the damper system. More precise determination of the rotor electromagnetic parameters will also make it possible to improve accuracy of calculating the current distribution between the excitation winding and the damper system in dynamic processes of the synchronous machine. In addition, the new approach extends capabilities of the IEC Standard.

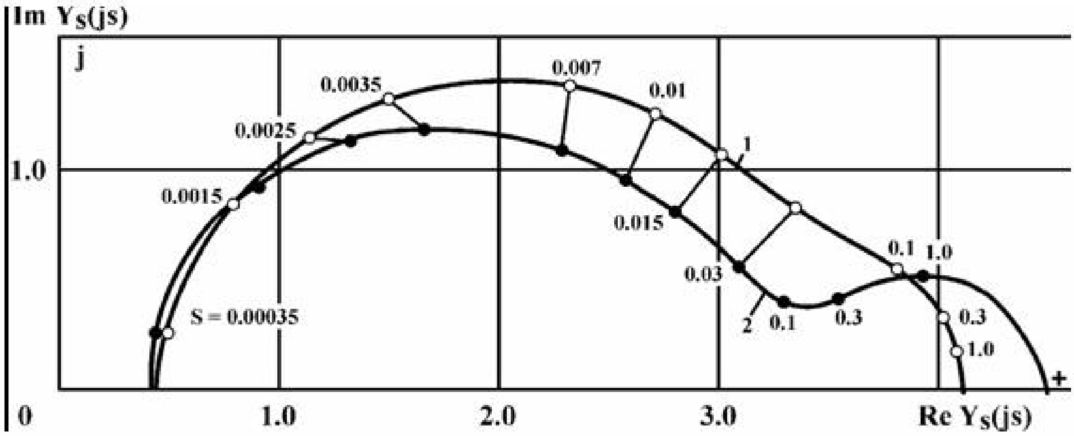

Figure 4. Frequency response characteristics of the TBB-800-2 turbogenerator: 1 – obtained from the sudden disconnection test;
2 – obtained from DC decay in the armature winding at the standstill test.

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