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A Dynamic On-Line Parameter Identification and Full-Scale System Experimental Verification for Large Synchronous Machines

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Abstract: An on-line parameter identification and full-scale experimental verification for large synchronous machines (>50 MVA) is presented in this paper. A step change of excitation is imposed to a generator when the machine is in normal operation. The transient voltages, currents and the power angle are recorded. Based on the large disturbance equations and using the measured power angle as an observation argument in an identification algorithm, the synchronous machine electrical parameters (x_d, x_d', x_d'', T_{do}', T_{do}'', x_q, x_q'', T_{qo}'') and mechanical parameters (H, D) are obtained. In addition, the system parameters (equivalent infinite bus voltage V_{bus} and line reactance x_e) are identified as well. The proposed method has been repetitively applied to turbogenerators and hydrogenerators with capacities up to 300 MVA. In particular, a field test has been conducted on a system with a capacity of 15,000 MVA. The experimental results from all of the full-scale tests are consistent and the effectiveness of the proposed on-line identification method is verified. The plant experiences indicate that by adopting the identified parameters, the stability margin of the generator can be improved up to 5%, resulting in 30-50 MVA more power generation.

Keywords: synchronous machine, parameter identification, stability limit

I. Introduction

The importance of obtaining accurate parameters of synchronous machines (SM) is ever increasing because of the increased power system capacity, especially for developing countries. It is estimated that the installation of new generating units and transmission lines in PR China will be 8-10% more annually based on the existing capacities for the next two decades. Power system stability analysis becomes very critical, and suitable models are needed with accurate system parameters. Due to the complicated nonlinear phenomena of saturation and eddy currents of the generator, the selection of a proper model and the determination of the associated parameters is challenging and stimulating to the engineers and researchers in the power area.

Traditional methods had been developed under the guidance of IEC Standards and some National Electrical Standards from many countries to measure the parameters [1-3]. However, all of these methods are conducted under off-line conditions. Therefore, the parameters obtained by these methods can not truly characterize the generator behavior under various load conditions. The issues and problems associated with off-line measurement for large synchronous machines have long been addressed by many researchers in the 70's, and many methods have been developed to consider the impact of operating conditions upon parameter variations. The on-line methods seemed to be most attractive and favored by the system operation engineers. Since then, a profusion of literature has been published and many contributions made to the on-line parameter identification. Among them, in 1977, C. C. Lee and O. T. Tan used a Least Square Estimation (LSE) to estimate the parameters of a small synchronous machine in lab from the responses of a three-phase short circuit transient [4]. In 1981, M. Nambu used Kalman Filter to estimate the transfer function of a synchronous machine in a local power network [5]. In 1983, R. D. Long used the pseudo-stochastic signal to estimate the parameters of a synchronous machine in a dynamic model [6]. Especially, in 1985, a special task force of IEEE was formed and headed by Dandeno to summarize various frequency and time domain methods used for measuring large synchronous machine parameters. These parameters are used in a machine model for which stability studies are undertaken. Many valuable suggestions were made which contributed greatly towards the on-line parameter identification schemes[7].

Although research on the on-line parameter identification today is not as active as nearly a decade ago, certain work is still going on [8-10] with regard to the three major problems concerning large synchronous machines. Among the three problems, the first is the dilemma for how to select a properly defined input signal for on-line parameter identification. That is, while an oversized input signal may disturb the system dramatically and possibly fail the generator in normal operation, a weak input signal is unable to excite all the inner modes of the generator, resulting in insufficient information for parameter identification; the second is how to select identifying model. While a complete model might not be available for on-line identification, an over-simplified one is not able to reflect the real situation of a generator during transient; and the final and also the most important one is how to verify the effectiveness of the estimated parameters on a large scale system.

Since 1987, much of the research work at Tsinghua University in PR China has been made to solve the three problems mentioned previously, with particular emphasis placed on effective on-line parameter identification and experimental validation using full-scale system testing [11-14]. The type of disturbance selected for parameter identification in this paper takes full advantages of the excitation change of the generator itself being identified. That is, a step change of excitation is imposed on the generator while in normal operation. The transient voltages, currents and the field voltage together with the power angle are recorded. Based on the model of large disturbance equations and using the power angle as an observation argument, the electrical parameters (x_d, x_d', x_d'', T_{do}', T_{do}'', x_q, x_q'' T_{qo}'') and mechanical parameters (H, D) are estimated by an extended LSE technique. In addition, the system parameters (equivalent infinite bus voltage V_{bus} and line reactance x_e) are identified as well. At present, this on-line parameter identification method has been repetitively used to 100 MVA, 200 MVA, 300MVA turbogenerators and 50MVA, 75 MVA, 300 MVA hydrogenerators. In particular, a system test has been made on a large scale system with 15,000 MVA capacity in the Northeast region of PR China. The experimental results from all of the full-scale tests are consistent and the effectiveness of the proposed on-line identification method is verified. In effect, the model and the associated parameters identified by the proposed method closely describe the dynamic behavior of the generator as well as that of the system. The plant experiences indicate that by adopting the new parameters, the stability margin of the generator when connected to the system can be improved up to 5%, resulting in 30-50 MVA more power generation.

The research topics regarding the parameter identification for large synchronous machines are comprehensive and research activities have been conducted for seven years at Tsinghua University. This paper is only concerned with the on-line parameter identification algorithm and its full-scale system experimental

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verification. The paper is organized as follows. First, a set of incremental equations for a large synchronous machine are summarized, and the identification algorithm using the extended Least Square Estimation method is discussed; second, the algorithm implementation and testing results are presented; third, procedures and results of a full-scale system experimental verification are given. Finally, a summary of the contributions are presented dealing with on-line estimation.

II. Model of Synchronous Machine

To estimate the parameters of a large synchronous machine, suitable dynamic equations must be chosen. The incremental equations characterizing the d-axis, q-axis and motion behavior are derived in this section. The following classical assumptions are made as a starting point: i) there is one equivalent damper circuit in d- and q-axis respectively; ii) the time constant of damper winding is much smaller than that of the excitation winding; and iii) $p\lambda_q=0$ and , $p\lambda_d=0$ implying that the flux linkages along the d- and q-axes can not be changed instantaneously.

A. Incremental D- and Q-Axis Equations

When a synchronous machine is operated in steady state, a perturbation can be applied to the machine so that incremental voltages, currents and power angle are generated. These incremental variables are best expressed by the incremental equations, and contained in these equations are the synchronous machine parameters which authentically describe the machine characteristics around the operation point. Along the D-axis, the incremental equations are found to be

$$\frac{d\Delta E'_q}{dt} = \frac{1}{T'_{do}} \Delta E'_q - \frac{x_d - x'_d}{T'_{do} x''_d} \Delta E''_q + \frac{x_d - x'_d}{T'_{do} x''_d} \Delta V_q + \frac{k}{T'_{do}} \Delta V_{fd} \tag{1}$$

$$\frac{d\Delta E''_q}{dt} = \left(\frac{1}{T''_{do}} - \frac{1}{T'_{do}}\right)\Delta E'_q - \left(\frac{1}{T''_{do}} + \frac{x_d - x'_d}{T'_{do} x''_d} + \frac{x'_d - x''_d}{T''_{do} x''_d}\right)\Delta E''_q$$
$$+ \left(\frac{x_d - x'_d}{T'_{do} x''_d} + \frac{x'_d - x''_d}{T''_{do} x''_d}\right)\Delta V_q + \frac{k}{T'_{do}} \Delta V_{fd} \tag{2}$$

$$\Delta i_d = \frac{1}{x''_d} (\Delta E''_q - \Delta V_q) \tag{3}$$

$$\text{with} \quad \Delta E'_q(0) = 0 \text{ and } \Delta E''_q(0) = 0 \tag{4}$$

where ΔV_q, ΔV_{fd} are the inputs. $\Delta\, i_d$ is the observable output. x_d, x'_d, x''_d, T'_{do}, T''_{do} and $k = x_{ad}/R_{fd}$ are the parameters to be estimated.

Similarly, the incremental equation along the Q-axis can be found:

$$\frac{d\Delta E''_d}{dt} = -\frac{x_q}{T''_{qo} x''_q} \Delta E''_d - \frac{x_q - x''_q}{T''_{qo} x''_q} \Delta V_d \tag{5}$$

$$\Delta i_q = \frac{1}{x''_q} (\Delta E''_d + \Delta V_d) \tag{6}$$

$$\text{with} \quad \Delta E''_d(0) = 0 \tag{7}$$

where ΔV_d is the input, $\Delta\,_q$ is the observable output, and x_q, x''_q and T''_{qo} are the parameters to be estimated. The primary reason to choose the incremental equations as the framework is to emphasize the dynamic behavior of a machine and avoid calculating the initial conditions of the state variables.

Equations (1) through (7) are derived from the classical d-q equations for a synchronous machine when the machine is primarily operated in steady state but subject to perturbations. Under such circumstances, the machine variables change around the operation point. Refer to [16] for detailed derivation of the incremental equations.

B. Incremental Motion Equations

To describe a large synchronous machine completely from the system point of view, we further assume that the large synchronous machine is connected to an infinite bus V_{bus} through a line reactance x_e as shown in Fig. 1.

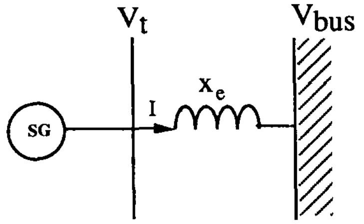


Fig. 1 System diagram for single machine to infinite bus

In order to estimate the parameters associated with the system, the incremental motion equations are needed. Since we can only measure the power angle δ_t in test, various angles and angular velocities can be related to δ_t by the following equations:

$$\omega = \frac{d\delta_t}{dt} + \omega_t \text{ and } \omega_t = \frac{d\theta}{dt} + \omega_c \tag{8}$$

where ω is the angular velocity of the rotor, ω_t is that of the terminal voltage V_t, ω_c is that of infinite bus V_{bus}, and θ is the angle between V_t and V_{bus}. The angular relationship is best illustrated by the phasor diagram in Fig. 2.

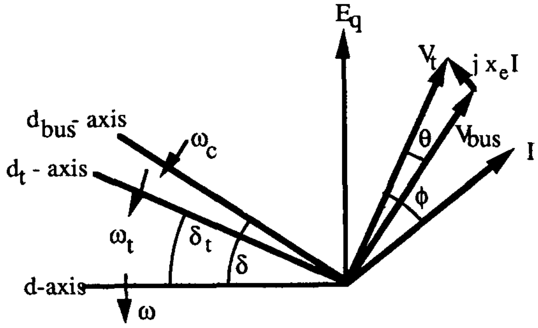


Fig. 2 Relationships between angles and velocities

The line equations of the system are

$$V^2_{bus} = V^2_t + (I\, x_e)^2 - 2 V_t\, I\, x_e \cos(90^\circ - \phi) \tag{9}$$

$$\text{or} \quad V_t = b_1 V^2_{bus} + b_2\, x_e^2 + b_3\, x_e \tag{10}$$

where, $b_1 = \frac{1}{V_t}$, $b_2 = -\frac{I^2}{V_t}$ and $b_3 = 2\, I \cos(90^\circ - \phi)$.

The system parameters V_{bus} and x_e can be derived by linear regression from the inputs of V_t, b_1, b_2 and b_3. Then, the transient of θ can be determined from the phasor diagram as shown in Fig. 2. The transient of ω_t is obtained from equation (8). Therefore, the final motion incremental equations are:

$$\frac{d\Delta\omega}{dt} = -\frac{1}{H}(\Delta M_e + D\Delta\omega) \tag{11}$$

$$\frac{d\Delta\delta_t}{dt} = \Delta\omega - \Delta\omega_t \tag{12}$$

with the initial conditions

$$\Delta\omega\,(0) = 0, \quad \Delta\omega_t(0) = 0, \quad \text{and} \quad \Delta\delta_t(0) = 0 \tag{13}$$

where ΔM_e and $\Delta\,\omega_t$ are inputs; $\Delta\delta_t$ is the observable output, H is the inertia constant of the machine set; and D is the mechanical damping coefficient (dimensionless). Both H and D are the parameters to be estimated.

Note that Eqs. (1)-(13) describe the synchronous machine not only in terms of the electrical variables but also the motion variables. In addition, this set of equations are augmented to such extent that the system parameters V_{bus} and x_e are also included. It may be anticipated that parameter identified from Equations (1)-(13) are very representative when the behavior of the synchronous machine connected to a large system is concerned. Indeed, the parameter identification and its large system experimental verification is to be discussed in later sections.

III. Parameter Identification Algorithm

The entire parameter identification algorithm for large synchronous machines presented is established by the following state space equations:

$$\dot{X}_m = A(\alpha)X_m + B(\alpha)U$$
$$Y_m = C(\alpha)X_m + D(\alpha)U \tag{14}$$

where X_m is the state variable vector; Y_m is the observable output vector, U is the input vector, and $\alpha=(\alpha_1, \alpha_2, ..., \alpha_n)^T$ is the parameter vector to be estimated. $A(\alpha)$, $B(\alpha)$, $C(\alpha)$, and $D(\alpha)$ are matrices associated with α.

According to the extended Least Square Estimation theory, if the initial value $X_m(t_0)$ is known, then the estimated values of α must satisfy an object function $J(\alpha)$, where

$$J(\alpha) = \int_{t_0}^{t_f} (Y_r - Y_c)^T R\, (Y_r - Y_c) dt = \mathbf{\mathit{min}} \tag{15}$$

with Y_r the real output vector of the system, Y_c the calculated output vector of the system relevant to the parameter vector α, and R a diagonal positive-definite weighted matrix [15]. Theoretically, α could be found by solving

$$\frac{\partial J(\alpha)}{\partial \alpha^T} = 0 \tag{16}$$

Since it is very difficulty to solve Equation (16) directly, we can find an alternative way to solve it numerically. First, replace $Y_c(\alpha)$ by its Taylor's expansion, neglecting the higher order terms,

$$Y_c(\alpha) = Y_c(\alpha_0) + \left(\frac{\partial Y_c}{\partial \alpha^T}\right)_{\alpha_0} (\alpha - \alpha_0) \tag{17}$$

and let $\Delta\alpha=\alpha-\alpha_0$. Then, substituting $\Delta\alpha$ and Equation (17) into Equation (15) , we obtain

$$J(\Delta\alpha)_{\alpha_0} = \int_{t_0}^{t_f} [(Y_r - Y_c(\alpha_0) - \left(\frac{\partial Y_c}{\partial \alpha^T}\right)_{\alpha_0} \Delta\alpha)^T R$$
$$(Y_r - Y_c(\alpha_0) - \left(\frac{\partial Y_c}{\partial \alpha^T}\right)_{\alpha_0} \Delta\alpha)]\, dt \tag{18}$$

which is called a quasi-objective function. The estimated value of parameter α is assumed to satisfy

$$\frac{\partial J(\Delta\alpha)}{\partial \alpha^T} = 0 \tag{19}$$

From Equation (19), we have

$$\Delta\alpha = \left(\int_{t_0}^{t_f} \left(\frac{\partial Y_c}{\partial \alpha^T}\right)^T_{\alpha_0} R \left(\frac{\partial Y_c}{\partial \alpha^T}\right)_{\alpha_0} dt \right)^{-1} \bullet$$
$$\int_{t_0}^{t_f} \left(\frac{\partial Y_c}{\partial \alpha^T}\right)^T_{\alpha_0} R\, (Y_r - Y_c(\alpha_0))\, dt \tag{20}$$

If Equation (19) is completely equivalent to Equation (16), the estimated value can be derived easily by

$$\alpha = \alpha_0 + \Delta\alpha \tag{21}$$

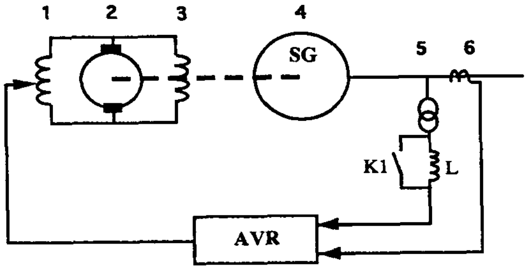
Unfortunately, this is not the case. In general, iteration is needed in the form of

$$\alpha_{k+1} = \alpha_k + G\, \Delta\alpha_k \tag{22}$$

to search for the values of α until $J(\Delta\alpha)_{\alpha k}$ falls within a chosen error limit, where G is a diagonal matrix with its main elements $0 < g_{ii} < 1$. The convergence of the iteration is ensured by choosing the designed value of α as the starting value for iteration. Refer to [15] for detailed derivation of Equations (14) - (22).

IV. Algorithm Implementation and Estimation Procedures

The equations derived in Section III and the estimation algorithm established above form the core for implementing the on-line parameter identification scheme. The algorithm is realized by a computer program and the inputs as specified in Eqs. (1) through (13) are directed to the software to start the program execution. Since this is an on-line parameter identification method, a properly connected system and a properly selected perturbation signal are essential. Fig. 3 shows the schematic connection of a large synchronous machine to be estimated. It is seen that a switch "K1" has been placed in the system to initiate perturbation signal. In order to give a sufficient perturbation so as to excite the inner modes but, at the same time, not to affect the synchronous generator normal operation, a particular excitation change is designed.



1- feild winding of excitor, 2 - excitor, 3 - field winding of generator, 4 -generator, 5 - PT, 6- CT, L- variable inductance, K1-switch

Fig.3 The principle diagram of excitation perturbation of SM

Before perturbation, open switch K1 and adjust the variable inductor L so that the machine operates in steady-state. Then, close K1 rapidly so as to change the excitation voltage suddenly to produce a reactive power perturbation.

The typical sequence to carry out a cycle of parameter identification is as follows:

a) connect the generator to a large power system and load it with a normal condition;
b) apply a sudden change of excitation by turning on or off Switch K1;
c) record the transients of line voltage V_{ab}, V_{cb}, phase currents i_a, i_b, and i_c, field voltage V_{fd} and power angle δ_t on a tape recorder;
d) input the acquired data to the computer and estimate the parameters immediately by the just mentioned algorithm.

Since 1988, the parameter identification method has been used repetitively in 100MVA, 200MVA, 300MVA turbogenerators

Table 1. Designed and identified parameter values for four large synchronous machines

		x_d (pu)	x_d' (pu)	x_d'' (pu)	T_{do}' (sec)	T_{do}'' (sec)	k	x_q (pu)	x_q'' (pu)	T_{qo}'' (sec)	H (sec)	D	V_{bus} (pu)	x_e (pu)
#1	Dsig.	1.806	0.286	0.183	6.2	0.24,	1271	--	--	--	9	3	1.22	--
	Esti.	1.414	0.333	0.208	5.85	0.194	1552	1.302	0.396	0.955,	11.2	1.89	0.99	0.016
#2	Dsig.	1.932	0.24	0.141	6.58	0.1	--	--	--	--	8.5	--	--	--
	Esti.	1.755	0.318	0.184	5.15	0.078	1475	1.258	0.557	1.284	7.2	0.61	1.01	0.154
#3	Dsig.	0.879	0.303	0.202	6.45	--	--	0.602	0.206	--	11.0	3	--	--
	Esti.	0.699	0.342	0.276	4.11	0.285	1700	0.46	0.28	0.08	10.6	1.07	0.95	0.101
#4	Dsig.	1.09	0.34	0.229	8.51	0.115	270	0.728	0.234	0.249	8.03	5	1.0	0.1
	Esti.	0.949	0.473	0.351	7.26	0.124	577	0.322	0.119	0.065	11.2	3.43	0.89	0.173

#1) 100MVA #2) 200MW turbogenerators, #3) 75MVA #4) 300MW hydrogenerators

and 50MVA, 75MVA, and 300MVA hydrogenerators of PR China. The results of on-line identification of four generators in 100MVA, 200MVA turbogenerators and 75MVA, 300MVA hydrogenerators are summarized in Table 1.

The validity of the identified parameters is proved by comparing the simulated transients using the identified parameters with respect to the tested transients. Figs. 4, 5 show the transient currents i_d and power angle δ_t respectively. In these figures, the thick lines representing the tested transients and the thin lines are the simulations with the estimated parameters. It is very clear that the tested and the estimated results are in favorable agreement, indicating the accuracy of the identified parameters. For the purpose of comparison, the simulation results using the design parameters provided by the manufactures are also plotted against the tested results. As shown in Figs.6 and 7, the difference between the simulated and tested data is substantial.

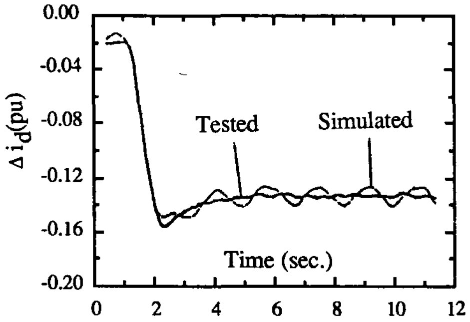


Fig. 4. Measured and simulated i_d with identified parameters (100MW Turbo.)

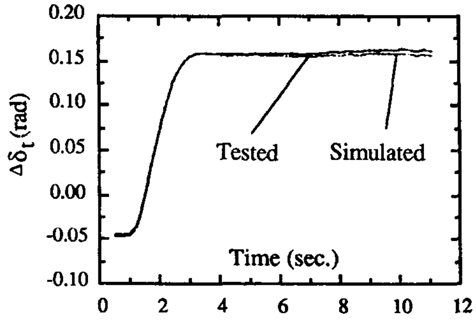


Fig.5. Measured and simulated δ_t with identified parameters (100MW Turbo.)

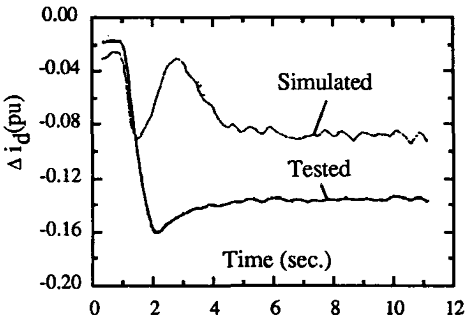


Fig. 6. Measured and simulated i_d with designed parameters (100MW Turbo.)

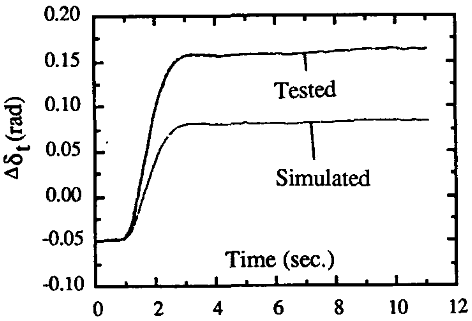


Fig. 7. Measured and simulated δ_t with designed parameters (100MW Turbo.)

From the identified parameters for the aforementioned large synchronous machines, we can conclude the following:

1) In addition to the traditionally identified electrical parameters, the mechanical parameters (H, D), and the system equivalent parameters (V_{bus}, x_e) can be successfully estimated by using the approach. The number of estimated parameters can be as many as 12;

2) The values of the estimated parameters x_d and x_q with saturation and eddy current effects included are 25% smaller than the designed nominal values for hydrogenerators and 15-25% for turbogenerators.

3) For a round-rotor generator, x_d is about 14% greater than x_q.

V. Large Scale System Experimental Verification

Note that the above conclusions are made regarding the parameters of a synchronous machine itself. As far as the final purpose of parameter identification concerned, it is far more important to emphasize the use of the identified parameters for system evaluation, such as system stability limit, power flow, economic planing, etc. than the synchronous machine performance evaluation alone. Therefore, it is very critical to verify the validity of the identification algorithm and identified parameters using a large scale system experimental testing. To this end, a special large scale system (15,000MVA) test was conducted in Sept. 1992 in Tongliao Power Station in PR China. The actual system structure diagram, a typical example of a single machine tied to an infinite bus, is shown in Fig. 8. The large system experimental verification include three major tasks: a) machine terminal response verification, b) power system oscillation verification and c) system stability analysis.

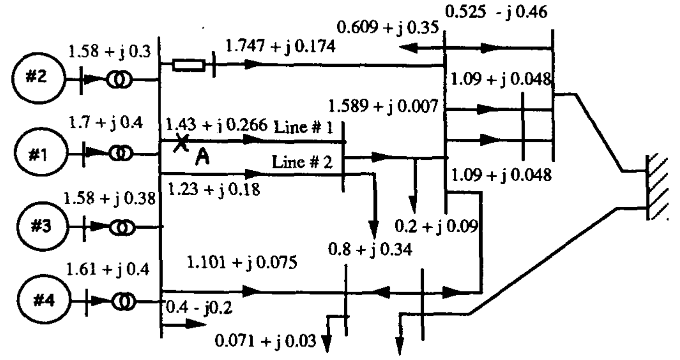


Fig. 8 Power flow diagram in Tongliao region during testing

A. Machine Terminal Response Verification

The large scale system test is proceeded with a perturbation imposed on the system. That is, Line $1^\#$ (three phase), about 5 kilometers long from Tongliao Power Station to the transformer substation, was suddenly cut off from the system by opening the switch at location "A" in a no-fault manner. About 1,000MW active power through Line #1was immediately transferred to Line #2 which is in parallel to Line #1. Line #1 then is restored to the system in 1 minute. During this interval, the corresponding transients were recorded simultaneously for all machines, and the parameters of generator #2 is estimated. In the second step, the identified and the designed nominal parameters are both used to simulate the terminal responses of Generator #2 by EMTP, and the results are shown in Figs. 9 and 10. It is evident that the simulated i_d and the power angle δ_t using the identified parameters are very close to the recorded transients while the simulated ones using the designed nominal parameters substantially deviate from reality. Since this test is conducted with the machine connected to a large system, the parameters identified under such a circumstance are representative for the system analysis application.

B. System Power Oscillation Verification

For the same transient condition stated above, the system power oscillation are investigated. The recorded currents, voltages and power flow are used to verify the accuracy of the identified parameters. Note that since 12 parameters have been identified through the identification algorithm, the use of E_q''-model (Eqs. 1,2,5) to predict the power system oscillation is fully warranted. The identified parameters are used in EMTP simulation for the power oscillation prediction and the result is plotted against the actually measured one in Fig. 11. As opposed to E_q''-model, another EMTP simulation is done using E'_q-model (Eq. 1) with the parameters provided by the manufacture and the result is shown in Fig. 12. It is very clear that the result with the on-line identified parameters is far better than that by the simple E_q'-model with the given parameters. The power oscillation of generator #2 is further summarized swing by swing in Table 2. It can be observed that although both simulations predicted the first swing well, the simulation using E_q''-model with the on-line identified parameters is obviously much more accurate than E_q'-model simulation for the next several swings. It is with the identified parameters that E_q''-model can be effectively used.

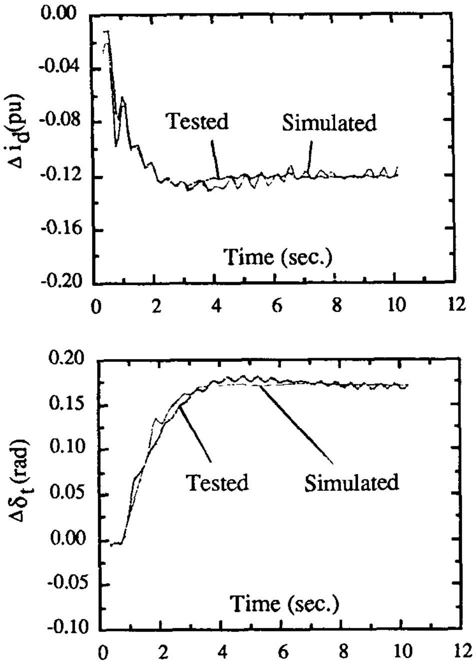


Fig.9 Measured and simulated (with identified parameters) i_d and δ_t

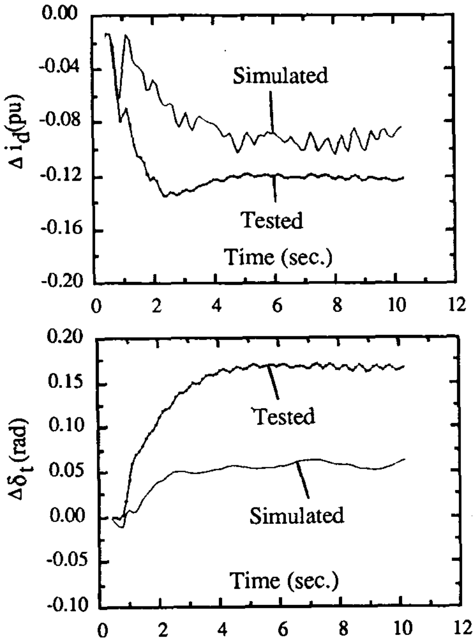


Fig.10 Measured and simulated (with designed parameters) i_d and δ_t

C. System Stability Analysis

Since the parameters are verified by the terminal responses and the system power oscillation test in a large scale system testing, the parameters are very reliable to be used for stability prediction under various fault conditions. The system stability limits under fault conditions, such as three-phase line-to-ground, and single-phase line-to-ground, are evaluated by computer simulation for the four turbogenerators (200MVA/unit) in Tongliao Station. Table 3 summaries the results.

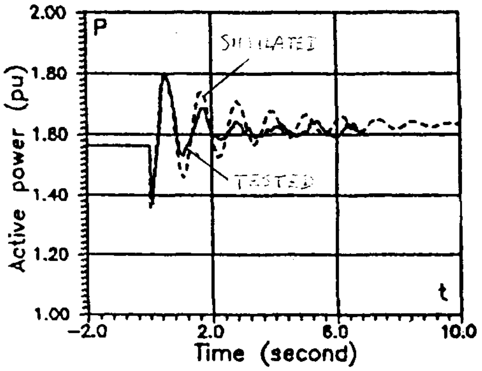


Fig. 11. Prediction of power oscillation with model E_q''

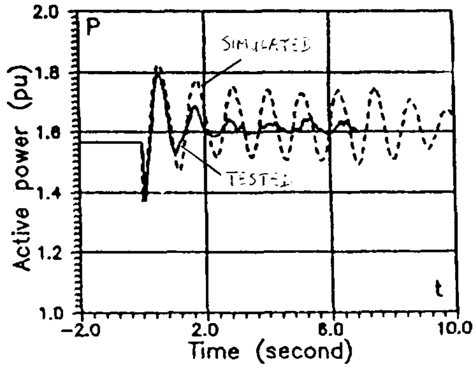


Fig. 12. Prediction of power oscillation with model E_q'

Table 2: Power oscillation analysis of output active power in Tongliao Power Station

Model	1st swing	2nd swing	3rd swing	4th swing	# of swings
Eq'	0.5/1.823	1.7/1.776	2.9/1.754	4.0/1.738	sustained
Eq"	0.5,/1.802	1.7/1.724	2.8/1.683	3.9/1.663	8
Real	0.52/1.801	1.72/1.689	2.8/1.6445	3.9/1.678	6

Note: numerator/denominator = second/amplitude

Table 3. Stability limits of turbogenerators in Tongliao Station

	Three-phase cut off	Single-phase line-to-ground
Model E_q', P_{m1}	742 (MW)	728 (MW)
Model E_q'', P_{m2}	782 (MW)	757 (MW)
$\Delta P=P_{m2}-P_{m1}$	40 (MW)	29 (MW)
$\Delta P/P_{m1}$ (%)	5.29	4.02

The calculated results show that the total output from Tongliao Station can be increased by 4-6% (30-44 MW), taking various types of fault conditions into consideration. Presently, Tongliao Station is taking the full advantage of the results, and more electricity, valued at about 8 million dollars per year, is generated.

In another case, a load (winter season operation) condition with fault conditions is investigated. The results are summarized in Table 4. Again, using the on-line identified parameters and E_q''-model, the stability limit has been found 4-6% more than that previously predicted by E_q'-model with the manufacture given parameters.

VI. Conclusions

This paper presents a dynamic on-line parameter identification algorithm and its full-scale system experimental verification. The following conclusions have been reached:

Table 4. Stability limits for turbogenerators in Tongliao Station

	fault 1	fault 2	fault 3	fault 4
E_q', P_{m1}	715 (MW)	709 (MW)	723 (MW)	>800 (MW)
E_q'', P_{m2}	759(MW)	735 (MW)	767 (MW)	>800 (MW)
$\Delta P=P_{m1}-P_{m2}$	44(MW)	26 (MW)	44 (MW)	/
$\Delta P/P_{m1}$ (%)	6.15	3.66	6.08	/

fault 1 three-phase cut-off, fault 2 single-phase permenet line-to-ground, fault 3 single-phase cut-off, fault 4 single-phase broken suddenly

1). The on-line parameter identification algorithm is very convenient to be carried out on site and the number of identified parameters can be as many as 12, including electrical and mechanical ones as well as those of the electrical power system.

2). For on-line identification, the effects of saturation and eddy current in a generator are automatically included. Compared to the parameters given by the designer or off-line estimations, the identified parameters from the on-line identification procedure are more accurate.

3). E_q''-model combined with the identified parameters can be conveniently used for stability limit prediction and more closely account for the complicated behavior of a large synchronous machine than the E_q'-model.

For a long period of time, due to the lack of correctly identified parameters, the analysis and estimation of a system transient stability have relied on the E_q'-model with the nominal parameters provided by the manufactures. For the first time in PR China the work presented in this paper provides reliable evidence for the utility companies that E_q''-model with the estimated parameters are much more effective than E_q'-model with typical manufacture given parameters. Consequently, utility companies can now explore the advantages of on-line estimation which should result in increased power production and larger stability margins.

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