

UNIQUE SOLUTION FOR DYNAMIC PARAMETERS IDENTIFICATION OF A SYNCHRONOUS MACHINE USING DC DECAY TEST

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***Abstract:** Dynamic modelling of synchronous generators has an enormous significant in power system studies. The DC decay test is one of a basic conventional method applied for determining the dynamic parameters of synchronous machines. The conventional curve fitting methods yield to non-unique and inaccurate solutions depending on the initial guesses and nature of the numerical methods. In this paper, the test is performed on a conventional synchronous machine. A genetic algorithm-based method is then applied for identifying uniquely the parameters of a new fitness function yielding to most precise transient and normal operating results.*

***Keywords:** Synchronous Generator, Dynamic Parameters, DC Decay Test, Genetic Algorithm*

1. Introduction

Parameters Identification of synchronous machines is very important for analysis of both steady state and transient performances of generating units [1]. There have been many researches for characterizing two-axis models of synchronous machines using numerous sorts of tests [2]. The computational methods are used to identify the synchronous machines parameters in some works [3-

4]. An accurate modelling of synchronous machines requires both practical and accurate mathematical simulations [5]. The test-based methods are expensive, time consuming and usually confer approximated or inaccurate values for dynamic parameters. Errors in the experimental results are unavoidable because of existing tolerances of the test rig instruments and simplifying approximations employed in the measurement process.

In this paper, the DC decay test is performed to measure the stator currents in d and q position when a direct current decays in the short circuited stator winding. The purpose of the most methods using the DC decay test is identifying the dynamic parameters. In many circumstances these parameters are neither accurate nor unique. In this paper by defining the new fitness function, the genetic algorithm based method is developed to solve the problem with a unique solution and less approximation (more accurate). A 0.65^{kVA} machine is used for experimental purpose to determine the steady state and transient conditions parameters using DC decay test currents and the proposed curve fitting approach.

2. DC Decay Test Process

A DC current in the stator winding could be

created by connecting the stator to a DC voltage source. This current decays after the voltage reach to zero which can explain the dynamic behavior of the machine. The machines dynamic parameters could be derive by processing the current reduction in the stator winding. Since the current reduction affected by rotor position, the DC decay test is usually performed in direct and quadratic states separately. Each test consequents the dynamic parameters of related own axis.

The most suitable configuration of DC decay test is shown in figure 1, which involves three phase of the stator. When the rotor winding is parallel with stator flux, the test consequents the d-axis parameters and the q-axis parameters are obtained when the rotor winding is vertical to stator flux. The rotor winding is usually short-circuited. When S_1 is close the DC current in the stator reach to its steady state value. This current decays after opening the S_1 and closing S_2 simultaneously. The descriptor equations of the stator current after this phenomenon are derive by analysis the equivalent circuit of the machine [2].

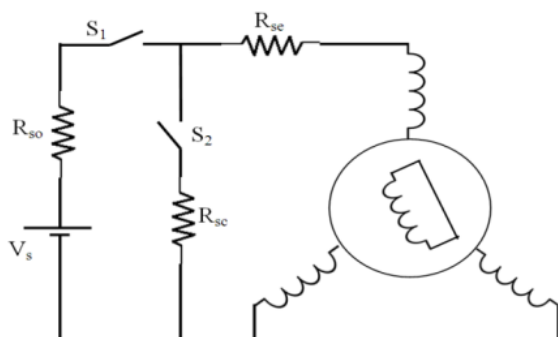


Fig. 1. The DC decay test configuration

3. The test bed

a) Synchronous machine

A 0.65 kVA , 380 V , 4 pole synchronous machine is selected as case study for experimental test. The machine is coupled with a DC shunt motor as prime mover. The synchronous machine is shown in figure 2.



Fig. 2. The studied synchronous machine

b) Switches

The simultaneous operation of S_1 and S_2 is one of the key problems in this test. Sometimes the DC decay test is performed using power semiconductor switches. We use a conventional mechanical switch as S_2 and a fast cartridge fuse as S_1 . By closing the S_2 , the power source is short-circuited which leads to immediat operating of S_1 fuse.

c) Measurements

In addition to conventional multi-meter, a data acquisition system is used to record the stator current. The selected system is an Eagle- μ DAQ Lite model with the sample rate as much as 49kSamp/sec . The device is shown in figure 3.



Fig. 3. The data acquisition module

4. Data processing

The DC decay test is performed and the recorded currents in d and q axis are shown in figure 4 and 5.

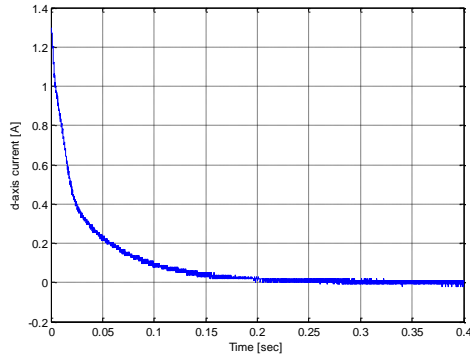


Fig. 4. d-axis decay current

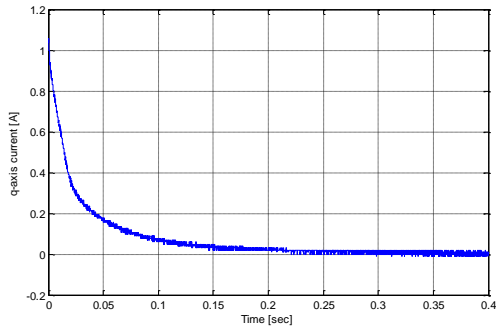


Fig. 5. q-axis decay current

A minor different between two above figures is due to the different between X_d and X_q impedances. The figures are normalized to the steady-state values of d and q current that are 1.3 and 1.055 respectively. The figures must follow the equations (1) and (2) respectively which determine the dynamic parameters at each axis [1,6].

$$I_d(s) = \frac{s^2(L_d T_d' T_d'') + s(L_d T_d' + L_d T_d'') + L_d}{s^3(L_d T_d' T_d'') + s^2(R_{eq} T_{do}' T_{do}'' + L_d T_d' + L_d T_d'') + s(R_{eq} T_{do}' + R_{eq} T_{do}'' + L_d) + R_{eq}} \quad (1)$$

$$I_q(s) = \frac{s(L_q T_q'') + L_q}{s^2(L_q T_q'') + s(R_{eq} T_{qo}'' + L_q) + R_{eq}} \quad (2)$$

The classical methods such as graphical decomposition are the conventional approach in curve fitting process [1]. These methods exhibit suitable fitting even in transient and sub-transient terms as shown in figure 6 [1,6].

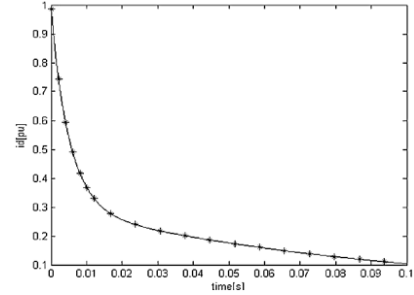
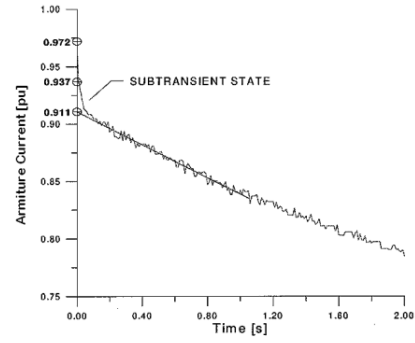


Fig. 6. Examples of classical curve fitting methods

On the other hands, it is clear that the graphical decomposition curve fitting approach always leads to unique resolvent for dynamic parameters of equations (1) and (2). The literature review shows that there is not any discussion on curve fitting resolvent uniqueness. We believe nobody thought on several different sets of parameters that all of them fit the equation (1) on figure (4). The problem maybe arises from the extra propagation of graphical decomposition method in this situation. The problem is investigated more in this paper.

The graphical decomposition methods always lead to unique solution in curve fitting process but the stronger algorithms can search any feasible resolvent in a wide range. The Genetic Algorithm (GA) is selected as an advanced solution method in optimization problems. GA can search any feasible solution that minimizes the error between fitted and experimental data of stator DC reductive currents.

5. The Genetic Algorithm

The genetic algorithm (GA) is a method for solving optimization problems especially in which the objective function is discontinuous, no

differentiable, stochastic, or highly nonlinear. This algorithm is based on natural selection, which repeatedly modifies a population of individual solutions. Each individual solution is a string of variables. A random function creates the initial population and at each step, the individuals from the current population are selected to be parents producing the children for the next generation. Generally, there are three ways to generate the children.

- Crossover rules: A large numbers of children are fabricated by combination of parents through crossover rules.
- Elite Children: The individuals who have the best fitness are selected as children for the next generation without changing called elite children.
- Mutation rules: The mutation rules apply random changes to individual parents to form children. This option provides genetic diversity and enables the algorithm to search a broader space.

Over successive generations, the population evolves toward an optimal solution. Special stop conditions are suggested for this algorithm that varying in different optimization problems. But usually the algorithm terminates when the cumulative change in the fitness function value over specified stall generations is less than agreed tolerance. This procedure is shown in figure 7 concisely.

6. Dynamic Parameters Deriving

The candidate function for minimization that is known as fitness function is the first step of dynamic parameters deriving. This function is usually defined by sum of square difference between calculated and experimental stator current. The fitness functions are defined in d and q axis separately as shown below.

$$F_d = \sum_{i=1}^n (i_{d_i(acquired)} - i_{d_i(equation)})^2 \quad (3)$$

$$F_q = \sum_{i=1}^m (i_{q_i(acquired)} - i_{q_i(equation)})^2$$

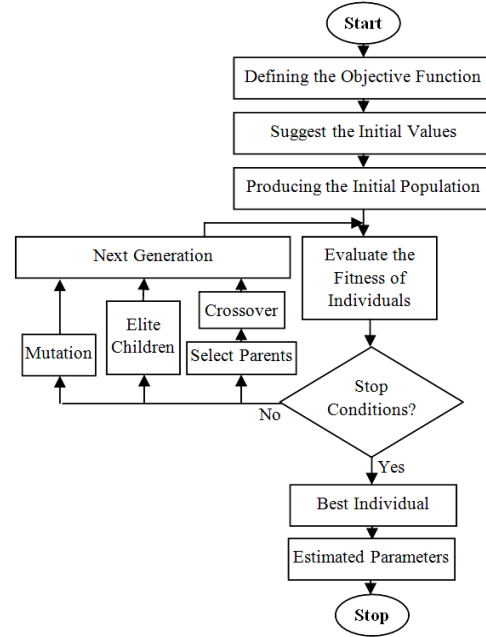


Fig. 7. The genetic algorithm

The fitness function minimizing lessen the error between calculated and experimental stator currents that results the dynamic parameters. The GA can search different resolvent in this curve fitting process. The majority of the components of GA involve the stochastic functions such as initial population, selection parents, crossover rules, mutation etc. Hence, the GA has the different resolvent in each operation for a multi solution problem and the minor different resolvent for unique solution one.

There are many sets of parameters that lead to a curve fitted on decay stator currents as shown in Table 1, which found by GA. Figures 8 to 11 show the related curves of these sets.

Table 1. Different groups of dynamic parameters

Dynamic Parameters	Run 1	Run 2	Run 3	Run 4
X_d	359.34	281.90	370.11	373.42
X'_d	191.11	412.42	293.00	318.56
X''_d	193.88	225.15	232.39	186.26
T'_d	0.020	1.014	0.038	0.036
T''_d	0.013	0.046	0.038	0.023
T'_{do}	0.037	0.693	0.048	0.040
T''_{do}	0.013	0.085	0.048	0.040

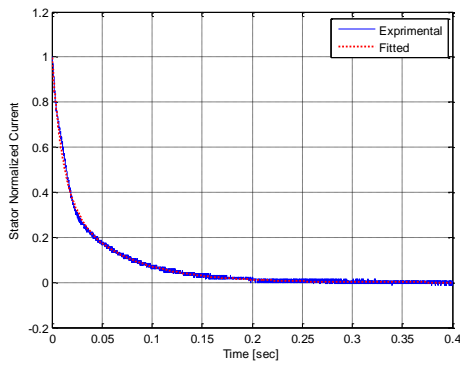


Fig. 8. Fitted curve of set 1 of dynamic parameters

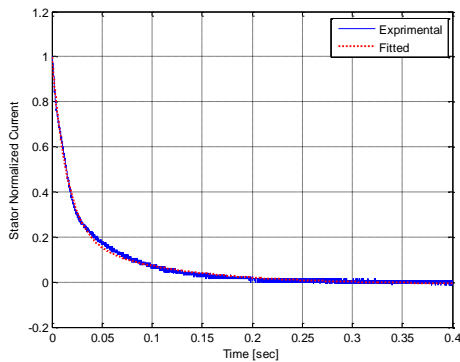


Fig. 9. Fitted curve of set 2 of dynamic parameters

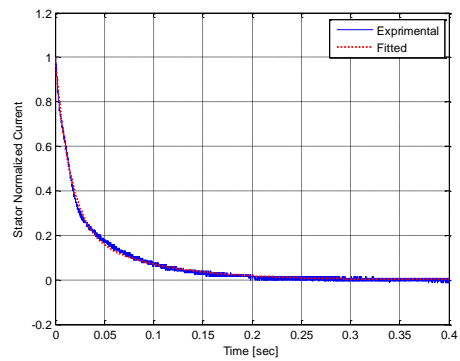


Fig. 10. Fitted curve of set 3 of dynamic parameters

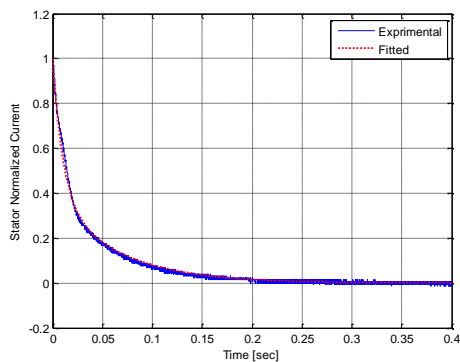


Fig. 11. Fitted curve of set 4 of dynamic parameters

Significant difference between the values of these sets, recognizes the fact that there is no unique solution for this curve fitting problem. The resultant non-uniqueness of mentioned curve fitting process exhibits a stickler challenge in DC decay test. We are proposed a solution for this problem in this paper.

Some references present an equation for field current during the current decays in stator [2]. The simultaneous fitting on field and stator currents add a constraint to the problem, which reject some of resultant in table 1. More investigation show that the GA can find different resultant even by simultaneous fitting on field and stator currents. So this is not a suitable solution for non-uniqueness.

It is clear that the synchronous reactances (X_d , X_q) are the most effective parameters in the stator current equation. So, it was proposed that these parameters be determined first via a separate test. Then the values of synchronous reactances are taken into account in the curve fitting process as a constraint. The Slip Test was proposed to determine the synchronous reactances values.

7. Slip Test

The slip test is a well-known approach to determine the synchronous inductances that was explored in many references [7,8]. The method is based on supporting the stator with a rated frequency voltage source. The field winding is open circuited while a strong prime mover rotates the rotor at a minor less than synchronous speed. The speed difference between rotor and stator rotatory field named slip speed, leads to an induced voltage in field winding. On the other hand, the stator field is switching between d and q axis alternatively. Therefore, the amplitude of terminal voltage and current oscillates. Figure 12 shows a typical example of slip test results [7]. The direct and quadratic reactances obtain by dividing the terminal voltage and current in d and q position respectively.

$$X_d = \frac{V_{a(\max)}}{I_{a(\min)}} \quad (4)$$

$$X_q = \frac{V_{a(\min)}}{I_{a(\max)}}$$

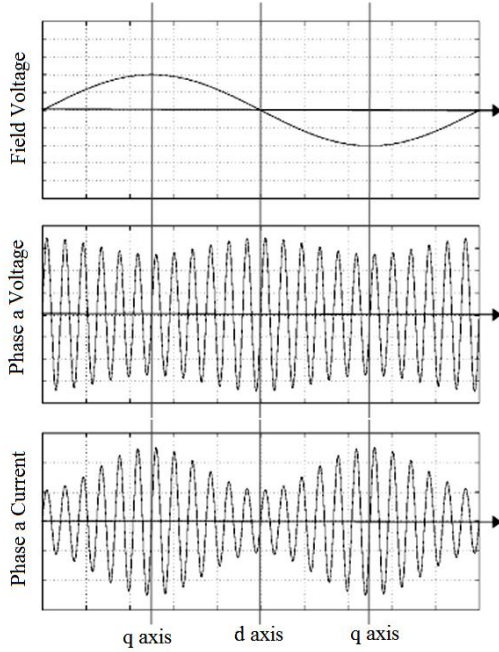


Fig. 12. Typical example of slip test results

The slip test was performed on the studied synchronous machine with a shunt DC motor as prime mover. The coupled machines appear in figure 13. The terminal voltage and current was acquired as shown in figure 14. Now one can calculate the synchronous reactances via equation (4).



Fig. 13. Slip test setup

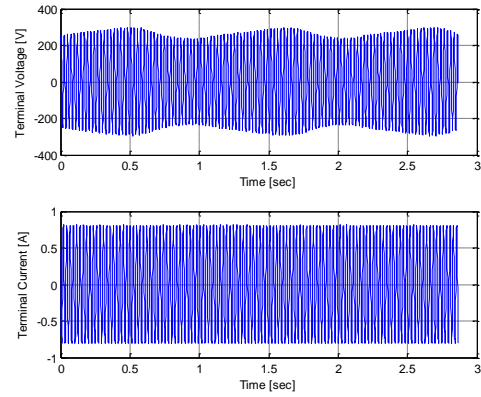


Fig. 14. Slip test results

$$X_d = \frac{298.9}{0.83} = 360.12 \, \Omega$$

$$X_q = \frac{253.4}{0.84} = 301.6 \, \Omega$$

If the synchronous reactances values have been considered in the curve fitting process as a constraint, a near-unique solution appears. Therefore, the goal functions should be modified as below.

$$F_d = k_d \cdot (X_d - 360.12)^2 + \sum_{i=1}^n (i_{d_i(\text{acquired})} - i_{d_i(\text{equation})})^2 \quad (5)$$

$$F_q = k_q \cdot (X_q - 301.6)^2 + \sum_{i=1}^m (i_{q_i(\text{acquired})} - i_{q_i(\text{equation})})^2$$

The multi variables, many fitting points and near-equations arrange the curve fitting as a potentially multi-solution problem. Notwithstanding the multi-solution essence of curve fitting approach, the modified goal function almost leads to a near-unique resolvable. Table 2 shows three resolvable that obtained by running GA for the new goal function. The minor differences are due to GA inherent stochastic process and are unavoidable. The average of three resolvable considered as final values for dynamic parameters of synchronous machine. Figure 15 to 17 show the fitting of each resolvable.

A similar test in quadratic axis results the dynamic parameters of q-axis that are show in table 3.

Table 2. Obtained dynamic parameters by new method

Dynamic Parameters	Run 1	Run 2	Run 3	Average
X_d	360.03	360.12	360.48	360.21
X'_d	323.65	330.99	317.93	324.19
X''_d	227.53	228.12	232.69	229.44
T'_d	0.487	0.122	0.345	0.318
T''_d	0.024	0.021	0.019	0.021
T'_{do}	0.542	0.132	0.391	0.355
T''_{do}	0.035	0.031	0.026	0.030

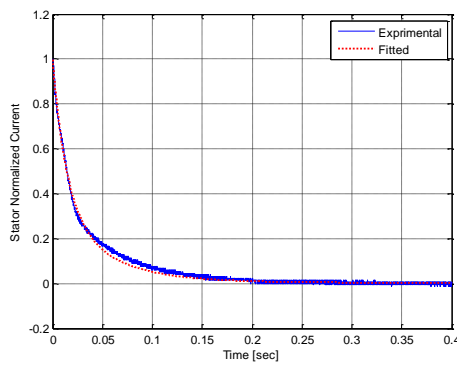


Fig. 15. Fitted curve on set 1 of new dynamic parameters

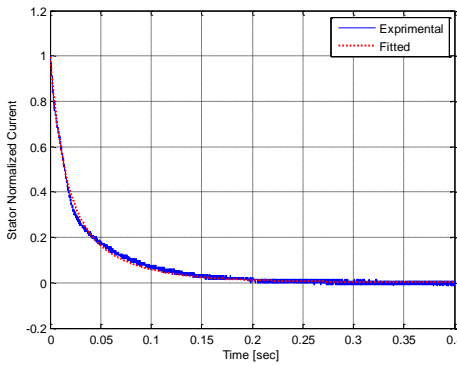


Fig. 16. Fitted curve on set 2 of new dynamic parameters

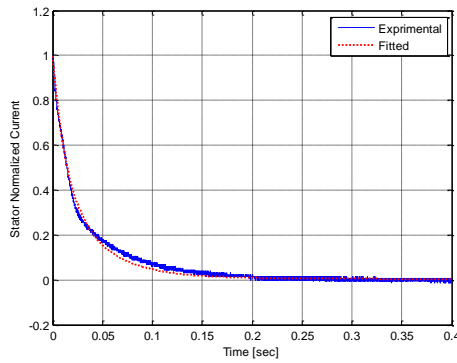


Fig. 17. Fitted curve on set 3 of new dynamic parameters

Table 3. Q-axis's dynamic parameters

Dynamic Parameters	Run 1
X_q	301.13
X''_q	281.33
T''_q	0.347
T''_{qo}	0.515

Although the proposed goal function leads to a near-unique solution of GA but different resolvent maybe will obtained by stronger algorithm. On the other hand, the proposed modification requires an extra test (slip test).

8. Conclusion

The DC decay test is an important method to determine the dynamic parameters of synchronous machines. An experimental investigation of test procedure and detailed theoretical study of curve fitting process exhibits a problem with resolvent uniqueness. A new goal function was proposed to overcome the problem. This function involves the predefined synchronous reactances. The slip test was applied to determine the synchronous reactances. It was shown that the proposed modified procedure could moderate the problem.

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