

Estimation of Optimal Value of Synchronous Impedance Using Genetic Algorithm

Pratik Chavda*, **Prof. Vihang Dholakiya[†]**, **Prof. HormazAmroliya[‡]**

**Institute of Technology, Nirma University, Ahmedabad, Gujarat 382481, India.*

[†]Institute of Technology, Nirma University, Ahmedabad, Gujarat 382481, India.

[‡]Institute of Technology, Nirma University, Ahmedabad, Gujarat 382481, India.

Abstract

The paper presents an estimation method to determine the synchronous impedance of the synchronous generator. The synchronous impedance of cylindrical rotor alternator is estimated based on the equivalent circuit model and voltage regulation. Genetic algorithm based impedance estimation technique is adopted, where only machine rating is used. Conventional methods viz., synchronous impedance method uses rated voltage and rated current obtained from more than one operating condition to determine synchronous impedance value. However, Genetic Algorithm based method uses the rated voltage and current, i.e. without isolation or disturbing the normal operating condition of the machine to estimate the value. The test results of the GA-based estimation method are found to be closer to test results of conventional methods.

Keywords: Equivalent circuit model, genetic algorithm, impedance estimation, synchronous generator.

INTRODUCTION

The alternator, synchronous motor and synchronous converter are considered under the category of synchronous machine. Alternators are widely used for the power generation. Determination of its impedance is useful in performance computations, power system load flow studies, power factor correction, and in diagnostics of internal faults of alternator. In recent years, there is an increment in the research of modeling and estimation of synchronous machine parameters. The need for such estimation arises because generator impedance values computed from predetermination methods tend to vary substantially from design values and hence it is unreliable. The present paper addresses this problem using genetic algorithm method for synchronous impedance estimation of the synchronous generator.

This paper starts with the approach for solution showing the equivalent circuits of the synchronous machine considered and described in Section III. Section IV presents other conventional techniques to estimate parameters of the cylindrical rotor and Section V explains the impedance estimation using genetic algorithm technique, and finally, the results are discussed in Section VI.

RELATED WORK AND PRIOR RESEARCH

In order to derive correct instant for smooth synchronization, it is observed that when the alternators are in synchronization, synchronizing current $I_s = 0$. In order to detect so, it is desired to determine synchronizing reactance by which one can estimate synchronizing current under different operating conditions.

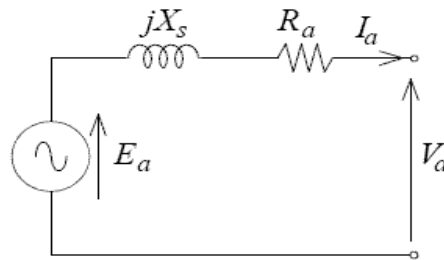


Fig. 1. Equivalent circuit of cylindrical rotor alternator

The synchronous reactance fundamentally is combination of direct axis reactance and armature reaction reactance, which is dependent on nature of the load hence and power factor in a certain range. As a result of that depending upon the loading condition and in a range of desired voltage regulation, the value of synchronous reactance does not remain constant and it varies over a range. So that there is one idea to obtain one optimum value of synchronous impedance using GA. By using this optimum value of synchronous impedance will be determined. After calculating synchronous impedance, synchronizing current will be calculated. if the synchronizing current is zero than both alternators can be synchronized.

APPROACH FOR SOLUTION

The simple equivalent circuit model of cylindrical Rotor synchronous generator is shown in Fig. 1. Conventional pre-determination methods such as synchronous impedance method are used to determine synchronous impedance (Z_s) and hence their performance, viz. regulation and efficiency.

Estimation of the synchronous impedance for cylindrical rotor in Fig. 1 requires good degree of accuracy. It is important because they have direct effecting on the performance of machine that is efficiency, voltage regulation. However, the impedance determined from the conventional methods uses the test data from open circuit test, short circuit test in which the test conditions vary widely from actual load condition of the machine.

Therefore it is clear that the synchronous impedance computed from these Pre-determination methods tend to vary with its actual values because operating conditions varies.

From the above facts, it would be beneficial to estimate impedance value using some optimization techniques. This paper uses the Genetic Algorithm approach to obtain the best value of synchronous impedance from its search space.

An appropriate objective function that is defined based on the equivalent circuit models shown in Fig. 1 and voltage regulation equation 5. Then the objective function is to be maximized to estimate the impedance using GA. The results of GA based impedance estimation technique is compared with the results of conventional methods. The suggested GA based impedance estimation methodology maximizes an objective function that is derived from the equivalent circuit models and voltage regulation. The objective functions used for impedance estimation are discussed in Section 4.

DETERMINATION OF SYNCHRONOUS IMPEDANCE USING O.C. AND S.C. TEST

Synchronous impedance method though gives inconsistent results for voltage regulation, is quite useful because it introduces the concept of synchronous reactance. This procedure can be applied to cylindrical rotor synchronous machine because the resultant air-gap flux is not affected by the angular position of the rotor. The iron part of the magnetic circuit is assumed to have constant permeability, i.e. saturation is neglected.

The drop in terminal voltage is due to i) armature resistance drop IR_a ii) leakage reactance drop IX_l and iii) armature reaction drop. Drop in voltage due to armature reaction may be accounted for by assuming the presence of fictitious reactance X_a in the armature winding. The leakage reactance X_l and the armature reactance X_a combined to give synchronous reactance X_s . Hence $X_s = X_a + X_l$.

Therefore the total voltage drop in alternator under load is given by

$$IR_a + jIX_s = I(R_a + jX_s) = IZ_s \quad (1)$$

Where Z_s is known as synchronous impedance of the alternator. Open circuit characteristic (O.C.C) and short circuit characteristic (S.C.C) are required for the determination of Z_s and hence regulation. The reading of open circuit line to line terminal voltage $V = E_0$ are taken for various values of field excitation current I_f . These data are plotted as O.C.C. The short-circuit characteristic of the machine is obtained by means of the short-circuit test conducted with switch closed. While the rotor is running at synchronous speed N_s , the rotor field is kept unexcited to begin with. The field excitation is the gradually increased. while the current in all the three ammeters should be identical, practically a small unbalance will always be found on account of winding and field current dis-symmetries which can not be completely avoided in a machine. Therefore, I_{sc} the short circuit current per phase is taken as the average value of the three ammeter readings. In short circuit test entire emf E_0 is consumed in overcoming the short circuit current I_{sc} , through the synchronous impedance Z_s . Therefore,

$$Z_s = \frac{E_0}{I_{sc}} \quad (2)$$

Where E_0 = Open circuit terminal voltage for a certain field current;

I_{sc} = short circuit current for the same field

A. Observation table

Table I: Open Circuit Characteristics

Sr. No.	Field current I_f (A)	Armature line Voltage V_l (V)	Armature phase voltage V_{ph} (V)
1	0.1	112	64.66
2	0.2	233	134.68
3	0.3	305	176.09
4	0.4	360	207.84
5	0.5	400	230.94
6	0.6	426	245.95
7	0.7	443	255.76
8	0.8	460	265.98
9	0.9	470	271.35
10	1.0	480	277.12
11	1.1	495	285.78
12	1.2	505	291.58

Table II: Short Circuit Characteristics

Sr. No.	Field current I _f (A)	Line Current I _R (A)
1	0.1	1.30
2	0.2	2.3
3	0.25	2.8
4	0.3	3.28
5	0.35	3.81
6	0.4	4.36
7	0.45	4.9
8	0.5	5.55
9	0.55	6.0

O.C.C and S.C.C is drawn and from that,

$$Z_s = \frac{AB \text{ in volts}}{AC \text{ in amperes}} \tag{3}$$

SUGGESTED METHOD GENETIC ALGORITHM BASED IMPEDANCE ESTIMATION

Genetic algorithm is a strong and universal optimization method applied in the present optimization problem. A brief introduction of genetic algorithm layout and its execution are presented here.

A. The GA Methodology and Structure

To determine the synchronous impedance, the genetic algorithm method is executed. This algorithm starts like other optimization algorithm by determining the optimization parameters, the cost function and the cost. It ends after convergence test similar to other optimization algorithms. A step by step procedure for the genetic algorithm is shown in Fig. 2.

- 1) **Problem Representation:** To lighten this problem the Binary coded GA is used in this work, Binary Coded GAs must decode a chromosome into a Candidate Solution, assess the Candidate Solution and the resulting fitness send back to the binary-coded chromosome representing the assessed Candidate Solution.
- 2) **Initialization of the Population:** Genetic algorithm requires the initialization of the population. The size of the population is based on the nature of problem. The population size is a unvaried random number. Each one of the individuals is

initialized within the chosen range of the variables.

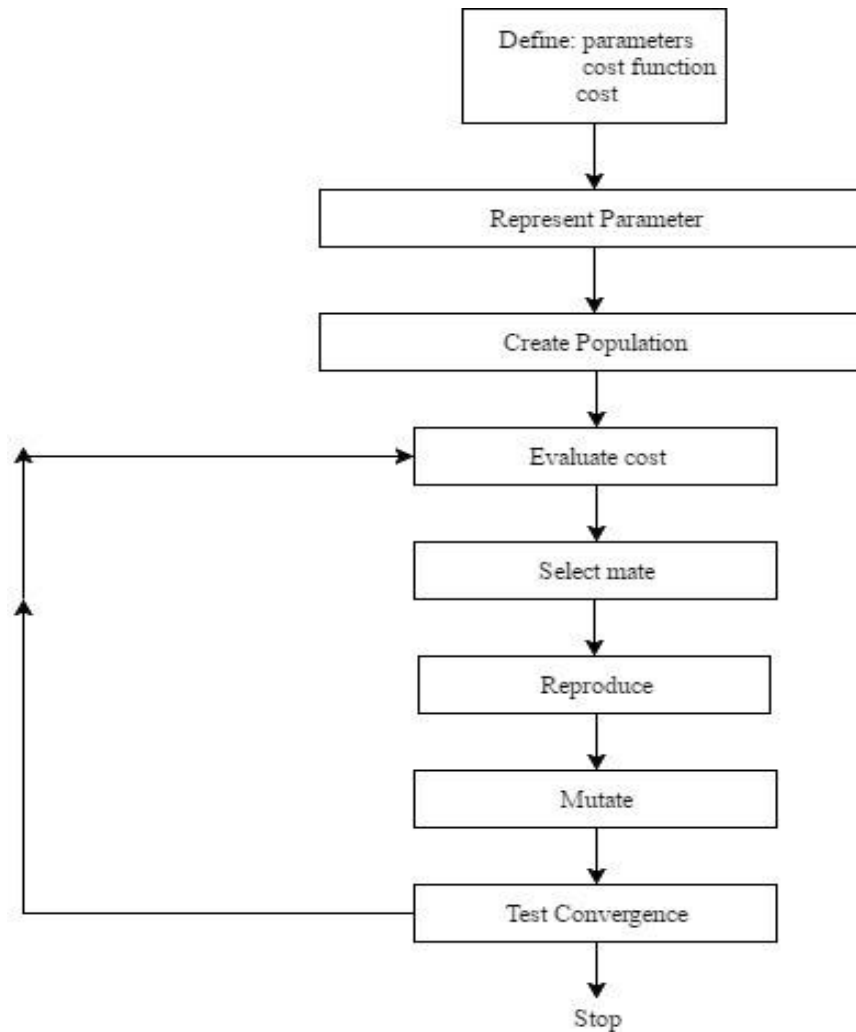


Fig. 2. Flowchart of a continuous genetic algorithm

3) Selection: The chromosomes with the higher probability which is called fittest chromosomes are selected for the next generation. To calculate fitness probability, there is required to compute the fitness of each chromosome. The Chromosome which has the highest fitness can be find from the probabilities, chromosome with the highest probability is taken as next generation chromosomes. Roulette wheel is used as the selection process in this work.

Roulette wheel: The basic part of the selection process is for randomly select from one generation to generate the foundation for the next generation. There is greater chance for fittest individuals to survive better than weaker ones. This

reproduces behavior in these fitter individuals will be likely to have a great probability to survive and approval to form the mating pool for the next generation.

- 4) Crossover: In crossover, there is need to randomly select a position in the parent chromosome then swapping sub-chromosome. Parent chromosome which will have partner which is randomly selected and the number of partner Chromosomes is controlled using crossover rate.

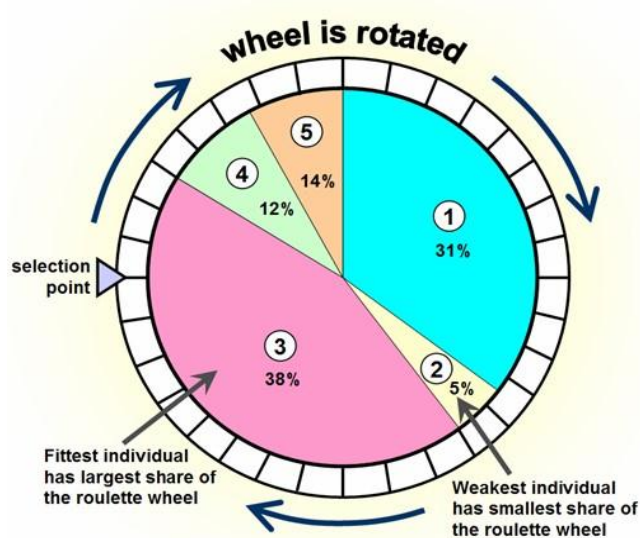


Fig. 3. Roulette wheel

- 5) Mutation: The mutation rate parameter decides the Number of chromosomes that have mutations in a population. In Mutation process, the gen at random position is replaced with a new value. The process is as follows. At starting of the process needs to determine the total length of gen in the population. The total length of gen is $\text{total gen} = \text{number of population} \times \text{number of gen in Chromosome}$. Mutation process is executed by producing a random integer between 1 and total generation. If generated random number is smaller than mutation rate (P_{mut}) variable, then marked the position of gen in chromosomes. Suppose we denote P_m 0.20, it is expected that (0.2) of total gen in the population that will be mutated. Finishing mutation process there will be one new generation in the genetic algorithm. These new generated Chromosomes will go for the same process as the previous Chromosomes such as evaluation, selection, crossover and mutation and it produces new generation of Chromosome for the next generation at the end. This process will be repeated for a predetermined number of generations.

IMPEDANCE ESTIMATION USING GA

A 3.2KVA, 415V, 4.4A, 50Hz, 1500RPM, three-phase, Cylindrical Rotor alternator is considered as the first case study. The objective function for the GA-based parameter estimation for the CR generator is obtained as follows.

$$E_0 = V_t + IZ_s \quad (4)$$

$$\text{Voltage Regulation}(V.R.) = \frac{E_0 - V_t}{V_t} \times 100 \quad (5)$$

From the equation 4,

$$E_0 - V_t = IZ_s \quad (6)$$

$$\frac{E_0 - V_t}{V_t} \times 100 = \frac{IZ_s}{V_t} \times 100 \quad (7)$$

$$V.R. = \frac{IZ_s}{V_t} \times 100 \quad (8)$$

Now, from the equation 5,

$$Z_s = \frac{V.R. \times V_t}{100 \times I} \quad (9)$$

Eq. 9 is the fitness function that requires to be maximized for Cylindrical rotor Alternator. Thus the GA uses only one equations, Eq.9 and estimates unknown impedance, with its parallel search technique in its search space.

RESULTS

To compare the result with conventional method, O.C. and S.C test data is taken from section IV-A.

Table III. Comparison of experimentally determined and estimated Results

	Synchronous impedance Method	GA based Method	% Error
Synchronous Impedance (Zs)	39.93ohm	39.72ohm	0.01

The genetic algorithm main program is run for 10-20 times with the set values for generation, population size, cross-over rate and mutation rate. Each time the results obtained were same. This shows the repeatability of the suggested method.

The genetic algorithm based method uses direct rated data in comparison with the conventional methods which uses test data obtained from different operating conditions. Any change in circuit parameters due to change in load is taken care of in genetic algorithm based impedance estimation. So this method helps in calculating the synchronous current to determine synchronization instant for alternator.

CONCLUSION

Estimation of synchronous impedance of alternators using the genetic algorithm based method is suggested in this work. The genetic algorithm based method is chosen because of its advanced features and is better suited for this problem as compared to other techniques. For synchronous impedance estimation, no isolation of the machine was required and the value of synchronous impedance is determined on-site. The estimated values are compared with the value of impedance obtain using the O.C. and S.C. test. The suggested Genetic algorithm based estimation method is identified to be adaptable and superior to the conventional methods.

REFERENCES

- [1] A New Method for Estimation of Large Synchronous Generator Parameters by Genetic Algorithm *Bahman BahmaniFirouzi, Ehsan Jamshidpour and TaherNiknam*
- [1] Haupt, R. L., Haupt, S. E. (1998). Practical Genetic Algorithms. New York: Wiley- Interscience.
- [2] Paul C. Krause, Oleg Wasynczuk, Scott D. Sudhoff. Analysis of Electric Machinery and Drive Systems (2nd ed.).
- [3] On-Line Synchronous Machine Parameter Estimation from Small Disturbance Operating Data *H. Tsai, A. h'eyhani, J. Deincko, R. G. Farmer, F*
- [4] Test and Simulation of Network Dynamic Response Using SSFR and RTDR Derived Synchronous Machine Models. *Rusche, P.A.E., G.J. Brock, L.N. Hannet, J.R.Willis*
- [5] Genetic Algorithms In Search,Optimization, And Machine Learning. *GOLDBERG, D. E.*
- [6] In Situ Parameter Estimation of Synchronous Machines Using Genetic Algorithm Method. *Gopalakrishnan, Kalarikovilagam Srinivasan, Hosimin, Thilagar Srinivasan*

