Revisiting ZPF method in Novel Computing Environment

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Abstract— The performance parameters of a synchronous generator include mainly the efficiency and the voltage regulation. There is literature available in abundance about the determination of voltage regulation, involving the graphical constructions of plotting various characteristics and determining the results by calculations. In this paper the authors have developed a special purpose MATLAB® program to plot the characteristics and to determine the voltage regulation using Zero power factor method. The program made for the task is simple and user friendly. The performance of the program is tested for different loads as well as the power factor conditions.

Keywords—*synchronous generator,voltage regulation,Potier triangl, ZPF method.*

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I. Introduction

A synchronous generator is a pioneer element in a power system irrespective of the power system size. The generic characteristics of a synchronous generator are the efficiency and voltage regulation. In detailed studies of various power system studies the voltage regulation is found to be assuming a priority compared to the efficiency. Therefore, it is needed to design or operate a synchronous generator so as to fulfill the voltage regulation requirements with a due care and consideration. In literature various methods have been discussed to estimate the voltage regulation. In this paper the authors have carried out the computations using novel computing tools and tried to find out whether the constraints discussed in the preceding literatures can be relaxed to a certain extent or not.[9]

II. Voltage Regulation

A. Definition

The regulation of a synchronous generator is the rise in terminal voltage of an isolated machine when full load at given power factor is removed from the machine, the field excitation and the speed remaining constant. Thus, if V be the normal rated voltage and the terminal voltage rises to E_t when full load is thrown off[1-5]. The voltage regulation can be explained by equation (1).

The per unit regulation is $= \dfrac{E_t - V}{V}$ per unit. (1)

The inherent voltage direction of a generator relies on upon the resistance and the spillage reactance and all the more especially on the armature response. The qualities got depends likewise on the PF of the heap since this decides the direct polarizing segment of the armature response. An interest for close direction of the machine makes a machine uneconomical to worked since it for the most part includes a long crevice and a much field copper.

In most places close inherent regulations is not necessary since the automatic voltage control is commonly used and this avoids the fluctuation of voltage with load.

B. Significance of Voltage Regulation

The role of constant voltage in a power system is as important as a blood pressure in a human body. It is the natural tendency of synchronous machine to exhibit a substantial variation in the load condition, which is a function of the load current magnitude and power factor.

In addition to this, there is magic action of armature reaction taking place in the machine playing a role like additional magnetic poles.

Thus, an accurate method of voltage regulation becomes necessary for synchronous machines.

C. Methods to calculate Regulation

The voltage regulation of an alternator can be determined by various methods.

1. Design data
2. Direct loading characteristics

3. Synchronous Impedance method or EMF method
4. Ampere-Turn method or MMF method
5. Zero Power Factor method or Potier Triangle Method [1].

Out of which, method 1 is very much restricted for the outside world as the data for calculations are not so simply available and therefore, it is restricted at documentation level for quoting the catalog data.

Method 2 is also limited in the sense that all the times it is not possible to obtain loads of a variety of magnitude and power factor. Moreover, it is applicable only in case of small capacity alternators as full load can not be directly connected to high capacity alternators.

Method 3 is easily applicable for high capacity alternators and produces results relatively more simply but leading to high values of regulation than actual thus, being pessimistic.

Because of its excellent advantages of visualization of armature reaction on the worst most power factor, ZPF method is found to have a place like moon in the sky. It also produces the real time running condition of alternator with the minimum power consumption, but very interestingly the results obtained using potier triangle are deduced from manual graphing.

Accuracy of results depend on the accuracy of slope with which air gap line is drawn. The role of air gap line is extremely important as it discriminates between the linear and non-linear operating regions of the magnetic circuit.

MATLAB is one of the most powerful and versatile software to address a wide range of engineering problems. The excellent graphic commands of Matlab library provide a wonderful comfort and ambience in addressing complicated graphic problems.[5][6][9]

In addition to that the excellent zoom features and the cursor location facility have made the users to obtain the data/results up to a satisfactory level of accuracy and precision. Therefore in this problem Matlab is chosen wisely as a programming and a graphic tool.

The design data based calculations are elaborate and proprietary assets. Therefore in the field it is not possible to calculate the regulation using these methods. What we can have are only the measurements possible on the machine on various load conditions.

What so ever may be the beauty in the design of alternators, their testing is limited by the resources available in the testing laboratory. In our case also, exactly the same thing happen that the zero power factor load is not of that capacity as that of a synchronous generator. This fact is not only found in the real world infrastructure limitations but also discussed in profound religious literature.[8] And thus ZPF characteristic is not possible to be plotted at the rated current of the alternator.

III. CASE STUDY

A. Assumptions

Now as per the definition of regulation, we need the complete information for the fitment of insufficient information being used for completeness. This can be accomplished under the influence of some simple but logical and worthy assumptions which are as follows:

1) We assume that the armature reaction flux produced by any load current will be in prorate basis with respect to the load current at which ZPF is to be plotted.

2) There is not much variation in the frequency as the machine is loaded to the load current value under question (although logically some corrections can still be applied, but at present we will not)

3) The OCC is plotted over the entire possible range of field current variations.

B. Procedure for Voltage Regulation

Considering above assumptions, the procedure for finding out the regulation can be re-established.

Let I_z = The ZPF characteristic load current

I = the load current at which the regulation is sought

x= the fraction of I to I_z

From plotting the OCC and ZPF, on constructing the potier triangle we get X_l, the inductive leakage reactance.

Let IF_1 be the field current component required to overcome $I_z * X_l$ and IF_2 be the field current component required to overcome the armature reaction. Thus at the load current under reference IX_l will be X times $I_z * X_l$

Now,

$$E_1 = \sqrt{(V\cos\phi + xIz * Ra)^2 + (V\sin\phi + xIz * Xl)^2} \quad (2)$$

Let the new field current be IF_3 and it can be located by just drawing the horizontal line in parallel to X axis with a magnitude of E_1 as shown in equation (2).

The next objective is to add to this IF_3 an appropriate component of armature reaction and as per the assumptions, it will be $x * IF_2$.

Thus, the resultant field current can be obtained by appropriate vector addition of IF_3 and $x * IF_2$.

Hence, for various power factors and load currents, the induced emf at no load can be obtained by drawing a vertical line whose abscissa are cutting the OCC at no load induced emf point.

Thus, the percentage regulation can be obtained as,

$$\left(\frac{E_t - V}{V}\right) * 100$$

C. Experimentation

The experimentation for determining voltage regulation was carried out as per the circuit connection given in figure.
The machine specifications used for the experimentation are as follows:
3-phase Alternator, 7.5 KVA, 1500 rpm, 240 volt, 18 Amp
Field current 0.35 Amp.

The above mentioned machine was rewound hence resulting into reduced rated full load current carrying capacity.[1-4]

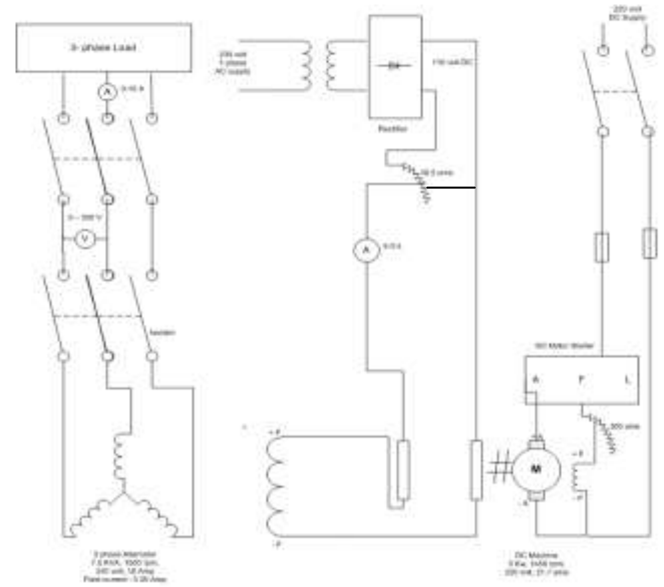

Fig 1. Experimental Setup for determination of regulation

The experimentation was carried out with two different cases:

1. Open Circuit Readings
2. Loading Condition Readings

The Open Circuit Readings for the field current I_F and voltage V are as follows in Table I.

TABLE I

OPEN CIRCUIT READINGS OF THE SYNCHRONOUS MACHINE

Sr. no.	Field Current I_F (Amps)	Voltage V (Volts)	Sr. no.	Field Current I_F (Amps)	Voltage V (Volts)
1	0.0	0	8	1.4	130
2	0.2	22	9	1.6	140
3	0.4	46	10	1.8	146
4	0.6	67	11	2.0	155
5	0.8	81	12	2.2	162
6	1.0	100	13	2.4	165
7	1.2	115	14	2.5	167

The field current and the voltage of the synchronous machine were measured for three different loading conditions. The loading conditions are as follows:

1. Resistive Load
2. Inductive Load
3. Capacitive Load

CASE I: Resistive Load

The following readings shown in table II were observed on connecting a lamp load to the alternator.

TABLE II

EXPERIMENT RESULTS WITH RESISTIVE LOAD

Sr. no.	Field Current I_F (Amps)	Voltage V (Volts)
1.	2.4	148
2.	2.3	144
3.	2.2	140

CASE II: Inductive Load

As ZPF test itself requires a purely inductive load, the ZPF test data can also be considered as the data for Inductive loading shown in table III. In most of the laboratories the variable inductors are usually available and therefore, the similar readings for other inductive loads can also be obtained comfortably.

TABLE III

EXPERIMENT RESULTS WITH INDUCTIVE LOAD

Sr. no.	Field Current I_F (Amps)	Load Current I_L (Amps)	Voltage V (Volts)
1.	0.4	6	0.0
2.	0.8	6	42
3.	1.0	6	50
4.	1.2	6	84
5.	1.4	6	100
6.	1.6	6	114
7.	1.8	6	124
8.	2.0	6	134
9.	2.2	6	140
10.	2.4	6	143
11.	2.5	6	148

CASE III: Capacitive Load

A 2 KVAR, 440 volts, 3 phase delta connected capacitor bank was also connected as a load and the following observations were obtained shown in table IV:

TABLE IV

EXPERIMENT RESULTS WITH CAPACITIVE LOAD

Sr. no.	Field Current I_F (Amps)	Voltage V (Volts)
1.	1.4	135
2.	1.5	138

IV. MATLAB ANALYSIS

The results obtained from the experimentation using different loading condition were fed to a user friendly MATLAB code to yield the Potier triangle as a part of computation of the percentage voltage regulation.

Initially the open circuit characteristics were plotted as shown in fig. 2.

ISSN: 2321-8169
787 - 791

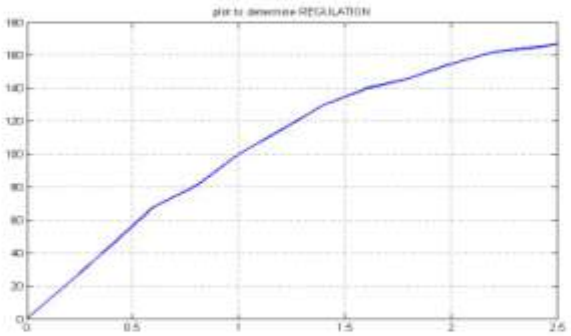

Fig 2. Open circuit characteristics plotted in MATLAB

Later on by determination of slope the air gap line has been drawn followed by plotting of ZPF characteristics at specified load current and power factor, thus obtaining the potier triangle as shown in fig. 3.

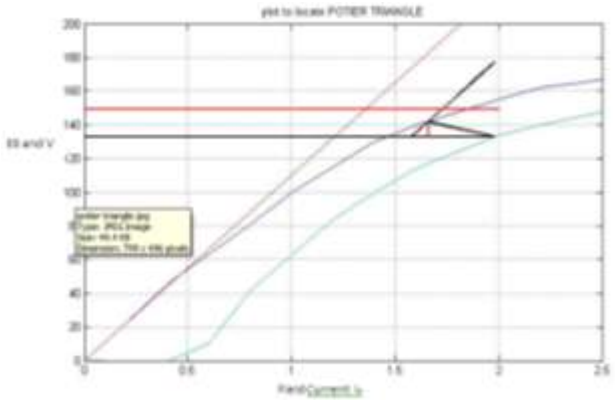

Fig 3. Plot of air-gap line and ZPF characteristics

Fig. 4 shows the enlarged view of potier triangle.

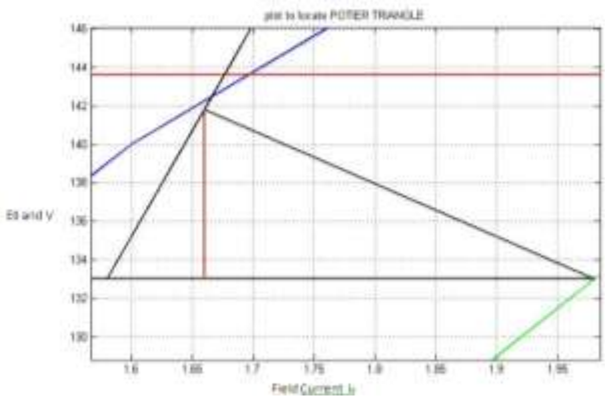

Fig 4. Enlarged view of Potier Triangle

$$E = \sqrt{(V\cos\phi + xIz * Ra)^2 + (V\sin\phi + xIz * Xl)^2} \quad (3)$$

Using the above mentioned equation (3) of induced emf, the field current IF_1 was determined for the rated value of voltage. Later on, the revised field current IF_3 was obtained by considering the armature reaction component and the value of induced emf E_2 produced by IF_3 is figured out from the open circuit characteristics as shown in fig. 5.

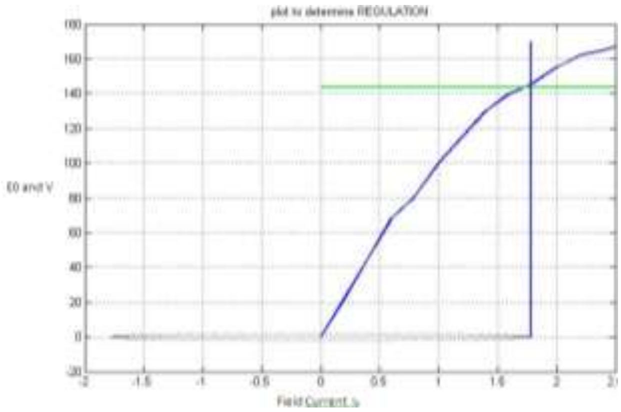

Fig 5. Plot to determine field current

Thus, regulation is determined by

$$\text{Percentage Voltage Regulation} = \left(\frac{E_2 - V_{rated}}{V_{rated}}\right) * 100$$

V. RESULTS AND DISCUSSIONS

The voltage regulation obtained through the MATLAB code for inductive load (PF = -1 lagging) was 2.6165 % whereas for capacitive load (PF=+1 leading) was -0.7970. Hence the capacitive loading is in fact an advisable condition in terms of field loading. For a PF of 0.8, the voltage regulation was found to be 12.72 % which indicated that the rewinding of the machine is also qualitatively good. So the required capacity of automatic voltage controller is relatively less, thus directly influencing the cost on the basis of inherent regulation. The results obtained on experimentation are found to be in agreement with the proposed revisions and in the formulas.

VI. CONCLUSION

All the required data for the calculation of regulation is found to be totally compatible to the MATLAB environment for plotting the characteristics and obtaining consequent information. The problems of manual graphing are solved and the ambience found for this experimentation is really pleasing and worth.

ACKNOWLEDGEMENT

The authors are thankful to BVM Engineering College for providing the inspiration and infrastructure support for carrying out the work. The authors are also thankful to Dr. B.R. Parekh, Prof. A. A. Shaikh and all other faculty members and technical assistants for providing valuable help and suggestions at all phases of the work. The authors are also thankful to the family members for their patience but silent support.

REFERENCES

[1.] M.G. Say, "The Performance and Design of Alternating Current Machines", 3rd Edition, CBS Publishers and Distributors, New Delhi, pp. 451-660.

[2.] Alexander S. Langsdorf, "Theory of Alternating Current Machines", 2nd Edition, McGraw Hill Book Company Inc., pp.400-408.

[3.] D.P. Kothari, I.J.Nagrath, "Electric Machines" Sigma Series, Tata McGraw Hill Education Pvt. Ltd. New Delhi, pp.190-191.

 ISSN: 2321-8169
787 - 791

[4.] Ashfaq Husain, “Electric Machines”, 2nd Edition, Dhanpat Rai and Company Pvt. Ltd. New Delhi.
[5.] Gabriela Dana Petropol Serb, “Numerical Approach of the Partial Magnetic Characteristics method used to find the voltage regulation in the design algorithm of a synchronous generator”, 13th International Conference on Optimization of Electrical and Electronic Equipment (OPTIM), 2012 ISBN-978-1-4673-1653-8/12-IEEE, pp. 745-750.
[6.] D.K. Patel, J.K. Chauhan, A.R. Patel and N.G. Mishra, “A User Friendly Simulation for Transformer Vector Group”, IEEE International Conference (CSNT-2012), ISBN- 978-1-4673-1538-8, pp. 820 – 824.
[7.] S.G.Tarnekar, P.K. Kharbanda, S.B. Bodkhe., S.D. Naik, “Laboratory Courses in Electrical Engineering”, S. Chand Publications, pp. 295-301.
[8.] Shrimad Ram Charit Manas by Goswami Tulsidas.
[9.] www.mathworks.com