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VARIABLE LOAD, CONSTANT SPEED, AND ESTIMATED CAPACITANCE RELUCTANCE GENERATOR

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ABSTRACT

Switched reluctance machine has various desirable features, which comes from its simple construction. They are the wide speed range, high temperature operation and small moment of inertia, constant frequency irrespective of load or capacitance variations with good efficiency and improved voltage regulation. It is possible to use it as a wind driven alternator which may be connected to the common network.

The steady-state analysis of the reluctance generator based on d-q axes transformation is carried out, with the saturation effect as an essential element. The required capacitance in the different operating conditions is determined to satisfy the main requirements of constant voltage for a loaded reluctance generator. This system proposed feasibility and validity are simulated on MATLAB/SIMULINK.

1. INTRODUCTION

Wind generation is one of the renewable energy power sources that help in reducing the carbon dioxide from our atmosphere [1, 2]:

- The construction and installation of the wind generator has the lowest environmental impact of all energy sources; it occupies less land area per KWH than any other energy source apart from the roof top solar energy.
- The green house effect of wind energy generator (WEG) is almost negligible compared with any other energy sources.
- Short time for construction, long work life, Low cost and maintenance.
- Due to the modern electronics, electrical and mechanical equipment the control of is excellent.

In order to extract energy from the wind, machine that can be controlled to generate at variable load and variable speed are preferred of advantage to ensure optimum performance. Among the common types of machines used for wind energy are: double fed induction generator (DFIG), induction generator and also synchronous generator [3]. Wind powered generators must operate efficiently under variable speed conditions. Although the efforts are getting it from conventional machines, a devoted special machine is welcome. The switched reluctance machine as a motor has been known for over 150 years. The generating mode of this machine SRG has created considerable interest during past few years in machine systems which either generate or regenerate [4].

The switched reluctance machine represents one of the simplest types of electrical machines and the Switched Reluctance Generator – SRG is a potential device for variable speed power generation [5].

Important work has been done in the field of analysis and design of reluctance motor, and some authors attempted to develop an equivalent circuit for RG, neglecting the effect of rotor saliency [6]. Another model similar to that of a salient pole alternator without field winding is

developed, with its analysis based on Park's transformation. Expressions for cut-off speeds under open circuit and pure inductive loads are derived [7], while a laboratory model obtained from induction machine with axially laminated anisotropic rotor is presented in [8].
In this paper, a simple analysis has been made to study the steady-state performance of an isolated self-excited RG under different operating conditions. The determination of capacitance values required to satisfy the rated voltage for various loads, it is the purpose of this work. The analysis is adapted and extended to be valid for operation of RG at any load, and the capacitance range required maintaining the voltage constant through definite variation of load is also obtained. A computer model based on d-q axes transformation is developed and some of the computed curves.

2. ANALYSIS OF A SELF-EXCITED RELUCTANCE GENERATOR

The generated voltage depends upon the speed of the external drive, the amount of terminal capacitance and the load current and power factor. Practical utilization of such idea in electric power generation was realized recently in conjunction with the increasing interest in wind energy as a substitute for nonrenewable energy resources.

2.1Effect of the Load Impedance Variation on the Load Angle

The steady-state analysis of RG based on d-q axes transformation is carried out taking the saturation effect as an essential element into consideration. We can calculated the load angle δ may be expressed in terms of Xq, Ra, φ, Z_L and the self-excitation capacitance C [9] as in the following relation:

$$\delta = \tan^{-1} \frac{X_q \cos\varphi - R_a \sin\varphi + Z_L R_a \omega C}{X_q \sin\varphi + R_a \cos\varphi + Z_L (1 - X_q \omega C)} \quad \textbf{(1)}$$

When the quadrature axis magnetizing reactance Xq, Ra is the armature resistance, φ is **power factor angle, the load impedance** $Z_L = \sqrt{R_L^2 + X_L^2}$ **and the** capacitive reactance Xc= 1/ωC. To enable the simulation and the comparison between the different studied cases, all of the obtained results have been computed and simulated for the SERG having the following data:
f = 50 Hz, Vn= 220 V, In= 2.2 A, Zb= 100 Ohm, Ra= 0.1 p.u, Xd (unsaturated reluctance value) = 3 p.u, Xq= 0.8 p.u., 0.8 lag power factor . For all figures, all values except the excitation capacitance are in per unit (P. U.).
Figure 1 shows the variation of the load angle δ against the self-excitation capacitance C, for variable load impedance. The load angle δ increases as the self-excitation capacitance C increases, reaching a definite value. The range bound by the smaller and higher values of C is the operating range corresponding to the load variation. The self- excitation capacitance must be increased to compensate the load impedance increase.

2. 2 Effect of the Load Impedance Variation on the Direct Axis Magnetizing Reactance

The direct axis magnetizing reactance Xd can be calculated as:

$$X_d = \frac{Z_L + R_a \cos\varphi + (Z_L \omega C - \sin\varphi) R_a \tan\delta}{Z_L \omega C - \sin\varphi - \cos\varphi \tan\delta} \quad \textbf{(2)}$$

Where the angular frequency ω = 2πf, with f is the normal frequency, given at the synchronous speed ns. Figure 2 shows the values of X_d against the excitation capacitance C at different values of Z_L at constant speed. The behavior of X_d with the excitation capacitance, under fixed speed is such as X_d decreases from unsaturated value to reach a certain minimum value. With more increasing the value of C, the d-axis reactance increases again gradually to a value nearer to the unsaturated reactance of the machine. The two values of the excitation capacitance corresponding to the unsaturated d-axis reactance define the range for which self excitation is possible. These two values of C (minimum and maximum) are called the cut in and cut off capacitance, respectively. The results of Fig. 1 and 2 show also, that the range of operation is relatively wide at light loads and the range is narrow at full load operation.

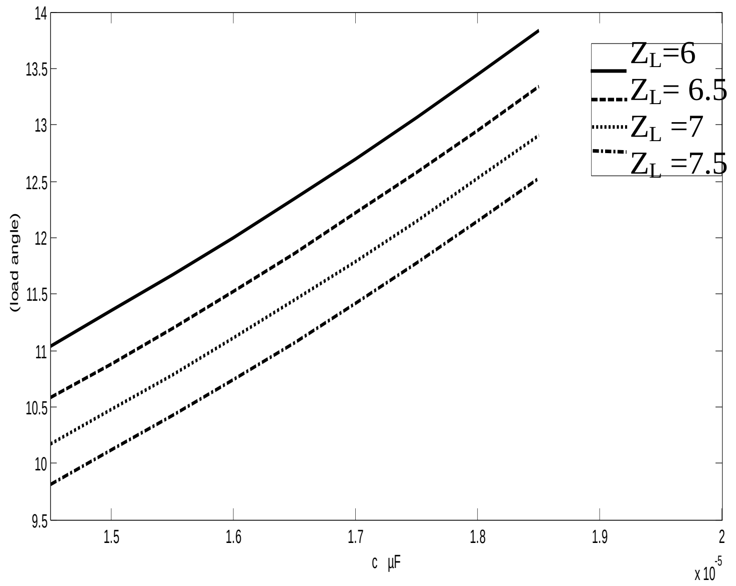

Fig. 1: load angle- excitation capacitance for variable load at 0.8 power factor.

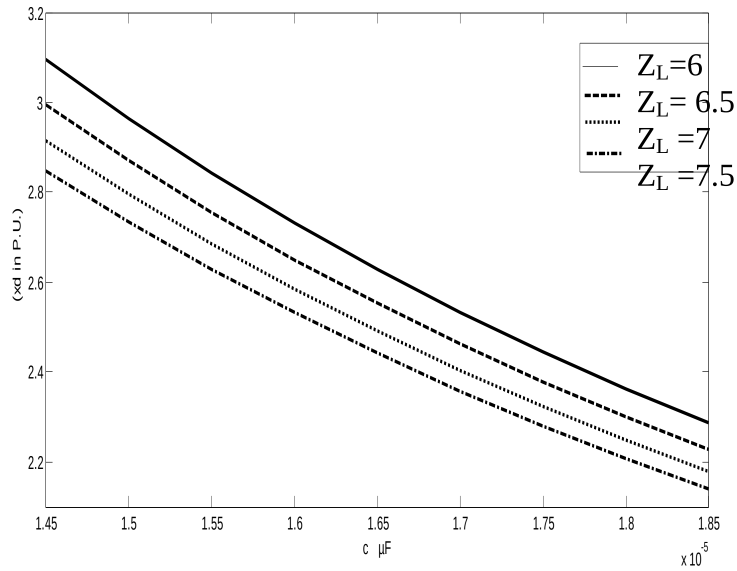

Fig. 2: Variation of d- axis reactance with the excitation capacitance for variable load impedance at 0.8 power factor.

The no load (open circuit) operation can be obtained from eq. 1 and 2, by taking their limits when both R_L and X_L tends to infinity, which yields the following simple relations:

$$\delta = \tan^{-1}\frac{R_a \omega\, C}{1 - X_q \omega\, C} \quad , \qquad X_d = \frac{1}{\omega\, C} + \frac{R_a^2\ \omega\, C}{1 - X_q \omega\, C} \qquad \textbf{(3 a, b)}$$

Similar results for other modes of operation such as pure resistive load (unity power factor), and pure inductive load (zero power factor) can be directly established.

2. 3 Effect of the Load Impedance Variation on the Terminal Voltage

On the basis of the analytical technique stated above, a suitable computation is carried out to study the steady-state performance of the isolated RG under different loads and various machine parameters. With the knowledge of the machine parameters, terminal capacitance, and load impedance, it is possible to determine the load angle and hence the d-axis reactance Xd.

From Eqs. (1,2) the load voltage my be expressed as:

$$V_L = I_d \frac{Z_L}{Z_L \omega\ C \cos\delta - \sin(\varphi + \delta)} \qquad \textbf{(4)}$$

By the extrapolation of the machine saturation curve, for each value Xd the corresponding Id is then predicted. It is evidented that the RG will fail to excite if the operation state requires a value of Xd greater than the unsaturated reactance of the- machine.

The d-axis saturation curve is represented by a suitable fitting technique to give Id as function of Xd which is given in the following predicted relation [9]:

$$I_d = 0.49 X_d^2 - 2.6 X_d + 3.8 \qquad \textbf{(5)}$$

Figure 3 shows the variation of the terminal voltage VL against the excitation capacitance C under fixed speed and for different values of load impedance. The excitation capacitance increases the terminal voltage decreases at constant value for excitation capacitance and form this value the excitation capacitance increases the terminal voltage increases reaching its maximum value at the end of the excitation range. It is obvious that the generator beyond this value of C does not operate and accordingly the terminal voltage drops to zero.

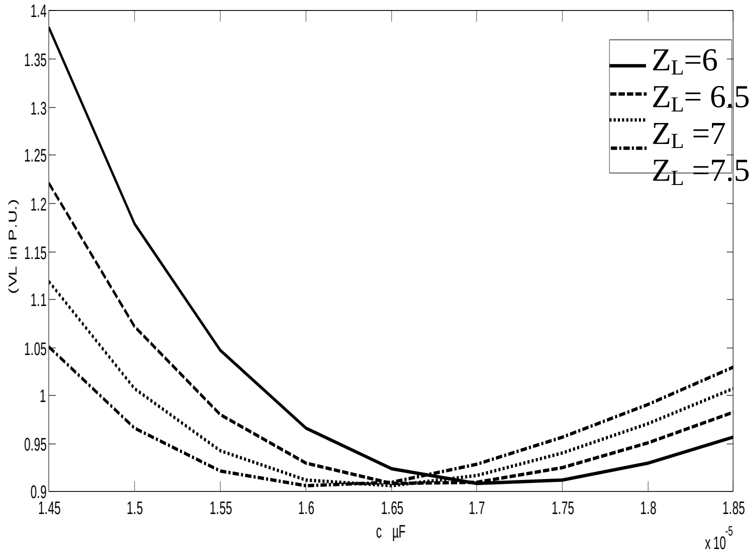

Fig. 3: The excitation capacitance against the terminal voltage at different variable load impedance at 0.8 power factor.

2. 4 Effect of the Load Impedance Variation on the load and capacitor currents

When V_L is known, the other performance variables of the RG such as load and capacitor currents can then be determined.

$$I_L = \frac{V_L}{\sqrt{R_L^2 + X_L^2}} \tag{6a}$$

$$I_c = V_L \omega C \tag{6b}$$

Figures 4, 5 shows the variation of the load current I_L and the excitation current Ic against the excitation capacitance C, for various loads impedance at 0.8 power factor.
Both the load and the excitation currents increase by increasing the self excitation capacitor. This is because of increasing the self excitation frequency.

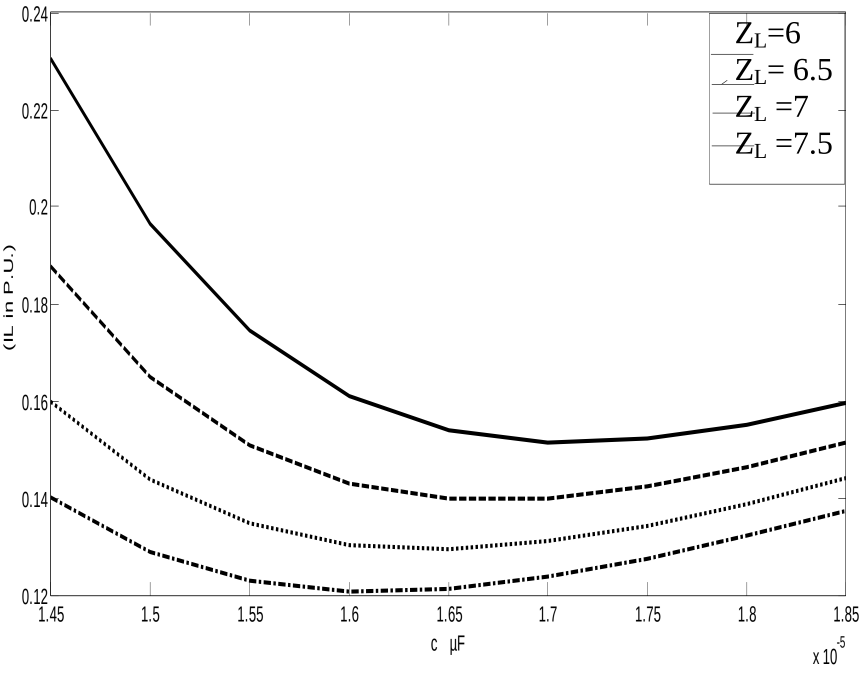

Fig. 4: Variation of load current with the excitation capacitance for variable load impedance at 0.8 power factor

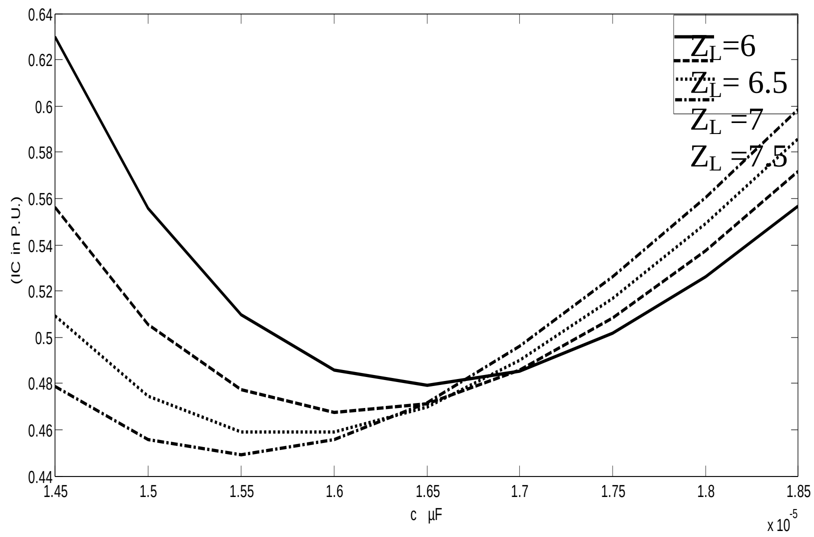

Fig. 5: Variation of excitation current with the excitation capacitance for variable load impedance at 0.8 power factor.

3. CONSTANT VOLTAGE SERG WITH THE LOAD IMPEDANCE VARIATION

Using Eq. 4, variation of the excitation capacitance with the load impedance at different constant terminal voltages are computed for the purpose of stable operation of the SERG that is connected to the main electricity network. It is obvious in Figure 6 that, the required excitation capacitance decreases with the increasing of the load impedance value at the maintained constant terminal voltage.

To provide constant terminal voltage of RG at any load variation, the self excitation capacitance must be varied in a suitable wide range. The computed self-excitation capacitance range for the described RG which gives constant voltage, through the load variations is about (15.5 to 18.5 μF). This range of C may be limited as well as the load variations are limited.

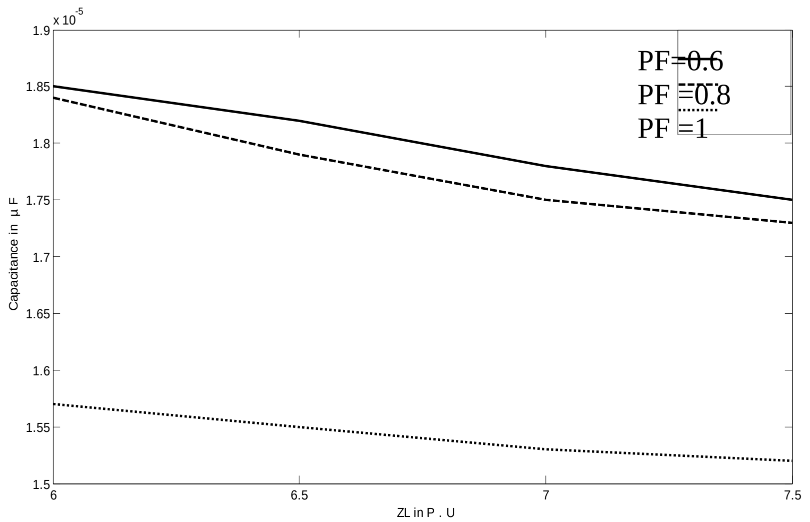

Fig. 6 : Variation of excitation capacitance with load impedance for variable power factor at constant terminal voltage.

4. CONCLUSIONS

This paper has presented a comprehensive technology review of switched reluctance generators.

The self-excited reluctance generator has good voltage regulation, high efficiency and fixed frequency irrespective of the load changes or capacitance variation. The generator provides also suitable operating conditions as a wind driven alternator, however, an intermediate frequency converter is required for feeding an isolated load.

The required self-excitation capacitance range which enables the terminal voltage of the generator to be constant for different load values.

When the power factor decreases, the excitation capacitance should be increased to compensate for the inductive components and to provide the SERG with the reactive power required for the self-excitation.

The suitable design data provides, high performance for high saliency ratio and avoids also, unrequited circuit resonance which occurs when the excitation and q-axis reactance approach each other within the speed range.

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