Performance Analysis of Isolated Self-Excited Reluctance Generators Connected to Diode Bridge Rectifier

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***ABSTRACT* - This paper presents the performance of a three-phase self-excited reluctance generator connected to a diode bridge rectifier. The steady-state mathematical model is used to perform the self-excited reluctance generator performance. The performance is presented under load and no load cases for different operation conditions. The experiments are performed using a prototype reluctance generator. MATLAB/SIMULINK software is used to simulate the system. The simulation results are compared with the experiment results.**

***Keyword**: Reluctance machine, Wind turbine, Induction generator.*

المستخلص– في هذه الورقة تم توضيح خصائص مولد الممانعة المغنطيسية الذاتي الاثارة موصل الي مقوم قنطرة. تم استخدام النموذج الرياضي في الحالة المستقرة لتمثيل أداء مولد الممانعة المغنطيسية الذاتي الإثارة. تم عرض الخصائص لهذا المولد في حالة الحمل والاحمل عند ظروف تشغيل مختلفة. لاجراء التجارب العملية تم استخدام نموذج مولد ممانعة مغنطيسية. كما تم استخدام برنامجMATLAB/SIMULINK لمحاكات النظام. تمت مقارنة النتائج المعملية بالنظرية التي تم الحصول عليها من بالبرنامج.

INTRODUCTION

The reluctance machines have simple salient pole. Its rotor has special construction with no windings on it. They have been used as motors and the study has concentrated on their design and performance [1-6]. Its terminal voltage when it used as generator is built-up by connecting sufficient capacitance across its terminal. This is called self-excitation. The frequency of generated voltage in the case of reluctance generator depends only upon the mechanical speed of rotation. This makes it easier to control [7].

Researchers considered using reluctance machines as isolated generators in wind turbines in the late eighties [8-17]. Self-excited reluctance generators have many advantages compared to self-excited induction generator [18-20]. In addition, they display a well-defined relationship between rotor speed and output frequency, and display low core and copper loss. To determine the performance characteristics of self-excited synchronous reluctance generators a number of different methods have been proposed [10-17]. This paper studies the performance analysis of the isolated self-excited generating system, employing reluctance machine as self-excited generator, connected to diode bridge rectifier with a variable speed prime mover such as wind turbine. This performance is performed under no- load and load conditions.

The analysis technique is used to simulate the performance of a prototype reluctance generator under no-load and load. The experimental results from a prototype machine are used to verify the analysis technique.

BUILT-UP VOLTAGE

Reluctance machines start as the induction machines and synchronize with supply near synchronous speed. Similar to induction machines, reluctance machines can operate as generator if the mechanical input power is increased. The reactive power can supplied from the main supply and the electrical power can be fed to supply grid and the machine will be operating as a constant speed generator unlike induction generator.

The machine may generate electrical power without the necessity for an external supply, if an excitation path is provided by sufficient amount of capacitance connected across the machine terminals, while maintaining rotation by some external mechanical power. The generated voltage is found to be dependent upon the amount of capacitance, speed, load current and power factor. The machine is termed in this case as "stand alone or isolated self-excited reluctance generator".

Physical explanation for voltage build-up can be set as follows: Due to presence of residual magnetism in rotor core voltage is induced in stator windings upon rotor rotation. Maximum induced voltage in stator windings occurs when stator conductors cut residual flux pole axis. If a capacitor is connected to stator windings this means that current in stator windings will have its maximum value in a position 90 ahead of voltage maximum position. In this way air gap flux increase and hence induced voltage till stable operating point is reached.

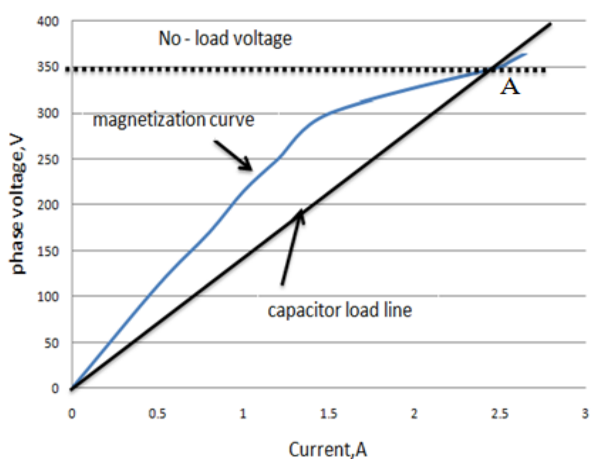

Figure 1: No-load characteristic at 50Hz

Stable operating point indicates that the machine is in saturation state. If the machine is not saturated the voltage will be zero and this is a basic point in self-excited machine, that is, without saturation there will be no stability in operation. The corresponding magnetizing curve is shown in Figure 1.

A 3-phase variable capacitance bank is connected to the machine terminals and self-excitation occurred for capacitor values over 20 µF per phase. Once self excited, the magnitude of the terminal voltage is determined by the point of intersection (A) of the machine magnetization curve and the capacitor load line. This point lies in the saturation region of the generator magnetization curve. Any increase in capacitance or rotor speed reduces the slope of the capacitor load line, thus increasing the generated voltage.

THREE-PHASE BRIDGE RECTIFIERS

Three-phase bridge rectifiers are commonly used for high power applications because they have the highest possible transformer utilization factor for a three-phase system. In this paper the three-phase bridge rectifier is used. It connected to the terminals of the reluctance generator as shown in Figure 2.

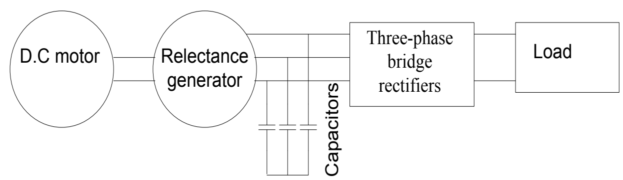

Figure 2: Schematic of Self excitation reluctance generator connected to diode bridge rectifier.

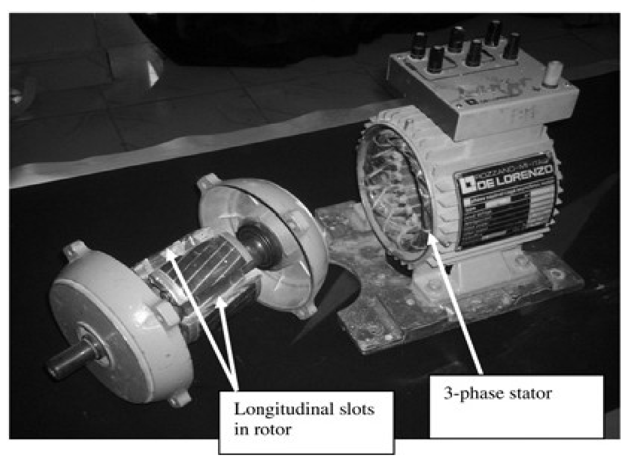

Figure 3: a photograph of the dismantled system

THE EXPERIMENTAL RESULTS

In this paper a three-phase squirrel-cage induction machine is used after its rotor had modified to a reluctance machine. The original induction machine is a four pole, 2.01 hp. 4-pole, 1500rpm 415V, Y-connected machine [10]. Figure 3 shows the photograph of the induction machine after milling four equi-spaced longitudinal slots along its squirrel-cage rotor. The dimensions of the rotor are shown in Figure 4.

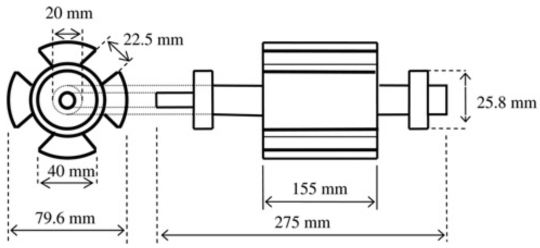

Figure 4: Design details of the rotor

A test is carried out to determine the significant machine parameters of the prototype reluctance machine. This test includes standard DC, locked rotor, load and no-load test [10]. Table 1 shows the parameters of the prototype of the reluctance generator at *fr*=50H.

A variable speed DC motor is used to act as the prime mover to rotate the rotor of the reluctance generator. A bank of balanced three phase capacitors is connected to the terminal of the prototype reluctance generator. The results for different values of excitation capacitance, speed, and load conditions are recorded.

Table 1: Prototype reluctance generator parameters at fr=50Hz

Item	Value
Air-gap length, mm	0.250
Unsaturated saliency ratio	3.700
Stator winding resistance, Ω	10.12
Unsaturated d-axis reactance, Ω	181.8
Unsaturated q-axis reactance, Ω	49.11
Pole arch to pole pitch ratio	0.490

No load performance

The generator is driven in this case at variable values of rotor speed while its terminals are connected to fixed value of a balance three phase excitation capacitors. Variations in induced voltage versus speed is shown in Figure 5 this for machine alone and Figure 6 shows the machine when it connected to diode bridge rectifier, that for capacitors 20, 32 μF per phase respectively.

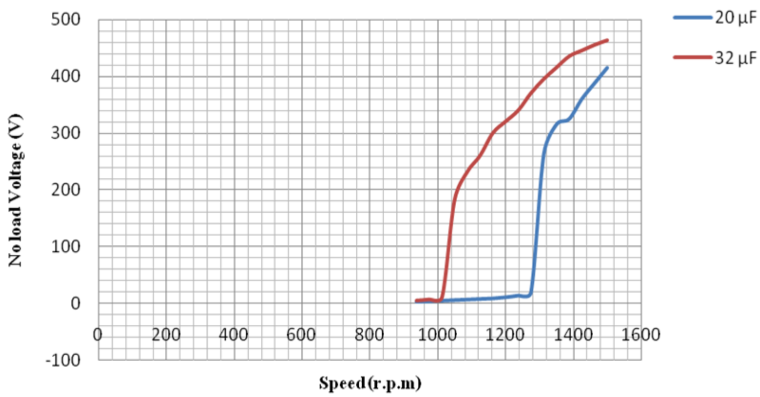

Figure 5: voltage build up against rotor speed of self-excited reluctance generator alone

Figure 6: voltage build-up against rotor speed of self-excited reluctance generator connected to diode bridge rectifier

It could be observed from Figures 5 and 6 that increasing generator speed leads to increased values of terminals voltage. As voltage build-up starts the initial rate of increase in voltage with respect to speed is observed to be high up to a certain level. When the machine terminal voltage is high, the core becomes highly saturated and such a rate decreases.

On the other hand, it is observed that increasing the value of capacitor leads to consequent increase in the terminal voltage at the same speed. It could be observed that voltage build-up for a specific capacitor occurs after a specific speed has reached. Such a speed is called the critical speed. Increasing the value of excitation capacitor will lead to decrease in the value of the critical speed for example it is 1000 rpm for capacitor 32 µF and 1100 rpm for capacitor 20 µF. Also it can be observed that when the generator is connected to a diode bridge the value of the critical speed is decrease.

Load performance

The initial build-up of the voltage is accomplished by connecting suitable values of capacitors. Once self-excitation has been achieved, the generator is loaded with resistive load. The load characteristic of the reluctance generator is very similar to a dc shunt generator. Figures 7, 8, and 9 shows load characteristics of reluctance generator for capacitance value 32µF at different rotor speeds while Figure 10 shows load characteristics at rotor speed 1200rpm and capacitance value 20µF. From load characteristics, it can be noted that an optimum combination of capacitors and rotor speed is exist, resulting in maximum output power.

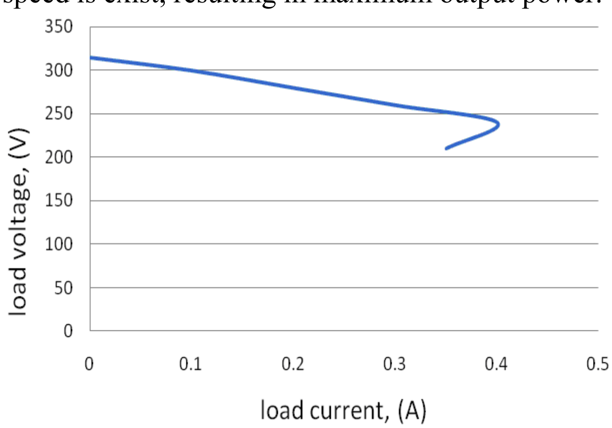

Figure 7 load current versus load voltage, C=32 µF and N= 1100rpm

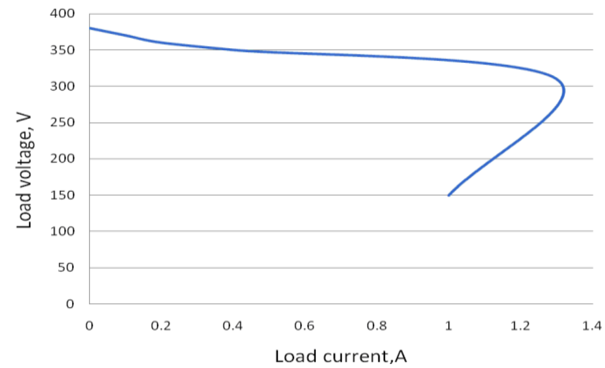

Figure 8: Load current versus load voltage C=32µF and N= 1200rpm

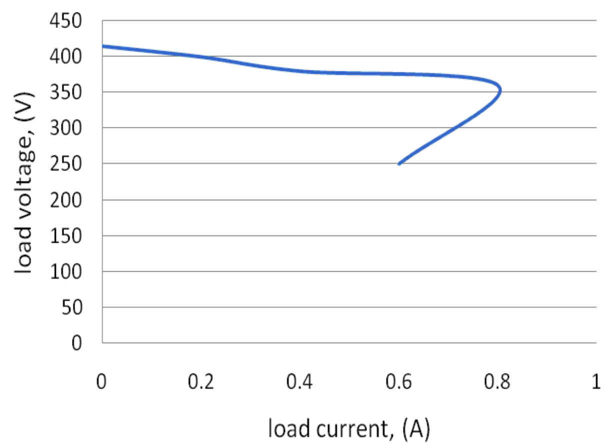

Figure 9: Load current versus load voltage C=32µF and N= 1300rpm

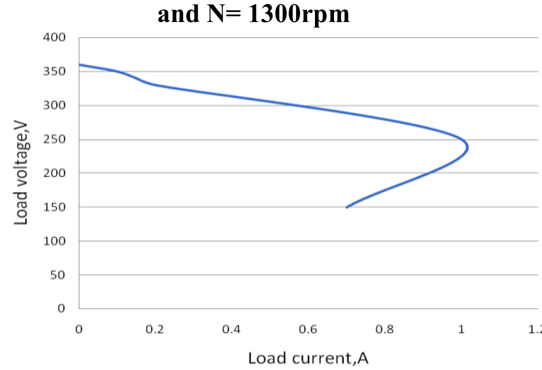

Figure 10: Load current versus load voltage C=20µF and N= 1200rpm

THE SIMUTATION RESULTS

A computer program, using the MATLAB/ SIMULINK is used to represent the self-excited reluctance generator connected to diode bridge rectifier. The load characteristics are shown in Figures 11 and 12 for two capacitance values 32 and 20µF respectively. The simulated results are presented and compared with corresponding results obtained experimentally. There are some different between simulated and experimental, it is found from the results shown in Figures 11 and 12 that the load current versus load voltage is polluted by the injecting harmonic from the rectifier load.

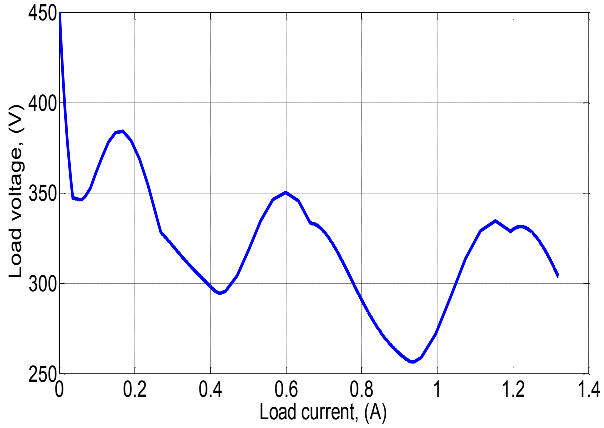

Figure 11: load current versus load voltage C=32µF

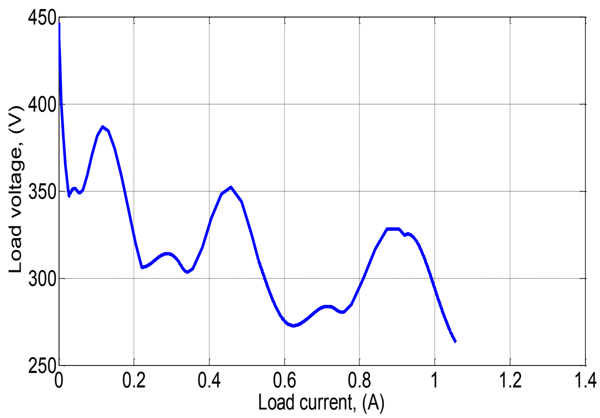

Figure 12: load current versus load voltage C=20µF

CONCLUSIONS

This paper presented the performance analysis of the isolated self-excited generating system, employing reluctance machine as self-excited generator, connected to diode bridge rectifier with a variable speed prime mover. The experimental performance of a self-excited reluctance generator is given. The reluctance generator has added advantage of no rotor copper losses due to synchronous nature of operation. Though a simple salient pole design has been used for experimental purposes but much improved performance can be achieved by employing optimized rotor structure. From the results it has been found that the reluctance generator is suitable.

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