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Development of an Experimental Platform to Drive the Switched Reluctance Machine

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Abstract. This paper presents the implementation of an experimental platform for the study and drive the Switched Reluctance Machine (SRM) 6x4 as generator and motor. The platform allows trials for the reluctance machine under various operating conditions such as speed, excitement and magnetization variable angles (θ_{off}), allowing study their behavior in wind generation. The test parameters are fully configurable through an application developed specifically for this job. It was also used a system of acquisition and processing of low-cost and high-performance data (*DSP / FPGA*), which guarantees the precise activation and control of all experimental platform. The experimental results are presented and discussed.

Key words

Switched Reluctance Machine, Workbench, FPGA.

1. Introduction

Currently a good portion of all the electricity produced in an industrialized nation is processed by electric motors. On generation, despite the diversity of alternative sources available, rotating electrical generators are responsible for almost all of the electricity produced. Giving unparalleled importance to electrical machines.

Thus, the electrical machines must be under constant investigation, in the search for better indices of efficiency and performance. In recent years, the development of power electronics and micro processed systems contributed to the improvement of these indexes systematically, allowing an increase in the exploitation of renewable energy sources as solar and photovoltaic.

This evolution of the electronic systems allowed the variable reluctance machine to become a strong candidate for use in wind energy applications[1], due to its intrinsic characteristics, such as: simple design, good power-to-weight ratio, high starting conjugate, ideal for applications with variable speeds.

Thus, this work presents the implementation of an experimental platform for the study and drive the SRM as a generator.

2. Constructive Aspects of SRM

Being composed primarily of a stator and a rotor with salient poles as shown in Figure 01, SRMs are machines simple to be designed and built, with the possibility of operation at variable or high speeds, has good heat resistance and eliminates the necessity of windings in the rotor thereby reducing its manufacturing costs.

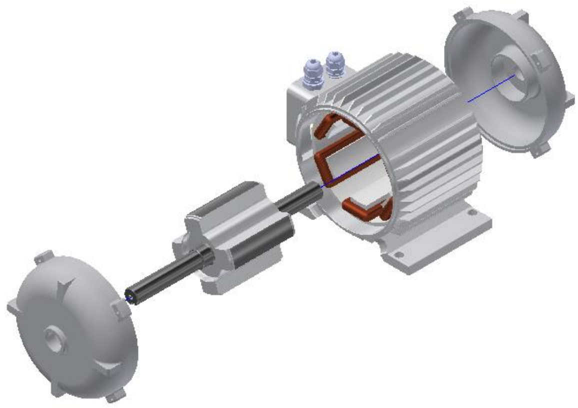

Fig. 1. General view of Switched Reluctance Machine.

The Switched Reluctance Machine operating as generator acquire mechanical power from a primary source and convert into electrical energy. When one of the rotor poles is aligned with the stator pole excited, a stable equilibrium is created, causing a natural tendency of the rotor aligns with the excited pole, which causes an increase in the inductance in this phase. The figure 02 shows the inductance profile obtained in SRM that depend mainly on the rotor shaft position and machine excitation current, the curve was obtained by finite element method and is presented in [1]. the curve represents a quarter turn, repeating the same behavior over the course of a ride, for all other stages the curve is shifted in 30 and 60 degrees.

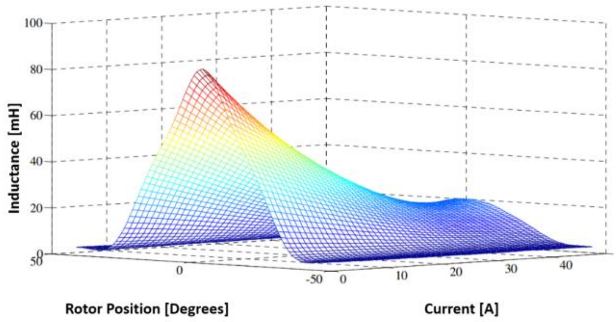

Fig. 2. Inductance profile for different values of current and position.

When an external force acts on the rotor in order to move it from its stable equilibrium position, comes a counter-electromotive force causing the voltage to rise and thus generating electricity. The counter-electromotive in SRM depends crucially on the current, speed of the machine and inductance variation of the position of axis.

As the excitement is done with direct current, the change in position will be always positive, so the sign of counter-electromotive force is determined by the inductance variation as a function of rotor position, thus defining the operation of SRM as a motor or generator.

3. Experimental Platform

The SRM drive process, along with its control can become somewhat complex and confusing, as you need to perform the interconnection of multiple devices and different circuits, generally with ground distinct and isolated. In order to facilitate the tests and trials, and leave the drive SRM of didactic and simplified form, a workbench is designed to drive SRM, allowing it to be operated as a motor and generator. Figure 03 shows a simplified diagram of designed workbench.

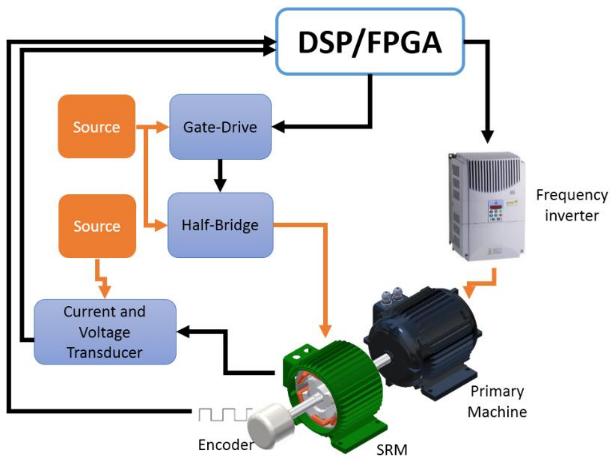

Fig. 3. Simplified diagram of the built workbench.

For detecting the instantaneous position of SRM axis, was used an absolute encoder. The signal from the encoder input is acquired by the DSP / FPGA device, then it is determined the actual position of the axis, thereby estimating the behavior of the inductance in each phase of the SRM.

Whereas the energization of machine phases while increasing the inductance, featuring actuation thereof as the motor, and the energizing of the phases SRM during the decrease of the inductance characterizes the operation as a generator, it was possible to determine the moment of activation (θ_{on} and θ_{off}) to each type of operation.

In operation the SRM needs a converter that provides excitement for it. The literature shows a variety of topologies of converters used for machine operation, however the most widely used due to operational characteristics is the Half-Bridge (HB) [1], [2], [4] e [7]. Figure 04 shows the circuit of this converter to drive an MRV 6x4 with a relay to determine the type of actuator to be held, motor or generator.

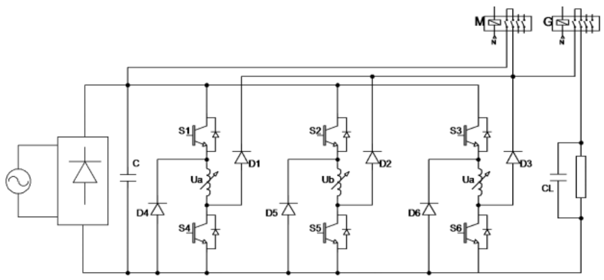

Fig. 4. Converter Half-Bridge (HB).

For construction of the HB converter was necessary to use two IGBT modules BSM50GD120DN2E3226, each module consists of six IGBT switches. An arrangement was made between two modules, so that in each module were used three IGBT switches and three freewheel diodes, Figure 05 shows the arrangement made between the IGBT modules.

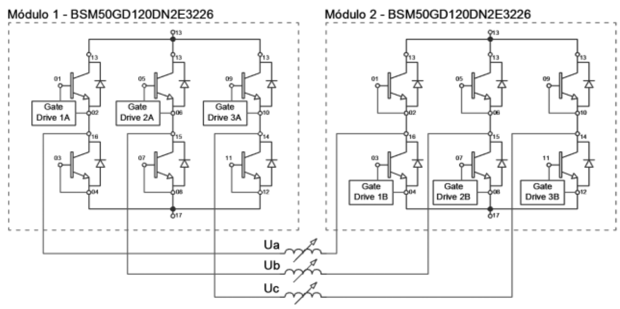

Fig. 5. Arrangement made between the IGBT modules.

For the IGBT keys drive was necessary to isolate signals coming from the controller, for this were built four galvanically isolated voltage sources, three for the top IGBT keys, one for each. For the lower keys was used only one source, since all the IGBTs have the transmitter in the same reference,

The circuit used to isolate the trigger signals for IGBT switches can be seen in Figure 06. The signal from the processor is isolated through an opto coupler, thus enabling the each drive pulse is on the same reference of the IGBT that will be triggered.

Also a signal transducer circuit was built to collect samples of current and voltage for the closed loop control. Being used two HALL effect sensors, one for voltage and one for current.

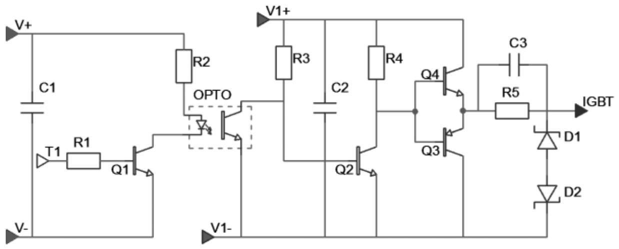

Fig. 6. Circuit used to isolate the trigger signals for IGBT switches.

To perform the control and drive of SRM was used a DSP / FPGA device. Allowing the drive is done by the DSP processor, FPGA device or in parallel between the two interfaces, significantly increasing the customization possibilities of the drive and control algorithms.

4. Experimental Results

The workbench was completed, allowing the activation and control of the reluctance machine for various purposes, enabling the development of new research into its operation and control techniques. The Figures 07 and 08 shows the photo of the finished workbench, along with SRM, Primary Machine and the encoder.

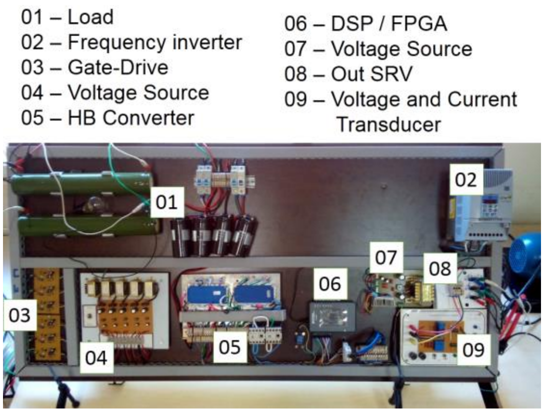

Fig. 7. Finished Workbench.

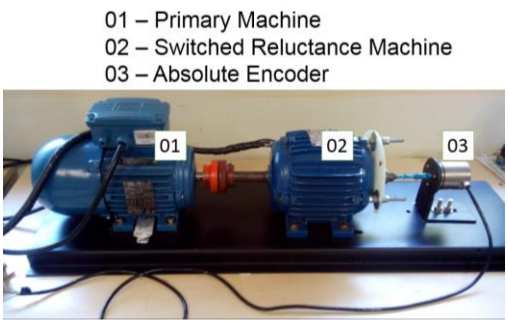

Fig. 8. Primary Machine, SRM and Encoder.

A supervisory interface was developed in Labview®, allowing the main view SRM's drive information such as:

- Show which phase is energized;
- View the encoder read values;
- Select the desired type of drive, motor or generator;
- Manually control the value of θ_{off} angle;
- Manually change the value of the spin on the primary machine;
- Move the encoder reference in relation to the phases of the machine;

The Figure 09 shows oversight screen developed.

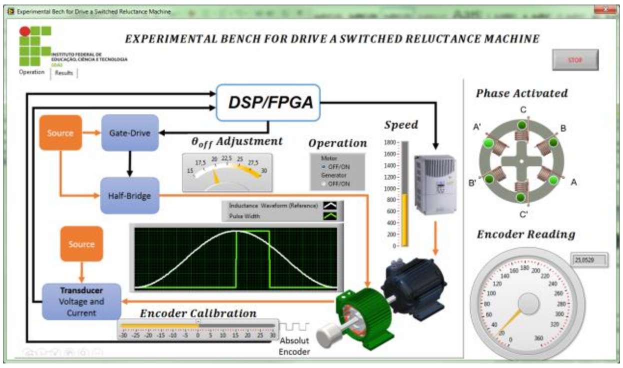

Fig. 9. Supervisory interface.

Some drives were made to check the operation of the the workbench and investigate the behavior of SRM from various points of operation. Figures 10 and 11 show the waveforms of the voltage and current while driving the SRM as a motor.

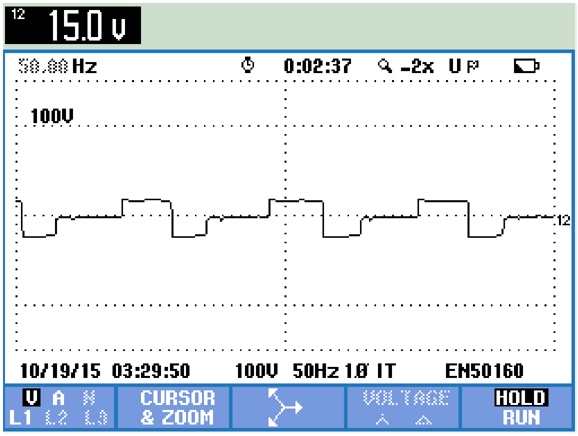

Fig. 10. Voltage waveform (Motor).

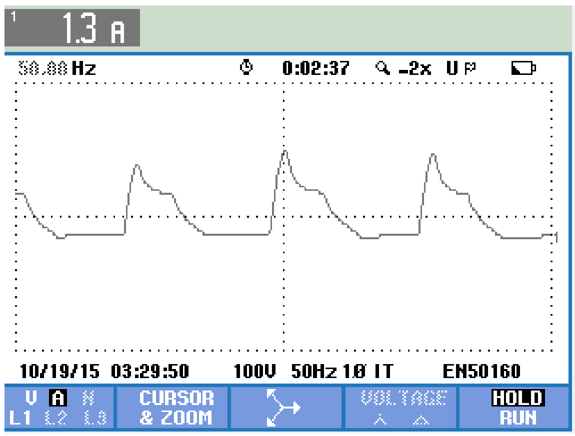

Fig. 11. Current waveform (Motor).

During the activation of the SRM as generator were collected waveforms of voltage and current, these waveforms are shown in Figures 12 and 13. Figure 14 shows the waveform of voltage at the load.

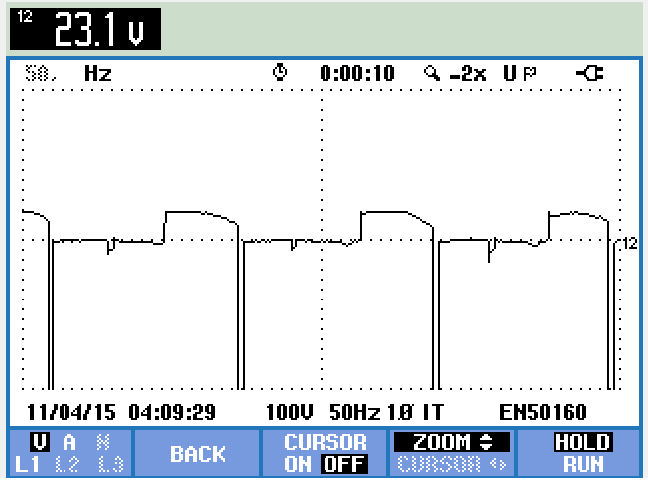

Fig. 12. Voltage Waveform (Generator)

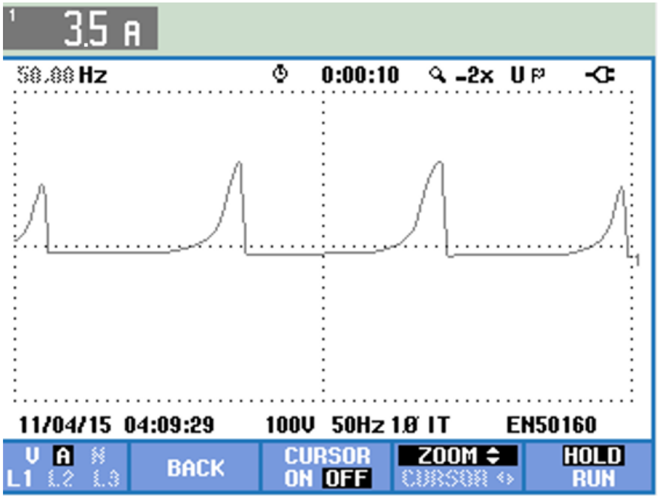

Fig. 13. Current Waveform (Generator).

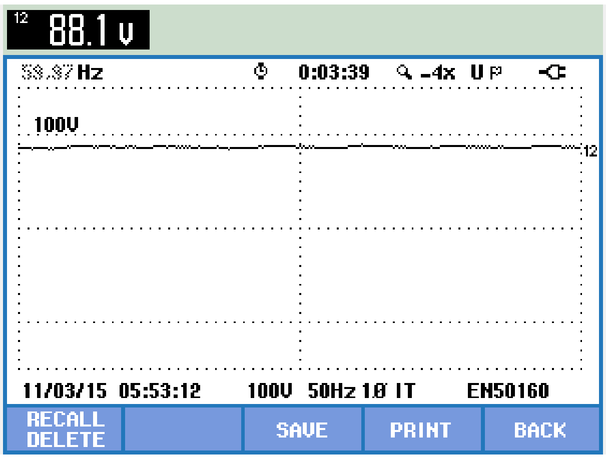

Fig. 14. Load Waveform.

During the drive as a generator, were carried out some tests to check the SRM behavior driven as generator, and checking the voltage generated due to the variation in the excitation voltage, θ_{off} and speed.

In the first test, the speed of SRM was 900 RPM and the resistive load 66,1Ω, the drive was done varying the excitation voltage 5 to 25V, while the θ_{off} was varied 15 to 30 degrees. The figure 15 displays those obtained results.

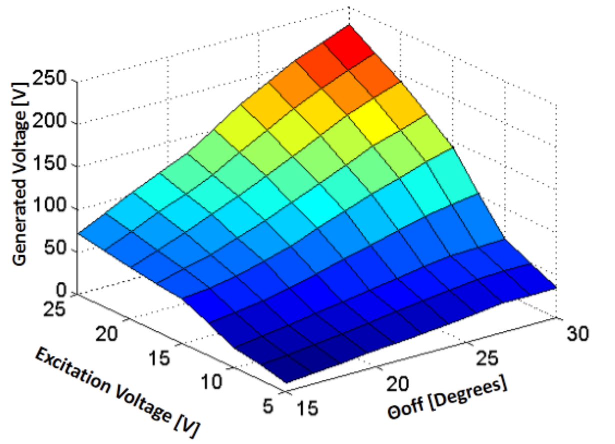

Fig. 15. Voltage generated due to the variation of excitation and θ_{off} value.

The Figure 16 represents the behavior of the voltage generated according to various excitation values. It can be seen from this figure, that there an elevation in voltage generated while the excitation is increased.

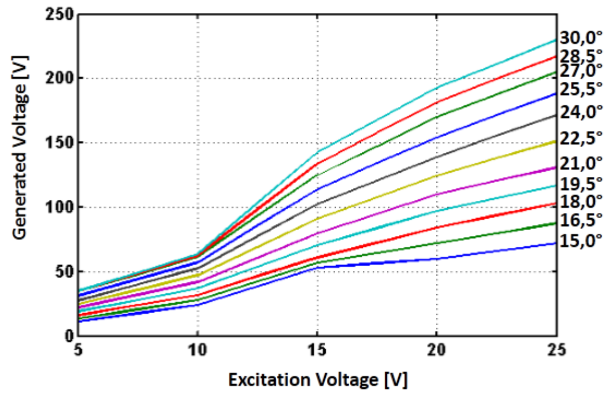

Fig. 16. Voltage generated due to the excitation range for different values of θ_{off}.

Similar behavior is observed for the variation of the angle θ_{off}, The Figure 17 shows the curves obtained by varying θ_{off}, each curve with different excitation values.

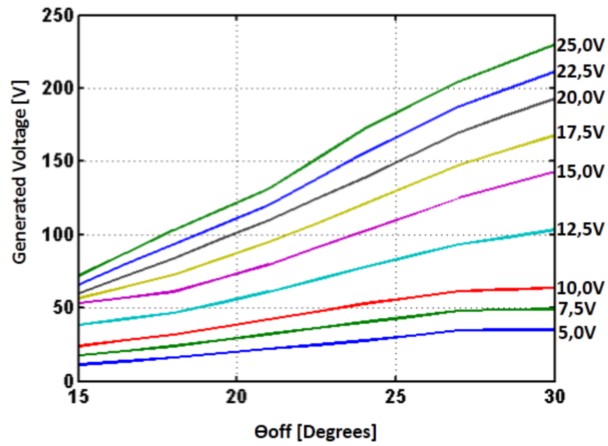

Fig. 17. Voltage generated due to the variation of the θ_{off} for different values of excitation voltage.

Due to be purely resistive load, the load power behavior was similar to the tension, showing a variation of 10 the 800W within the range of excitation used, as shown in Figure 18.

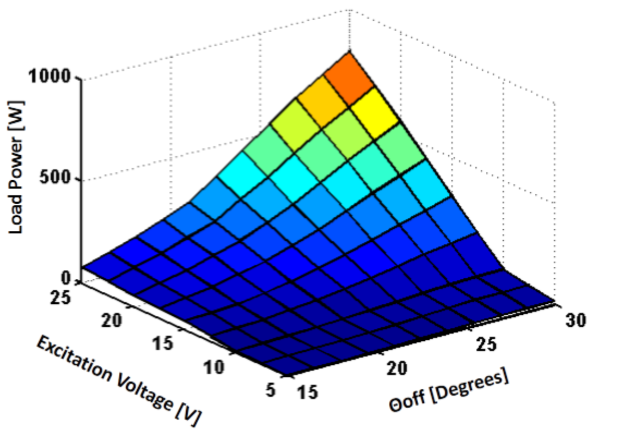

Fig. 18. Power generated due to the variation of excitation and θ_{off} value.

The curves in Figures 19 and 20 show the curves obtained at each measurement.

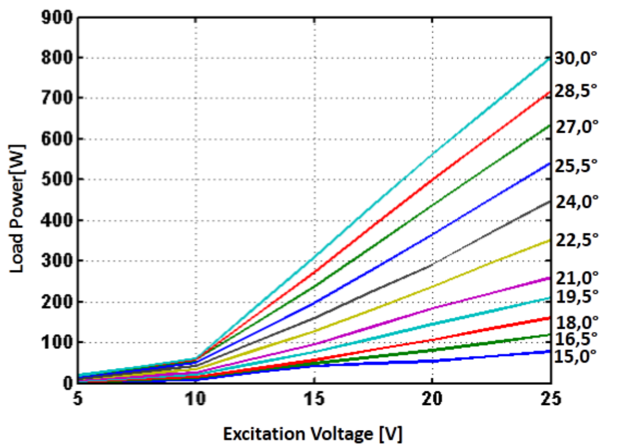

Fig. 19. Power generated due to the excitation range for different values of θ_{off}.

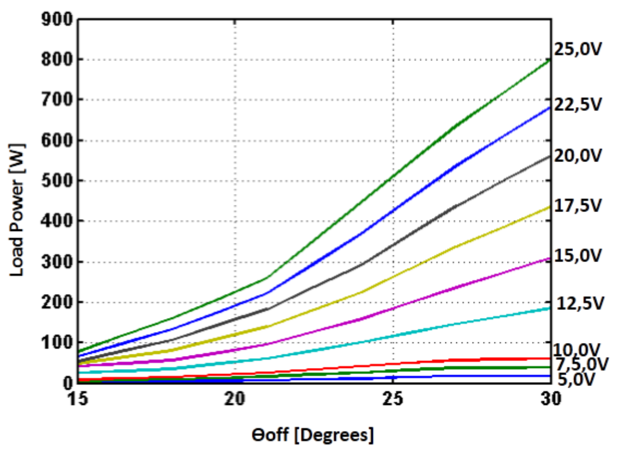

Fig. 20. Power generated due to the variation of the θ_{off} for different values of excitation voltage.

Through the collected results, it was possible to perceive the behavior of SRM, and the influence that θ_{off} and the excitation voltage is on the generated voltage. During tests the generated voltage ranges from 11,2V (5V/15degrees) to 231V (25V/30degrees), showing that it is possible to control the generated voltage by modifying the excitation voltage, the θ_{off} value or both.
Another test was performed by varying the drive speed of the SRM and keeping constant the excitation voltage (15V). The speed varied between 600 and 1200 RPM. The figure 21 present the results obtained.

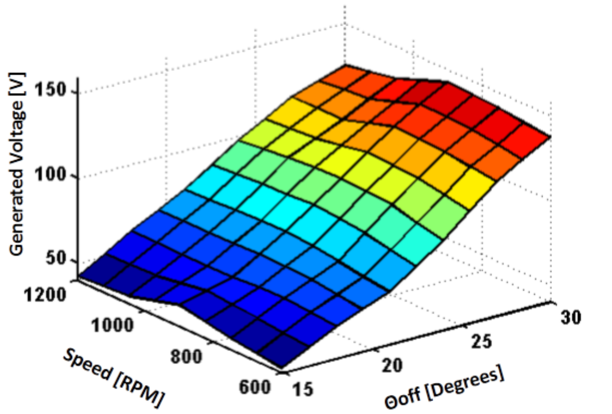

Fig. 21. Voltage generated due to the variation of speed and θ_{off} value.

From the results obtained, it realizes that the SRM drive speed also influence the generated voltage, but more mildly compared the influence of excitation voltage or variation of θ_{off} angle. Demonstrating that the Reluctance Machine presents an interesting behavior for applicaions involvind variable speed, as in wind generation, where the conduct of wind if fickle, showing different speeds throughout the day. Simplifying the project, eliminating the need to use mechanical drive, speed control.Figure 22 shows this behavior.

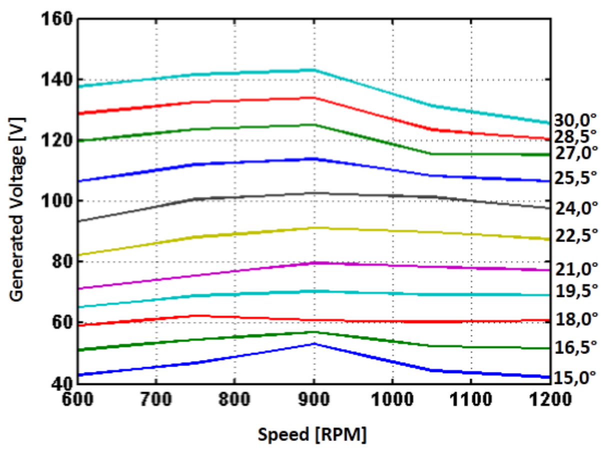

Fig. 22. Voltage generated due to the speedn range for different values of θ_{off}.

As in the variable excitation test, the power in load has similar behavior to the generated voltage, showing slightly higher values to low rotational speed. This behavior can be explained because at lower speeds, each phase of SRM remain energized for longer. Reinforcing the applicability of Switched Reluctance Machine for

applications involving wind generation, which usually feature low rpm [1].
The results are shown in Figures 23 and 24.

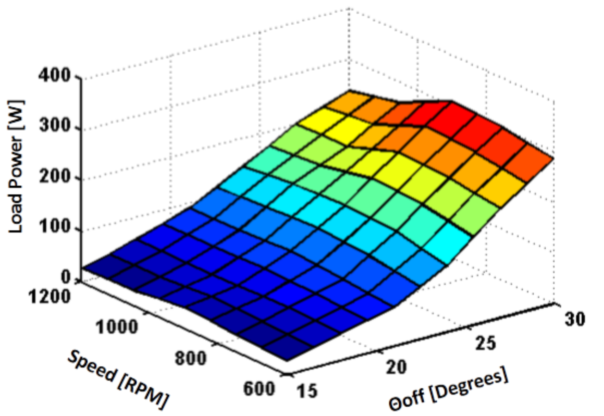

Fig. 23. Power generated due to variation of speed and θ_{off}.

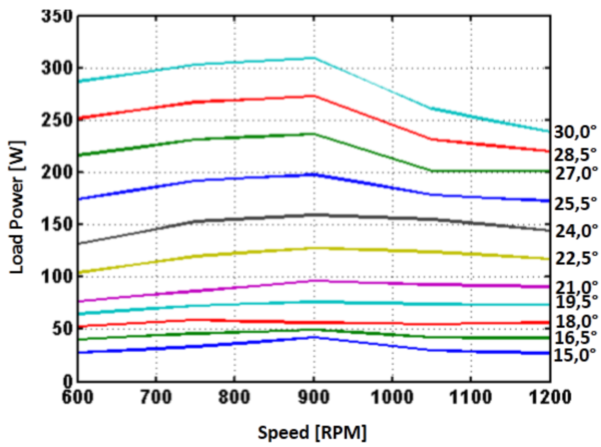

Fig. 24. Power generated due to the variation of speed for different values of θ_{off}.

Since this is a preliminary study in order to verify the functioning of the workbench and due to the fact be operating in open loop, the drive speed is made for relatively low rotation, from 600 to 1200RPM. For high speeds, it is expected that influence in the generated voltage have similar behavior to the presented, however this issue will be addressed in future work.

5. Conclusion

The bench was built and will be very useful for the study of the actuation and control of the reluctance machine, enabling the development of various research about the machine applied to wind generator, Allowing consider intrinsic characteristics of wind generation, such as wind profiles. The bench still allow research on the activation and control of SRM as motor, motor-generator and generator for other applications, such as automotive and aerospace. These results indicate the viability of the proposed system.

Acknowledgement

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