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CHARACTERIZATION OF A LOW POWER WIND TURBINE PROTOTYPE FOR INTERCONNECTION TO THE GRID

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ABSTRACT

In this article, a prototype of a low power wind turbine interconnected to the NETWORK and the controlled electronic converter for the rectification of the generated voltage was designed, which is used for the conditioning of the electrical power generated by low power wind systems for the Connection to the electric grid. Using different electronic components and free hardware development boards, the construction of a controlled three-phase rectifier prototype was carried out, divided into 3 modules, the first one in charge of obtaining a reference signal and synchronization of the voltage to be rectified, the second is the control circuit, which performs the time calculations for the activation of the third module, in charge of rectifying the triphasic voltage using thyristors (SCR), in which the moment of activation of the semiconductors can be controlled. Finally, tests of the prototype connected to a wind turbine built by teachers and students of the Technological University of Campeche were carried out, verifying its correct operation in the rectification of the voltage delivered by this generator.

I. INTRODUCTION

Energy obtained from wind provides an important part of the world's electrical energy to satisfy energy requirements, so it is necessary to have technologies that can take advantage of wind energy [1]. The objective of this research is to design, build and characterize a prototype of a low-power wind turbine for interconnection to the grid.

For the extraction of the kinetic energy of the wind and its conversion to useful energy for different activities and needs, in this development work a low-power wind generator for the purpose of converting the kinetic energy of the wind into electrical energy.

There are different topologies to convert the gross energy of the turbine into useful electrical energy. The most common way to use the energy provided by a wind turbine is the use of a rectifier followed by an inverter to connect it to an independent system. In this work, a converter and its control system for synchronization to the grid were developed [2].

To improve the performance of power converters, matrix converters described in [3] can be used. The energy extracted from the wind contributes to meeting energy demand, which is why the use of electronic converters is necessary, [4].

An inverter is needed to inject the energy obtained from the wind turbine into the electrical grid. Which regulates the speed of the turbine to obtain greater energy availability. The big disadvantage is the need for an active compensator for the reactive power demand, [5].

There are various control strategies for wind turbines which allow them to be classified, considering the advantages and disadvantages of the control algorithms to define future research trends. In [6] a critical review of the state of the art of wind turbine control technologies is carried out. wind turbines.

Wind turbines using doubly fed induction generators have many advantages, such as adjustable speed, constant frequency operating mode, self-governing powers for voltage and frequency control, active and reactive power controls, and maximum power point tracking. Artificial Intelligence can be used to control the turbine. There are various machine learning methodologies that allow the development of diagnostic tools to improve accuracy and stability, according to [7].

For the practical implementation of wind turbine control systems, different advanced control tools can be used. For large wind turbines it is increasingly complex, currently high-level optimization techniques are imposed to satisfy the design requirements. Within these techniques, multi-object optimal control, in particular, is a widely used methodology to achieve a control system that reconciles multiple design objectives that may normally be incompatible according to [8].

II. METHODOLOGY

In this article, the electrical characterization of two wind turbines was carried out, the first was a commercial model “iSTA Breeze i-500” and the second is an experimental design developed by the Technological University of Campeche (Mexico). Both wind generators produce up to 500 W of electrical energy. The characterization of the wind turbines was carried out using a characterization setup specifically designed for this purpose, allowing the main characteristics of both generators to be evaluated under controlled conditions.

The test bench for the characterization of the generators consists of a 5 H.P three-phase motor, driven by a frequency converter. Figure 1 shows part of the test bench, using the frequency converter, the rotation speed of the generator under test is regulated, obtaining different voltages, currents and powers for different speed conditions.

Figure 1: Testing bench.
Source: Authors, (2024).

The results of the tests carried out with the commercial generator and the prototype are shown in tables 1, 2 and 3.

Table 1: Results obtained in open circuit.

Open circuit test						
RPM	Commercial wind turbine			Prototype		
	Phase voltage A-B	Phase voltage A-C	Phase voltage B-C	Phase voltage A-B	Phase voltage A-C	Phase voltage B-C
511	11.84	11.61	11.84	37.46	36.97	37.81
466	10.80	10.73	10.76	34.08	33.77	34.23
423	9.87	9.68	9.77	30.85	30.73	31.42
382	8.83	8.72	8.81	27.99	27.73	28.12
340	7.58	7.74	7.83	24.80	24.68	25.03
297	6.86	6.77	6.84	21.68	21.62	21.92
255	5.88	5.80	5.86	18.59	18.52	18.77
212	4.89	4.83	4.83	15.54	15.43	15.59
169	3.95	3.88	3.89	12.33	12.36	12.51

Source: Authors, (2024).

As seen, at a given speed without load, the prototype can generate a higher voltage, for example 511 RPM, the prototype generates 37.81 V, almost 4 times the 11.84 V produced by the iSTA Breeze turbine at the same speed.

Table 2: Results obtained with three-phase load.

Commercial wind turbine									
RPM	Phase voltage A-B	Phase voltage A-C	Phase voltage B-C	Phase current A	Phase current B	Phase current C	Phase power A	Phase power B	Phase power C
511	9.60	9.51	11.11	1.30	1.30	1.40	12.48	12.36	15.55
464	8.63	8.55	10.08	1.20	1.20	1.30	10.36	10.26	13.10
424	7.73	7.66	9.02	1.10	1.20	1.20	8.50	9.19	10.82
382	6.84	6.74	7.98	1.10	1.10	1.10	7.52	7.41	8.78
341	5.95	5.87	6.98	1.00	1.00	1.00	5.95	5.87	6.98
299	5.06	5.01	5.92	0.90	0.90	0.90	4.55	4.51	5.33
254	4.22	4.18	4.88	0.70	0.70	0.80	2.95	2.93	3.90
214	3.43	3.36	4.02	0.50	0.50	0.60	1.72	1.28	2.41
169	2.63	2.56	3.00	0.30	0.30	0.30	0.79	0.77	0.90

Source: Authors, (2024).

Table 3: Results obtained with three-phase load.

Prototype									
RPM	**Phase voltage A-B**	**Phase voltage A-C**	**Phase voltage B-C**	**Phase current A**	**Phase current B**	**Phase current C**	**Phase power A**	**Phase power B**	**Phase power C**
511	33.95	33.81	34.52	2.20	2.40	2.30	74.69	81.14	79.40
464	30.92	30.77	31.14	2.20	2.30	2.20	68.02	70.77	68.51
424	28.13	28.11	28.32	2.00	2.10	2.00	56.26	59.03	56.64
382	24.99	24.99	25.28	1.80	2.00	1.80	44.98	49.98	45.50
341	22.04	22.04	22.31	1.70	1.80	1.70	37.47	39.67	37.93
299	19.03	19.04	19.28	1.50	1.60	1.50	28.55	30.46	28.92
254	16.00	16.13	16.43	1.30	1.40	1.30	20.80	22.58	21.36
214	13.22	13.17	13.22	1.10	1.20	1.10	14.54	15.80	14.54
169	10.29	10.27	10.37	0.80	0.90	0.80	8.23	9.24	8.30

Source: Authors, (2024).

As observed in the second test, with resistive load, approaching real operating conditions, the prototype provided 74.69 W, 81.14 W and 79.40 W per phase at 511 RPM, using equation 1, we obtain that the Total turbine power provided by the generator is 235.23 W, while the commercial model delivered 12.48 W, 12.36 W and 15.55 W per phase, giving a total of 40.39 W, which is 5 times less than the power delivered by the prototype.

$$P(total) = (\sum_{i=1}^{n} Vi * Ii)(W) \quad (1)$$

Figure 2 shows the average output voltages per phase of both wind turbines.

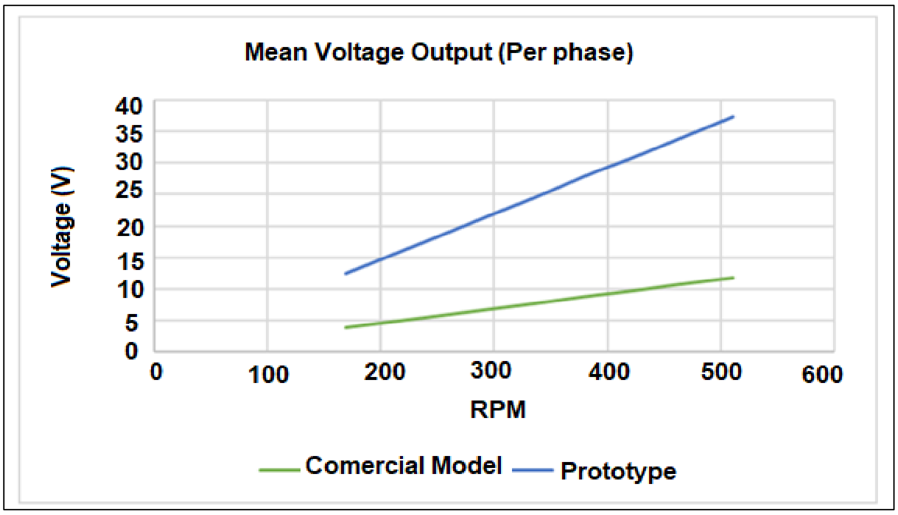

Figure 2: Output voltages.
Source: Authors, (2024).

In figure 3 you can see the difference in power delivered with three-phase load by the wind turbines under the same conditions.

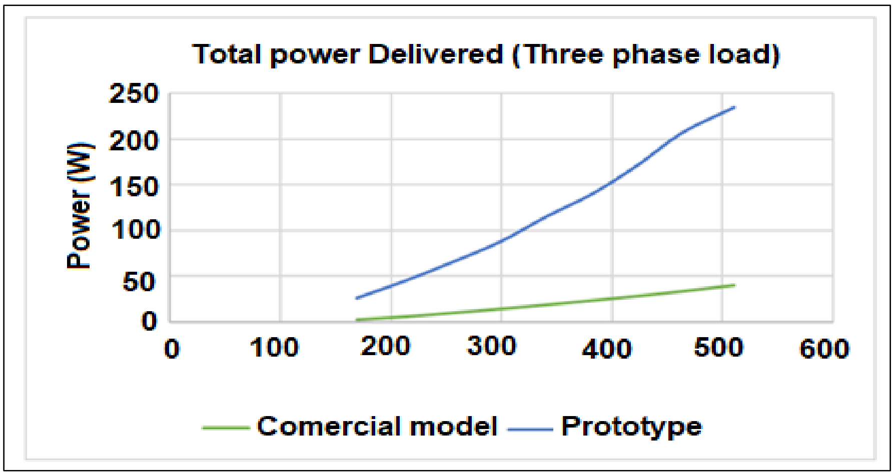

Figure 3: Output voltages.
Source: Authors, (2024).

III. TESTING OF THE DEVELOPED PROTOTYPE

Figure 4 shows the basic configuration of the three-phase full-bridge rectifier, used in the prototype. The input of the phases coming from the wind turbine can be seen, as well as the input of the firing pulses through the thyristor gates (SCR), the SCRs at the top have the same reference (ground) for their activation, while the SCRs at the bottom, each one has its own reference. The pulses applied to the SCRs allow current to flow through them, in the necessary time, thus achieving the desired rectification.

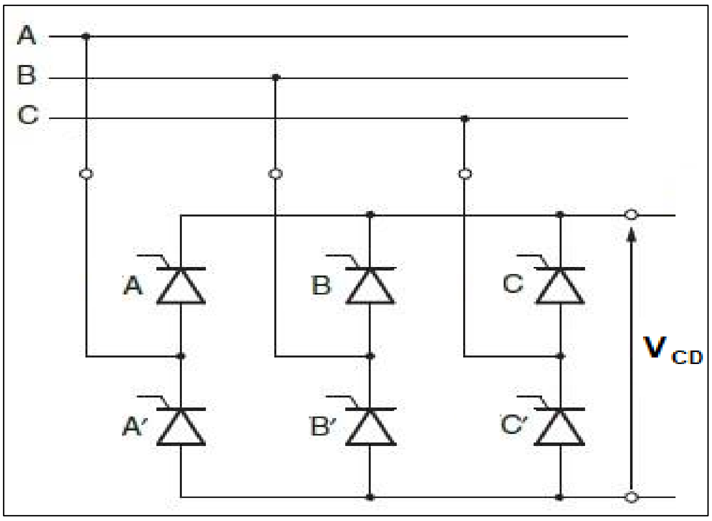

Figure 4: Full Bridge Rectifier with SCRs.
Source: Authors, (2024).

To characterize the generator prototype, the test bench was configured to obtain different output voltages. Figure 5 shows the generator outputs at different speeds.

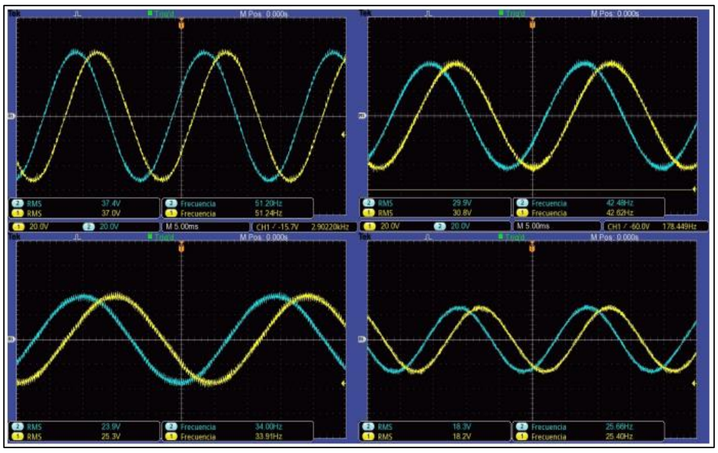

Figure 5: Wind Turbine Voltage Outputs.
Source: Authors, (2024).

In the prototype, different firing angles were used, at 0° (without delay in activating the SCR trigger), 18° (10% duration of the half cycle in delay), 36° (20% duration of the half cycle in delay), 54° (30% duration of the half cycle in delay), 72° (40% duration of the half cycle in delay), for the different levels of generated voltages. Table 4 shows the voltage outputs of the prototype with different firing angles at different speeds.

Table 4: Results obtained in open circuit.

RPM	Maximum Voltage	RMS voltage	Output voltages at different shooting angles				
			0º	18º	36º	54º	72º
511	53	37	49	46.7	46.4	45.5	43.5
423	44	30	40.2	40.3	38.1	38.5	38
340	35	25	31.2	29.9	30	27.6	29.2
255	26	18	22.1	22.4	21.8	20.8	20.8

Source: Authors, (2024).

In Figure 6, a 90 Hz sinusoidal signal is observed, which is taken as a reference to calculate the length of the trigger signals that are applied to the SCRs. In the same figure, the signals that activate the SCRs in one cycle are observed. of work.

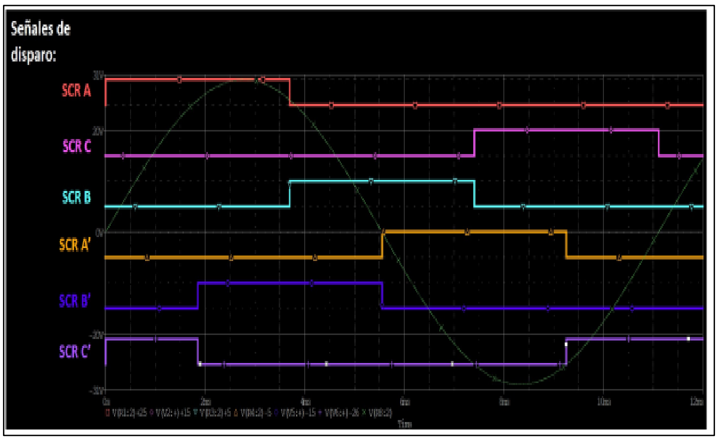

Figure 6. SCR Firing Order.
Source: Authors, (2024).

The trigger signals are generated by the control circuit, depending on the frequency that the wind turbine is delivering. The Arduino platform was used for the generation and synchronization of the trigger signals, due to its variety of options, compatibility, use of hardware and free software, flexibility, ease of use and large community of developers and users.

IV. CONCLUSIONS

The wind turbine prototype showed better performance compared to the commercial model, recognizing that there are large voltage variations in the prototype when the RPM decreases. This can be improved by reducing the air gap between the rotor and stator.

The prototype presents acceptable performance; its use with a controlled rectifier and a multilevel inverter for grid-connected operation is recommended. It is recommended to improve wind turbines and their conversion system in order to obtain the majority of wind energy and minimize power losses in the conversion to contribute to reducing dependence on polluting energy generation.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Francisco Eneldo López Monteagudo, Juan Carlos Guerrero Lujan, Jorge de la Torre y Ra, Leticia del Carmen Ríos Rodríguez.
Methodology: Francisco Eneldo López Monteagudo, Juan Carlos Guerrero Lujan, Jorge de la Torre y Ra, Leticia del Carmen Ríos Rodríguez.
Discussion of results: Francisco Eneldo López Monteagudo, Juan Carlos Guerrero Lujan, Jorge de la Torre y Ra, Leticia del Carmen Ríos Rodríguez.
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