Systematization and analysis of the available technical functions in low voltage variable speed drives for three-phase induction machines available on the Portuguese market

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Abstract

An analysis was made to the performance of an induction machine, with and without using a variable speed drive in order to understand the possible impacts in the active and reactive energy consumption, and also the the quality of the voltage and current waveforms as a consequence of using the drive. This analysis was made in a laboratorial environment, where several tests were conducted on an induction machine which was tested with and without load, with and without the variable speed drive, and also with voltage variation with an autotransformer, from which the relevant data was gathered. Additionally, a real application of the variable speed drives in a previous installation on a municipal swimming pool was used as an example of real world values of performance and economy. With all this, it is concluded that the energetic savings, and consequently, the economic savings which are a result of the use of the variable speed drive, are quite large, taking into account the original energy consumption from the network, and without that large of an impact to the quality of the voltage and current waveforms on the network. It should also be noted the versatility of the drive control, as it is the main player in allowing the operation to be as efficient as possible, by adjusting its functions to be as close as possible to the real needs of the system.

Keywords: energy efficience, energy quality, energy savings, electronic variable speed drive, induction machine

1. Introduction

Since the invention of the electrical machine that its speed command was an issue. If on one hand the DC machine can be easily controlled in that regard, the same can't be said about the induction machine, which in essence is a design that although efficient, it is only for its nominal characteristics, mainly in termos of its nominal speed. Thus, it becam imperative do research for new and effectiv ways not only to command but also to control the machine's speed, always with the goal of maximum efficience for its assigned task. As new solutions begin to show on the market to solve that problem, such as the variable speed drive, it is important to understand what the market can deliver, its characteristics, quirks, advantages and disadvantages so a proper choice can be made to the desired application. According to [1] and [2], the variable speed drive is a very effective device that can deliver good results, and with a potentially low cost of implementation, mainly for existant installations. As such, this paper will be centered on the performance analysis of a variable speed drive, some of its characteristics, how it can communicate with other devices, and how it performs in a real world application.

2. Methodology

The tests for the performance analysis of the induction machine and the variable speed drive were made in bench which contained said induction machine, a DC machine mechanically coupled to the induction machine which was used as a load. The bench had a network supply with a line voltage of 400V at 50Hz.

2.1. Load Setup

For the variable load tests, the induction machine was directly connected to the network, the resistor pack was connected to the output of the DC machine, and its value was within its 15 different preset values which were in the range of 40 to 600 Ω. For the constant load, a single value from the resistor pack was used.

2.2. Variable Voltage Setup

A similar setup was used as before, but only one preset value of the resistor pack was used, and the same for all tests. Between the network and the induction machine, an auto transformer was placed so a variable voltage could be delivered to the machine, at a constant frequency of 50Hz.

2.3. Variable Voltage and Frequency, with constant V/f ratio

For this tests, a variable speed drive was introduced between the network and the induction machine. The frequency could be selected from any value between 0 and 60Hz. For the load, the resistor pack was connected to the DC machine and setup according to the scenario.

3. Results

Some tests were conducted following the methodologies of the previous section in order to assess the performance of the drive and the machine.

3.1. Variable Load

In this scenario, only the load was changed, and the supplied voltage was the nominal.Tthe main values to be observed were power related, the active and reactive power provided by the network and the active power generated by the DC machine. The induction machine was both powered from the network and with the variable speed drive, which led to very different results. The DC generated power was very similar for both scenarios, as expected, and the active power provided was slightly higher when using the drive, which was also expected as the drive is an active component needing power for its operation. The biggest difference was in the reactive power, as although the reactive power is the expected value when connected directly to the network, taking in account the power factor of the machine, it decreases significantly when the drive is used. Not only the value is much lower, it changes from being inductive to being capacitive, thus showing the drive can be a very efficient power factor correction method, as per the results of table 1

3.2. Constant Load

Here, the load was constant and the input voltage changed, either directly with the auto transformer, or with the drive which in this case insured a constant V/f ratio. This scenario showed one of the advantages of the drive, which is a wide range of speeds where the machine can work as close to nominal conditions as possible, and as shown on table 3.2, there isn't a significant change on the machine slip in relation to its synchronous speed. When the voltage was changed on the auto transformer, the frequency was constant, so the ratio got bigger, thus reducing the machine performance, and reducing even more its efficiency.

3.3. No Load

In this scenario the goal was to see how low we could get the induction machine to accelerate and decelerate while it could still supply some relevante torque. Again, a clear advantage to the drive, as the constant V/f ratio ensured a good amount of torque on all of its speed range, while with the auto transformer the machine got to a point where although voltage was still supplied to it the frequency was the same at 50Hz, it could no longer overtake its starting torque as per the tables 3 and 4.

3.4. Harmonic impact

In a mix of the previous scenarios, some waveforms were obtained from the network, and a fourier analysis made around them. Although the voltage waveforms were similar wether the drive was used or not, the current changed drastically, as shown on figures 1 and 2 mainly because of the power electronics devices inside the drive, and their current requirements. What was observed was that the current requested from the network was still periodical with the same frequency as the voltage, it was no longer sinusoidal, so more harmonics were injected in the network. The THD values for the voltages and currents were also registered in table 3.4, where we can see as expected from the shape of the waveform a higher THD value for the current when the drive is used.

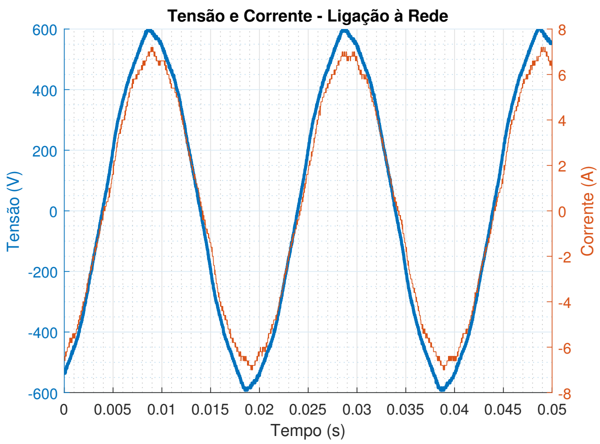

Figure 1: Voltage and Current when directly connected to the network

3.5. Efficiency

To evaluate the efficience of the operation of the drive, the power requested by the machine and the drive itself was registered on figure 3, from which we could compute on figure 4 the power used by the drive itself.

From here, we can compute the efficience of the operation of the machine and the drive, and as shown on figure 5, the results are indeed very good, with very high efficience mainly when working with

Table 1: Change in requested power from the network with a varying load, both using the drive and a direct connection.

	Network		Drive		Difference (%)	
Load	Active Power (W)	Reactive Power (VAr)	Active Power (W)	Reactive Power (VAr)	Active Power (W)	Reactive Power (VAr)
No Load	1359	1974	1513	-78	-11%	104%
600 Ω	1416	1965	1571	-79	-11%	104%
300 Ω	1472	1960	1625	-90	-10%	105%
200 Ω	1530	1973	1684	-91	-10%	105%
150 Ω	1586	1983	1741	-83	-10%	104%
620 Ω	1641	1982	1794	-100	-9%	105%
100 Ω	1695	1983	1849	-92	-9%	105%
85 Ω	1750	1981	1906	-110	-9%	106%
75 Ω	1803	1990	1957	-122	-9%	106%
66 Ω	1857	2005	2011	-115	-8%	106%
60 Ω	1908	2013	2052	-105	-8%	105%
54 Ω	1956	2009	2110	-126	-8%	106%
50 Ω	2006	2020	2157	-108	-8%	105%
46 Ω	2056	2034	2210	-125	-7%	106%
42 Ω	2016	2041	2249	-146	-7%	107%
40 Ω	2154	2051	2293	-141	-6%	107%

Table 2: Constant Load, using the drive

Frequency (Hz)	Speed (RPM)	ΔSpeed (RPM)	Slip (%)
50	1463	37	2
45	1322	28	2
40	1173	27	2
35	1025	27	2
30	873	27	3
25	723	27	4
20	576	24	4

Table 3: Registered speeds when increasing the voltage to the machine, with constant frequency

Line Voltage (V)	Speed (RPM)
20	stopped
35	70
50	1393
70	1455
100	1477
150	1490
200	1497
250	1497
300	1497
350	1497
400	1497

Table 4: Registered speeds when decreasing the voltage to the machine, with constant frequency

Line Voltage (V)	Speed (RPM)
400	1497
350	1497
300	1497
250	1497
200	1494
150	1490
100	1478
50	1393
35	100
20	stopped

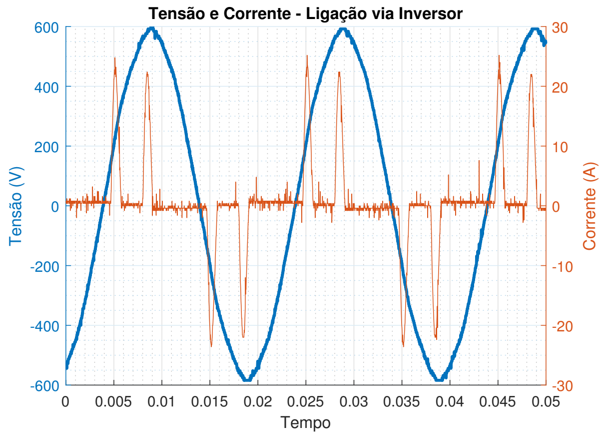

Figure 2: Voltage and Current when connected through the drive

load, which is a more real metric of the performance of the drive.

4. Analysis of a real application

A real world application of the variable speed drives was analysed, which consisted on the application of a drive to each induction machine of a swimming pool's water recirculation system [3]. A logic controller was used to control all the drives, not only their speed, but also to manage the "shifts" of the machines, in order to ensure a consistent wear across all machines, during their annual 8400 h operation.

4.1. Constraints

Some constraints had to be taken into account in order to deliver the same performance as before. The first one was the energy tariffs schedule, which in essence says that the machine would operate faster when the energy was the cheapest, and the slowest when it was more expensive. The slowest speed was determined by an independent water test which concluded that the machine could not operate be-

Table 5: Voltage and Current THD, with and without load

	Without Load		With Load	
Frequency (Hz)	Voltage THD (%)	Current THD (%)	Voltage THD (%)	Current THD (%)
10	100.03	229.83	–	–
20	100.03	221.27	100.03	179.25
30	100.03	186.71	100.04	215.62
40	100.03	206.93	100.03	225.15
50	100.02	187.79	100.03	181.11
60	100.04	194.24	100.03	178.13

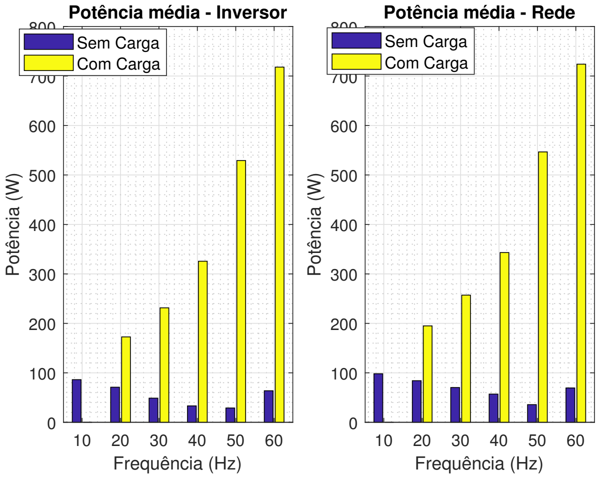

Figure 3: Average power requested by the machine to the drive (left), and by the drive to the network (right).

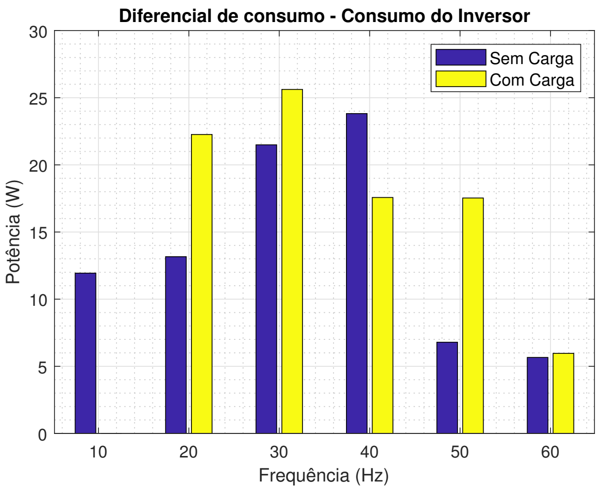

Figure 4: Requested power by the drive.

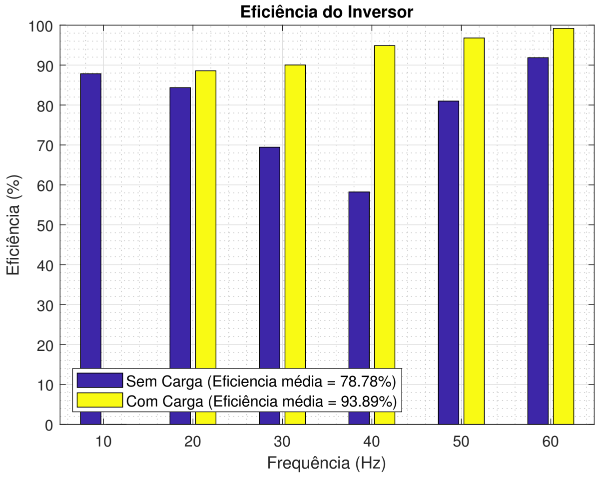

Figure 5: Drive efficience on the test scenarios.

low 70% of its nominal capacity. On top of that, the swimming pool schedule also determined that under some circumstances, such as kids activities, more recirculation was needed to keep the water quality. A schedule was made with all this constraints, and the controller programmed with it.

4.2. Results

The results were indeed very good. Instead of the machines operating at 100% all year, that was reduced to just 2475h, with the remaining hours split as 1100h at 90%, 2850h at 80%, and 2000h at 70%. This managed to deliver savings around 38.4%, which meant a reduction in the energy bill of almost 7000 euros. In addition to this, reactive power payments were a thing of the past, as a consequence of the drive's power factor correction.

5. Conclusions

The main goal of this paper was to see the effectiveness of the variable speed drive, understand its advantages, disadvantages, and know their functions. As per the results obtained, it is easy to conclude that the drive is a very effective way to not only control a machine speed, but also as a way to adjust its operation to the real needs of the system in order to return better efficiency. As power electronics evolve, the trend shall be for the drives to decrease their price, thus becoming an even better proposition in search of the best efficience possible for an induction machine.

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