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Induction versus BLDC motors for the oil and gas industry

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Abstract

In our days, the use of the Brushless DC motors with permanent magnets for large power applications is becoming very popular. A three phase induction motor has a stall torque making it easy to run just connecting it across the power lines. Also, it can be designed to run very efficient for a given point of operation making it a very attractive option for pump applications. By contrast, a BLDC motor does not have a stall torque and requires electronics to make to run. In spite of that, the motor can run very efficient along a wide range of speeds and at a higher power factor. Therefore, the natural question is: Is the BLDC more or less fit than an induction motor? This article tries to answer to this question walking the reader thru motors construction similarities and differences, the advantages and dis-advantages of the use of each motor type with a focus on the subsea oil and gas industry. Each motor kind has unique functional characteristics making it the best fit for a given applications.

1. Introduction

For almost a century, the brush DC motors have dominated the market of the direct current applications due to the two main advantages:

1. The motor speed is almost linear proportional with the input applied voltages and
2. The torque of the motor is almost linear proportional with the input electric current.

The magnetic materials of the motors do not have a linear behavior at very high motors loads due to the magnetic saturation effect. Assuming we stay away from those extreme conditions, the above two statements are true and can be described simplified by the equations 1 & 2.

$$V = K_v * n \quad (1)$$

$$T = K_T * I \quad (2)$$

where:

V = the input voltage applied to the motor
n = motor speed
T = the torque developed by the motor
I = the input current

The constants of proportionality, K_v and K_T are called voltage and torque constant, and their units of measurement are typically [V/KRPM] and [Nm/Amps] respectively. The numerical value of those two constants are the same if all the parameters are expressed in the international system of units including the motor speed expressed in radians per seconds.

As it can be seen from the equations 1&2, there is a simple linear relationship between the input electrical power (represented by the electrical current and voltage) and the output mechanical power, represented by the motor torque and speed. Also, the control of the motor speed and torque can be easily done, by controlling the motor input voltage and current respectively. Due to those simplicities, the brush DC motor was easily understood, operated and preferred. On the other hand, the presence of the brushes, port brushes mechanisms and the problems generated by them represented a major disadvantage for the standard brush DC motor. Thus, the people desire was to get an electric motor without brushes but to have preserved the advantages of the brush DC motors described by the equations 1&2. And that motor was called the brushless DC motor or BLDC.

As a reference, the cost of the brush DC motor commutator bars, brushes and port-brushes mechanism represent about 1/3 of the total cost of the DC motor. Also, it increases the motor length and lower its reliability. It is no surprise why in our days more and more applications require a BLDC instead of a brush type DC motor.

2. Motors constructions

In substance, the BLDC motor with permanent magnets is in fact a three phase synchronous motor. The DC letters reflect the fact that the motor behaves as a brush DC one, but it is not a DC motor.

Both motors types, a three phase induction motor and a three phase synchronous motor (BLDC) have the same stator construction, a three phase winding system, connected in "Y" or "Δ", uniform and symmetrically distributed along the stator slots and with winding phases situated at 120 electrical degree apart. The major difference between the two motor types is in the rotor. The BLDC motors has permanent magnets mounted on the rotor and the induction one has a winding connected in short-circuit. In many application, the rotor winding of an induction motor is made up of aluminum or copper bars inserted in the rotor slots and short circuited with a ring at the each side end of the rotor stack. This type of the rotor winding is called "squirrel cage". For short, if we take a synchronous motor (BLDC) and replace its rotor with permanent magnets with an identical rotor size having a squirrel cage type of winding on it, an induction motor is obtained.

3. Motor losses

The total motor losses of an induction motor are described by the equation (3) and by the equation (4) for a BLDC motor with permanents magnets case.

$$W_{total} = W_{Stator\ windings+\ steel} + W_{rotor\ steel} + W_{rotor\ windings} + W_{f,v} + W_{stray} \quad (3)$$

$$W_{total} = W_{Stator\ windings+\ steel} + W_{rotor\ steel} + W_{rotor\ magnets} + W_{f,v} + W_{stray} \quad (4)$$

where:

W_{total} = are the total watts losses in the motor;
$W_{stator\ windings\ +\ steel}$ = are the total watts losses in the motor stator, in the windings and steel combined;
$W_{rotor\ steel}$ = are the watts losses in the magnetic steel of the rotor;
$W_{rotor\ windings}$ = are the watts losses in the rotor windings;
$W_{rotor\ magnets}$ = are the watts losses in the rotor magnets;
$W_{f,v}$ = are the frictions and windages losses;
W_{stray} = are the stray load losses;

Comparing the loss equations of both motor types we see that it defers by only a term, the induction motor having losses in the rotor winding and the BLDC in the permanent magnets. Doing calculations of those terms, it can be seen that the losses in the rotor windings are significant larger than the losses in the permanent magnets. For small BLDC motors, sometimes the losses in its magnets are neglected due to their low value. Having high losses in the rotor windings, the induction motor is less efficient than an equivalent BLDC one. Thus, if there are applications where the efficiency of the motor is the only major criteria in selecting the motor type then, the BLDC may be the winner.

Besides the motors efficiency parameter, the temperature rise in the motor is important too. More losses in the motors mean more heat is generated or, in another words, the temperature rise in the motor will be higher. Thus, comparing the induction motor where more losses are present in the rotor with the BLDC one, the induction motor will run hotter or, if we want the temperature rise in both motors types to be the same then, the induction motor has to have a bigger frame size to allow more heat to be dissipated. In the end, for a given output power and the same operating temperature, the BLDC motor comes in a smaller package than an induction one due to its higher efficiency and less heat generation. A smaller motor frame size means also that the motors is cheaper due to the lower amount of materials usages.

For the off-shore oil and gas applications, where the motor has to operate deep under the sea level, the ocean pressure is very high putting a lot of force on the motor housings. Decreasing the motor envelope size, for the same ocean pressure, the forces acting on the motor frame are smaller. Therefore, the wall thickness of the motor housing will be smaller making in the end the motor to be cheaper and lighter. Due to its higher power density (defined as higher shaft output power per motor volume) the BLDC motor can be the right way to go versus the alternative one with the use of an induction motor.

4. Motors functionality

A three phase induction motor can run by simple connecting it across the power lines. It has a stall torque and does not need electronics to make it to run. Therefore, in the applications where the motor has to operate all the time just at one speed, the use of an induction motor can be the cheapest and robust solution. By contrast, the BLDC motor does not start by simple connecting it to the power lines. It needs electronics to make it to start. From this point of view, the induction motor has a major advantage.

There are others situations, like in the motion control applications, where the motor has to operate very efficient along a wide ranges of speeds. To get that, the usage of an induction or BLDC motor requires electronics for its speed and torque control. Assuming the electronics are the same and cost the same, the system that uses a BLDC motor is more efficient because the BLDC motor is more efficient. In addition, the use of the drive with a "phase advance" option can make the motor to run at a higher power factor and, in the same time, keeping low the motors current. Besides that, a low electric current operation is translated in a smaller and cheaper drive. The size of the drive/electronics is primary a function of the current it provides rather than voltage. Furthermore, the need of a less current enable the drive to operate at a higher chopping/commutation rate resulting in lower steel losses reflected in the motor. In addition, for the subsea oil and gas application, the umbilical cord will be thinner bringing down significantly the cost of the motion control systems. There is no surprise thus why the BLDC motors are more and more popular in the motion control systems.

Electric motors are seen by an AC power supplier as an inductive load. There are windings on a magnetic circuits inside the motors. Therefore, the relationship between the input and the output power of an induction or a BLDC motors is described by the equation:

$$P_{out} = P_{in} * \cos(\varphi) * \eta \tag{5}$$

where:

P_{out} = output power of the motor (the mechanical power)
P_{in} = input power of the motor (the electrical power)
$\cos(\varphi)$ = power factor
η = motor efficiency

	P_{in} [MVA]	η	$\cos(\varphi)$	$\eta * \cos(\varphi)$	P_{out} [MW]
BLDC motor	3	0.95	0.9	0.855	2.565
Induction motor	3	0.94	0.7	0.658	1.974

Table 1

In the table 1, to get a better understanding of the advantages and the dis-advantages, two motor types are selected for running, the induction and the BLDC. It is assumed the input electric power for both motors is the same 3 MVA. Both motor types are going to be run by a three phase sinusoidal drive. As it was expected, the efficiency of the BLDC motor is higher. The induction motor has more losses in the rotor as it was explained earlier. However, for a well-designed induction motor, its efficiency is not well below the efficiency of the BLDC motor. The major difference is in fact in the power factor of the motors. Thus, the output power of an induction motor will be significantly lower than the BLDC. In the end, for subsea oil and gas application, the product between the motor efficiency and the power factor is the one that matter the most, pushing the selection of the BLDC motor with permanent magnets to be the right choice.

A recent trend in the large power motor design is to design the motors for high voltage, so the motor current can be smaller for a given output power. Thus, the system with high voltage operation BLDC motors may not require a step down transformer, the drive will be smaller and cheaper, the umbilical cord will be thinner, the losses along the power line will be lower, the motor windings are easier made due to thinner cables. However, better insulation materials and higher engineering expertise are required to design and make that motor.

5. Conclusions:

The three phase induction motors will have a stall torque if the motor is connected directly across the power lines. Therefore, if only one speed operation is required all the time, as in pumps for the irrigation systems, a three phase induction motor can be the right way to go. The BLDC motor will not have a stall torque if it is connected directed across the power line. It needs electronics (a drive) to make it to run making the system, the motor plus its drive, expensive.

For applications where the motor has to run across a wide ranges of speeds then, a drive to run the motor and control its speeds and torque is required. In that case then, the BLDC motor can be the right way to go because it can run at a higher efficiency and a better power factor than and induction motor, the user needing in the end a smaller frame size motor to deliver the required output power.

For the off-shore oil and gas applications where the motors have to operate deep under the sea level, under very high water pressure, the BLDC motor with permanent magnets can be the way to go. It will have a smaller envelope size than an induction one making lower the mechanical stress on the motor housing. Also, the umbilical cord between the BLDC motor and its drive will be thinner making the system cheaper.