Doubly fed induction motor

For speed control of motor

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***Abstract*—Doubly-fed electric machines are electric motors or electric generators where both the field magnet windings and armature windings are separately connected to equipment outside the machine. This is useful, for instance, for generators used in wind turbines. By feeding adjustable frequency AC power to the field windings, the magnetic field can be made to rotate, allowing variation in motor or generator speed.**

***Index Terms*—doubly fed induction motor, speed control, different regulator**

I. Introduction

a three-phase wound-rotor induction machine operates as a synchronous machine when ac currents are fed into one set of windings and dc current is fed into the other set of windings. When ac currents are fed into both the stator and rotor windings of a three-phase wound-rotor induction machine, the machine also operates as a synchronous machine. In this situation, when the wound-rotor induction machine operates as a synchronous motor, it is referred to as a doubly-fed induction motor since electrical power from the power network is converted into mechanical power available at the machine shaft via both the stator and rotor windings of the machine. In doubly-fed induction motor operation, the machine has the same basic characteristics as conventional (singly-fed) synchronous motors. However, as ac currents are fed into both sets of windings of the motor, two rotating magnetic fields are created: one in the stator and another in the rotor. As in normal synchronous motor operation, it is the interaction between the stator magnetic field and the rotor magnetic field that creates the force acting on the rotor and causes the rotor to rotate. However, as both magnetic fields rotate (instead of just the stator magnetic field as in singly-fed operation), the rotation speed depends on the speed and direction of each of the two rotating magnetic fields. When both magnetic fields created in a doubly-fed induction motor rotate in the same direction, the rotor must rotate at a speed (n_{rotor})equal to the difference between the speed of the rotating magnetic field at the stator (n_{stator}) and the speed of the rotating magnetic field at the rotor so that the rotating magnetic fields at the stator and rotor remain attached to each other (i.e., so that the north and south poles of the rotating magnetic field at the stator remain aligned with the south and north poles of the rotating magnetic field at the rotor, respectively). The synchronous speed ($n_{S\ (DF)}$) of the doubly-fed induction motor is thus lower than the synchronous speed n_S obtained during normal singly-fed operation. This is illustrated in Figure 8a. In this case, the resulting synchronous speed of the doubly-fed induction motor is equal to:

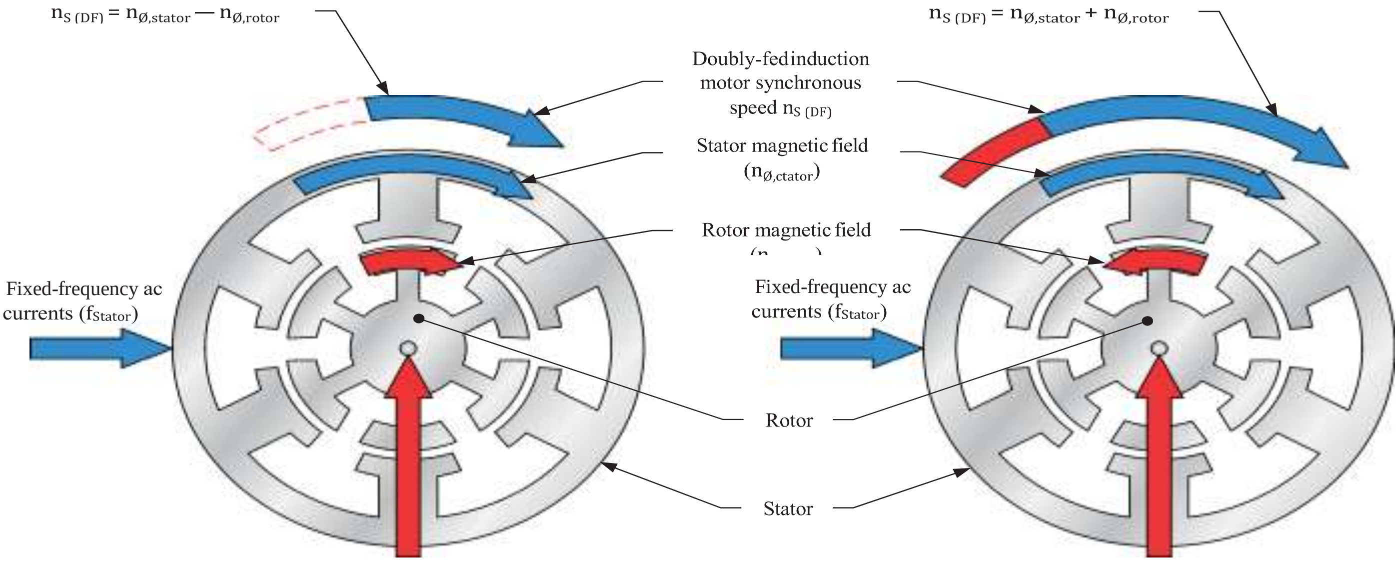
$$n_{S\ (DF)} = \frac{120 \times (f_{Stator} - f_{Rotor})}{N_{PoSe}}$$

Where $n_{S\ (DF)}$ is the synchronous speed of the doubly-fed induction motor, expressed in rotations per minute (r/min)

f_{Stator} is the frequency of the ac currents fed into the doubly-fed induction motor stator windings, expressed in hertz (Hz).

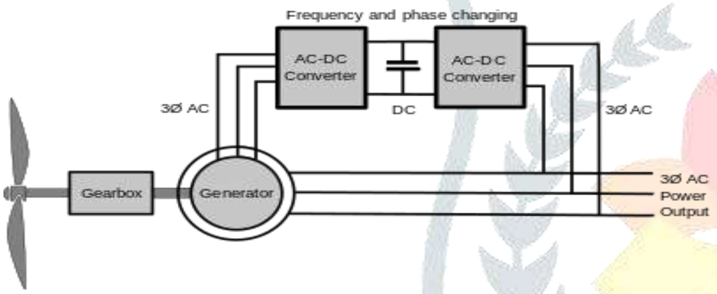
f_{Rotor} is the frequency of the ac currents fed into the doubly-fed induction motor rotor windings, expressed in hertz (Hz).

N_{PoSec} is the number of magnetic poles per phase in the doubly-fed induction motor.



(a) When the stator and rotor magnetic fields rotate in the same direction

Doubly-fed generator for wind turbine.



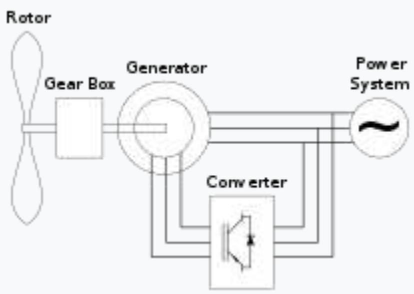
Doubly fed electrical generators are similar to AC electrical generators, but have additional features which allow them to run at speeds slightly above or below their natural synchronous speed. This is useful for large variable speed wind turbines, because wind speed can change suddenly. When a gust of wind hits a wind turbine, the blades try to speed up, but a synchronous generator is locked to the speed of the power grid and cannot speed up. So large forces are developed in the hub, gearbox, and generator as the power

(b) When the stator and rotor magnetic fields rotate in opposite directions

grid pushes back. This causes wear and damage to the mechanism. If the turbine is allowed to speed up immediately
when hit by a wind gust, the stresses are lower and the power from the wind gust is converted to useful electricity.
One approach to allowing wind turbine speed to vary is to accept whatever frequency the generator produces, convert it to DC, and then convert it to AC at the desired output frequency using an inverter. This is common for small house and farm wind turbines. But the inverters required for megawatt-scale wind turbines are large and expensive.
Doubly fed generators are one solution to this problem. Instead of the usual field winding fed with DC, and an armature winding where the generated electricity comes out, there are two three-phase windings, one stationary and one rotating, both separately connected to equipment outside the generator. Thus the term "doubly fed".
One winding is directly connected to the output, and produces 3-phase AC power at the desired grid frequency. The other winding (traditionally called the field, but here both windings can be outputs) is connected to 3-phase AC power at variable frequency. This input power is adjusted in frequency and phase to compensate for changes in speed of the turbine.
Adjusting the frequency and phase requires an AC to DC to AC converter. This is usually constructed from very large IGBT semiconductors. The converter is bidirectional, and can pass power in either direction. Power can flow from this winding as well as from the output winding.

Uses of DFIM

DFIG for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly (see brushless doubly-fed electric machines), but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine.



Principle of a Double Fed Induction Generator connected to a wind turbine

The principle of the DFIG is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency can freely differ from the grid frequency (50 or 60 Hz). By using the converter to control the rotor currents, it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generator's turning speed. The control principle used is either the two-axis current vector control or direct torque control (DTC). DTC has turned out to have better stability than current vector control especially when high reactive currents are required from the generator.

The doubly-fed generator rotors are typically wound with 2 to 3 times the number of turns of the stator. This means that the rotor voltages will be higher and currents respectively lower. Thus in the typical ± 30% operational speed range around the synchronous speed, the rated current of the converter is accordingly lower which leads to a lower cost of the converter. The drawback is that controlled operation outside the operational speed range is impossible because of the higher than rated rotor voltage. Further, the voltage transients due to the grid disturbances (three- and two-phase voltage dips, especially) will also be magnified. In order to prevent high rotor voltages - and high currents resulting from these voltages - from destroying the IGBTs and diodes of the converter, a protection circuit (called crowbar) is used.

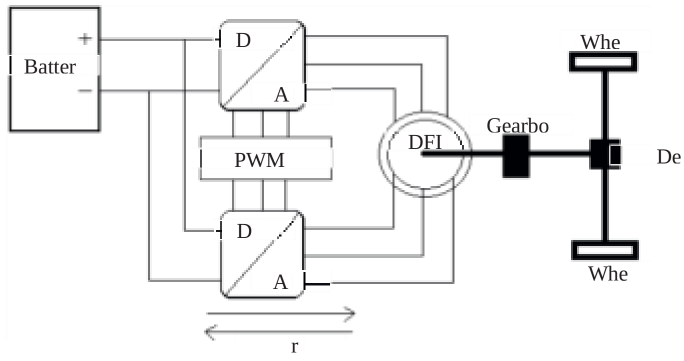
The crowbar will short-circuit the rotor windings through a small resistance when excessive currents or voltages are detected. In order to be able to continue the operation as quickly as possible an active crowbar [11] has to be used. The active crowbar can remove the rotor short in a controlled way and thus the rotor side converter can be started only after 20-60 ms from the start of the grid disturbance when the remaining voltage stays above 15% of the nominal voltage. Thus it is possible to generate reactive current to the grid during the rest of the voltage dip and in this way help the grid to recover from the fault. For zero voltage ride through it is

Common to wait until the dip ends because with zero voltage it is not possible to know the phase angle where the reactive current should be injected.

As a summary, a doubly-fed induction machine is a wound-rotor doubly-fed electric machine and has several advantages over a conventional induction machine in wind power applications. First, as the rotor circuit is controlled by a power electronics converter, the induction generator is able to both import and export reactive power. This has important consequences for power system stability and allows the machine to support the grid during severe voltage disturbances (low voltage ride through, LVRT). Second, the control of the rotor voltages and currents enables the induction machine to remain synchronized with the grid while the wind turbine speed varies. A variable speed wind turbine utilizes the available wind resource more efficiently than a fixed speed wind turbine, especially during light wind conditions. Third, the cost of the converter is low when compared with other variable speed solutions because only a fraction of the mechanical power, typically 25-30%, is fed to the grid through the converter, the rest being fed to grid directly from the stator. The efficiency of the DFIG is very good for the same reason.

However, the objective of this work is to operate the DFIM in a wide range of speed variation, for application in a drive train of an electric vehicle; for this the machine is connected through two power converters with pulse wide modulation control (PWM), these converters are both powered by a battery, which is a key element for development of electrical vehicles, namely the energy density is low and the charge time very long. In the drive train we use only one machine (DFIM) for the motorization of the vehicle, and for recovering energy during braking. The advantage of the power structure chosen is not only to operate the machine in a wide range of speed variation, but also to give to the machine the capacity to operate up to twice its rated power. So the power density is improved. Illustrates the schematic diagram of the drive train:

Fig (1): Representative diagram of the electric vehicle drive train



The ability of the DFIM to start with high torque makes possible the elimination of clutch and gearbox. The torque is the size dimensioning; therefore the machine must be heavier and bulky, so more expensive. The use of fixed ratio gearbox overcome these problems and allows to have a simple machine that can provide the required torque.

The power electronic converters used for power transfer between the battery and the DFIM are sized at 100% of rated power of the machine, those are bidirectional converter with PWM control, they absorb power from the battery when the machine operates as a motor and they provide to it when the machine operates as a generator (braking).

Semiconductors used depends on power level passing converters; for low powers are used IGBT. For high power converters based on IGCT or GTO semiconductors can be used. Variable speed drives with a rated power up to 40MW (IGCT) or 100MW (GTO) have been installed. A disadvantage of these semiconductor types is their lower switching frequency, compared with IGBT's

ROTOR POWER CHARACTERISTICS

The rotor windings of a conventional fixed-speed wound rotor induction machine are normally shorted by the slip rings so that there is no power output from the rotor of the induction machine. The rotor power under both generator and motor modes are rotor copper loss. For a DFIG, however, the rotor power means not only the rotor copper loss but also real and reactive power passing to the rotor, which is fed to the grid through the DFIG frequency converter. the simulated real power passing to the DFIG rotor, under the conditions of a) Vq = 0 pu and Vd = 0 to 0.4 pu, b) Vd = 0.2 pu and Vq = 0 to 0.4 pu, and c) Vq = 0.2 pu and Vd = 0 to 0.4 pu From the as well as the simulation analysis, it is found that

1) For both motoring and generating modes, the DFIG sends an additional real power through its rotor to the grid

2) The characteristics of power sent to the grid through DFIG rotor is mainly dependent on the amplitude of the injected rotor voltage

3) For high values of the injected rotor voltage, the real power delivered to the DFIG rotor is maximum at synchronous speed at which the DFIG rotor is equivalent to a short circuit. A proper control of Vq and Vd is essential to prevent high currents flowing in the rotor and

4) A comparison between DFIG stator and rotor real power shows that the rotor power is normally smaller than the stator power and the difference between the two really depends on the Vq and Vd values and the slip. There is also reactive power passing to the DFIG rotor. the simulated DFIG torque-speed and the rotor reactive power-speed characteristics under the condition of Vq = 0 pu and very small increment of Vd . With small increments in the rotor voltage, it can be seen from how the DFIG torque

characteristics change from normal induction machine to DFIM operating condition. The effect of injected rotor voltage on rotor reactive power is clear from Basically, when there is no injected rotor voltage, there is no power passing through the rotor to the DFIG frequency converter. As the injected rotor voltage increases slightly, there is reactive power passing through the rotor to the DFIG frequency converter as shown by From a detailed comparison study it is clear that that rotor reactive power is capacitive when the DFIG operates in a generating mode under a sub-synchronous speed and is inductive otherwise. More simulation results, demonstrate that with increased rotor injected voltage, the DFIG shifts more to sub- synchronous speed range for its generating mode and the reactive power passing to the DFIG frequency converter is more capacitive. This capacitive reactive power increases the capacitor voltage of the frequency converter.

Conclusion

The performance of a 2.2 kW DFIM (three-phase slip ring induction motor) under voltage sag has been studied through simulation and hardware experiments. Due to voltage sag peaks in torque, stator currents, rotor currents and total power taken from grid are considered for analysis in full speed region. Speed loss during sag is also analyzed. It is confirmed that results obtained from simulation are similar with experimental results under voltage sag. The performance of a 2 MW DFIM, under voltage sag has also been studied through simulation for full speed regions. The current and torque peaks are always produced when the voltage drops. On-sag operation, severe speed loss is obtained depending on sag depth and duration. While peaks in stator current, rotor current and total power taken from grid are more severe in post-sag duration. These peaks increased further when machine is operated in hyper-synchronous region. When sag is modeled abruptly, the peaks are more severe. However, this effect is smoothed when sag is modeled discretely. In case of increase in number of steps in discrete voltage recovery, the effects on DFIM system are less pronounced. These peaks reduced significantly when type-B and type-C sag are applied for the same durations, hence it is confirmed that voltage sag type-A with abrupt voltage recovery is most severe. In an experimental study small voltage sag ($h = 0.70$ and $\Delta t = 1$ sec) produces rotor current peak, which exceeds the RSC current limit resulting to enabled protection and deactivated RSC. It is noted that same RSC is capable to run the system in steady state. Overall, the operation of DFIM under voltage sag consumes large amounts of currents (around 3.0 pu) that create torque-frequency oscillation.

References

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