Appendix A
Doubly-Fed Induction Generators

Principles of Doubly-Fed Induction Generators (DFIG)

Doubly-fed electric machines are basically electric machines that are fed ac currents into both the stator and the rotor windings. Most doubly-fed electric machines in industry today are three-phase wound-rotor induction machines. Although their principles of operation have been known for decades, doubly-fed electric machines have only recently entered into common use. This is due almost exclusively to the advent of wind power technologies for electricity generation.

Doubly-fed induction generators (DFIGs) are by far the most widely used type of doubly-fed electric machine, and are one of the most common types of generator used to produce electricity in wind turbines. Doubly-fed induction generators have a number of advantages over other types of generators when used in wind turbines.

The primary advantage of doubly-fed induction generators when used in wind turbines is that they allow the amplitude and frequency of their output voltages to be maintained at a constant value, no matter the speed of the wind blowing on the wind turbine rotor. Because of this, doubly-fed induction generators can be directly connected to the ac power network and remain synchronized at all times with the ac power network. Other advantages include the ability to control the power factor (e.g., to maintain the power factor at unity), while keeping the power electronics devices in the wind turbine at a moderate size.

This manual covers the operation of doubly-fed induction generators, as well as their use in wind turbines. It also covers the operation of three-phase wound-rotor induction machines used as three-phase synchronous machines and doubly-fed induction motors. Although it is possible to use these machines by themselves, they are primarily studied as a stepping stone to doubly-fed induction generators.

Doubly-fed induction generator operation

The three-phase wound-rotor induction machine can be set up as a doubly-fed induction motor. In this case, the machine operates like a synchronous motor whose synchronous speed (i.e., the speed at which the motor shaft rotates) can be varied by adjusting the frequency of the ac currents fed into the rotor windings. The same wound-rotor induction machine setup can also serve as a doubly-fed induction generator. In this case, mechanical power at the machine shaft is converted into electrical power supplied to the ac power network via both the stator and rotor windings. Furthermore, the machine operates like a synchronous generator whose synchronous speed (i.e., the speed at which the generator shaft must rotate to generate power at the ac power network frequency) can be varied by adjusting the frequency of the ac currents fed into the rotor windings. The remainder of this exercise discussion deals with the operation of three-phase wound-rotor induction machines used as doubly-fed induction generators.

In a conventional three-phase synchronous generator, when an external source of mechanical power (i.e., a prime mover) makes the rotor of the generator rotate, the static magnetic field created by the dc current fed into the generator rotor winding rotates at the same speed as the rotor. As a result, a continually changing magnetic flux passes through the stator windings as the rotor magnetic field rotates, inducing an alternating voltage across the stator windings. Mechanical power applied to the generator shaft by the prime mover is thus converted to electrical power that is available at the stator windings. Taking into account the principles of operation of doubly-fed induction generators, it can thus be determined that, when the magnetic field at the rotor rotates in the same direction as the generator rotor, the rotor speed and the speed of the rotor magnetic field is shown in Figure 1.

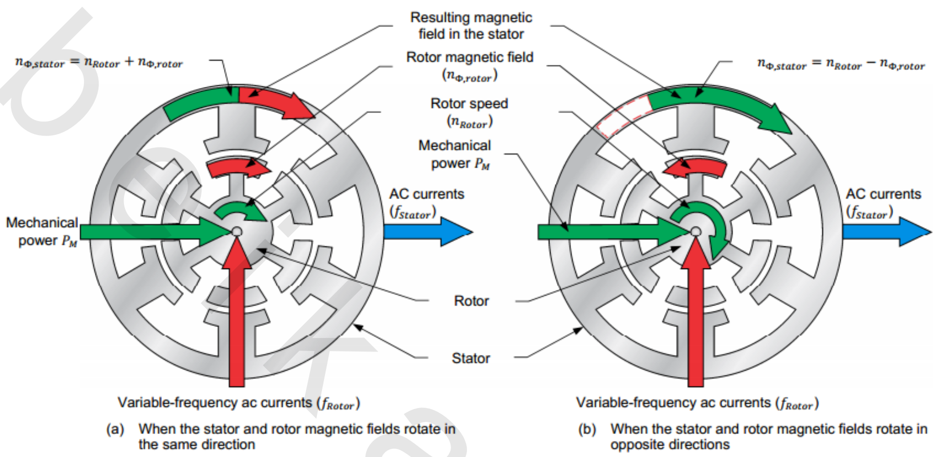

Figure 1Interaction between the rotor speed and the frequency of the rotating magnetic field created in the rotor windings of a doubly-fed induction generator

Using doubly-fed induction generators to produce fixed-frequency voltages

The primary reason for using a doubly-fed induction generator is generally to produce three-phase voltage whose stator frequency is constant, i.e., whose stator frequency remains equal to the network frequency of the ac power network to which the generator is connected, despite variations in the generator rotor speed caused by fluctuations of the mechanical power provided by the prime mover (e.g., a wind turbine rotor) driving the generator. To achieve this purpose, the rotor frequency of the ac currents fed into the rotor windings of the doubly-fed induction generator must be continually adjusted to counteract any of the variation in the rotor speed caused by fluctuations mechanical power provided by the prime mover driving the generator.
The frequency of the ac currents that need to be fed into the doubly-fed induction generator rotor windings to maintain the generator output frequency at the same value as the frequency of the ac power network depends on the rotation speed of the generator rotor, and can be calculated using the following equation:

$$f_r = f_s - \frac{p * n_r}{120}$$

Where:

f_r: Rotor frequency (HZ),

f_s: Stator frequency (HZ),

P: Number of poles,

n_r: Rotor speed (rpm)

Doubly-fed induction generators used in wind turbines

Most doubly-fed induction generators in industry today are used to generate electrical power in large (power-utility scale) wind turbines. This is primarily due to the many advantages doubly-fed induction generators offer over other types of generators in applications where the mechanical power provided by the prime mover driving the generator varies greatly (e.g., wind blowing at variable speed on the bladed rotor of a wind turbine). To better understand the advantages of using doubly-fed induction generators to generate electrical power in wind turbines, however, it is important to know a little about large-size wind turbines.

Large-size wind turbines are basically divided into two types which determine the behavior of the wind turbine during wind speed variations: fixed-speed wind turbines and variable-speed wind turbines. In fixed-speed wind turbines, three-phase asynchronous generators are generally used. Because the generator output is tied directly to the grid (local ac power network), the rotation speed of the generator is fixed (in practice, it can generally vary a little as the slip is allowed to vary over a range of typically 2% to 3%), and so is the rotation speed of the wind turbine rotor. Any fluctuation in wind speed naturally causes the mechanical power at the wind turbine rotor to vary and, because the rotation speed is fixed, this causes the torque at the wind turbine rotor to vary accordingly. Whenever a wind gust occurs, the torque at the wind turbine rotor thus increases significantly while the rotor speed varies little. Therefore, every wind gust stresses the mechanical components (notably the gear box) in the wind turbine and causes a sudden increase in rotor torque, as well as in the power at the wind turbine generator output. Any fluctuation in the output power of a wind turbine generator is a source of instability in the power network to which it is connected.

In variable- speed wind turbines, the rotation speed of the wind turbine rotor is allowed to vary as the wind speed varies. This precludes the use of asynchronous generators in such wind turbines as the rotation speed of the generator is quasi-constant when its output is tied directly to the grid. The same is true for synchronous generators which operate at a strictly constant speed when tied directly to the grid.

This is where doubly-fed induction generators come into play, as they allow the generator output voltage and frequency to be maintained at constant values, no matter the generator rotor speed (and thus, no matter the wind speed). As seen in the previous section, this is achieved by feeding ac currents of variable frequency and amplitude into the generator rotor windings. By adjusting the amplitude and frequency of the ac currents fed into the generator rotor windings, it is possible to keep the amplitude and frequency of the voltages (at stator) produced by the generator constant, despite variations in the wind turbine rotor speed (and, consequently, in the generator rotation speed) caused by fluctuations in wind speed. By doing so, this also allows operation without sudden torque variations at the wind turbine rotor, thereby decreasing the stress imposed on the mechanical components of the wind turbine and smoothing variations in the amount of electrical power produced by the

generator. Using the same means, it is also possible to adjust the amount of reactive power exchanged between the generator and the ac power network. This allows the power factor of the system to be controlled (e.g., in order to maintain the power factor at unity). Finally, using a doubly-fed induction generator in variable-speed wind turbines allows electrical power generation at lower wind speeds than with fixed-speed wind turbines using an asynchronous generator.
It would be possible to obtain similar results in variable-speed wind turbines using a three-phase synchronous generator and power electronics, as shown in Figure 2(a). In this setup, the generator rotates at a speed that is proportional to the wind speed. The ac currents produced by the generator are converted into dc current by an AC/DC converter, and then converted by another AC/DC converter back to ac currents that are synchronous with the ac power network. It is therefore necessary for the power electronics devices used in such a circuit to have the size and capacity to process 100% of the generator output power.
The power electronics devices used in doubly -fed induction generators, on the other hand, need only to process a fraction of the generator output power, i.e., the power that is supplied to or from the generator rotor windings, which is typically about 30% of the generator rated power. Consequently, the power electronics devices in variable-speed wind turbines using doubly-fed induction generators typically need only to be about 30% of the size of the power electronics devices used for comparatively sized three-phase synchronous generators, as illustrated in Figure 2(b). This reduces the cost of the power electronics devices, as well as the power losses in these devices.

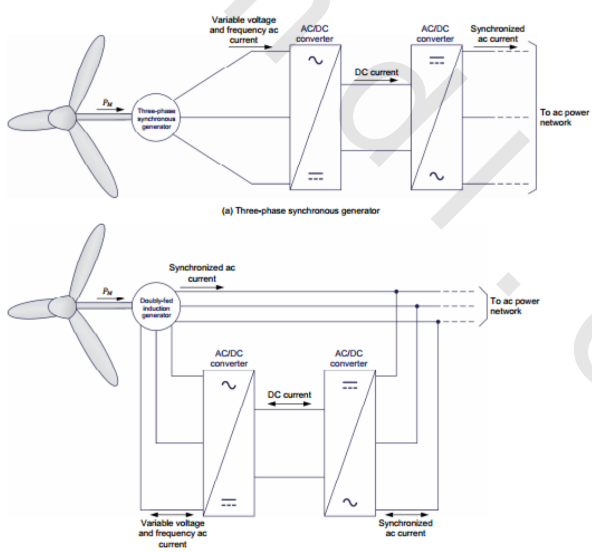

Figure 2 Circuit topologies for two types of generators found in variable-speed wind turbines

Power flow in DFIG

DFIG can be operated in two modes of operation namely sub-synchronous and super-synchronous mode depending on the rotor speed below and above the synchronous speed. The power flowing in the rotor of a doubly fed induction machine (i.e. of the wound rotor type) has three components. These are

a) the electromagnetic power transferred between the stator and the rotor through the air gap which is known as the air gap power P_s

b) The mechanical power P_m transferred between the rotor and shaft.

c) the slip power P_r which is transferred between the rotor and any external source or load.

These three components of rotor power are interrelated, under sub- and super-synchronous modes of operation, as shown in figure.3 where P_g is the grid power.

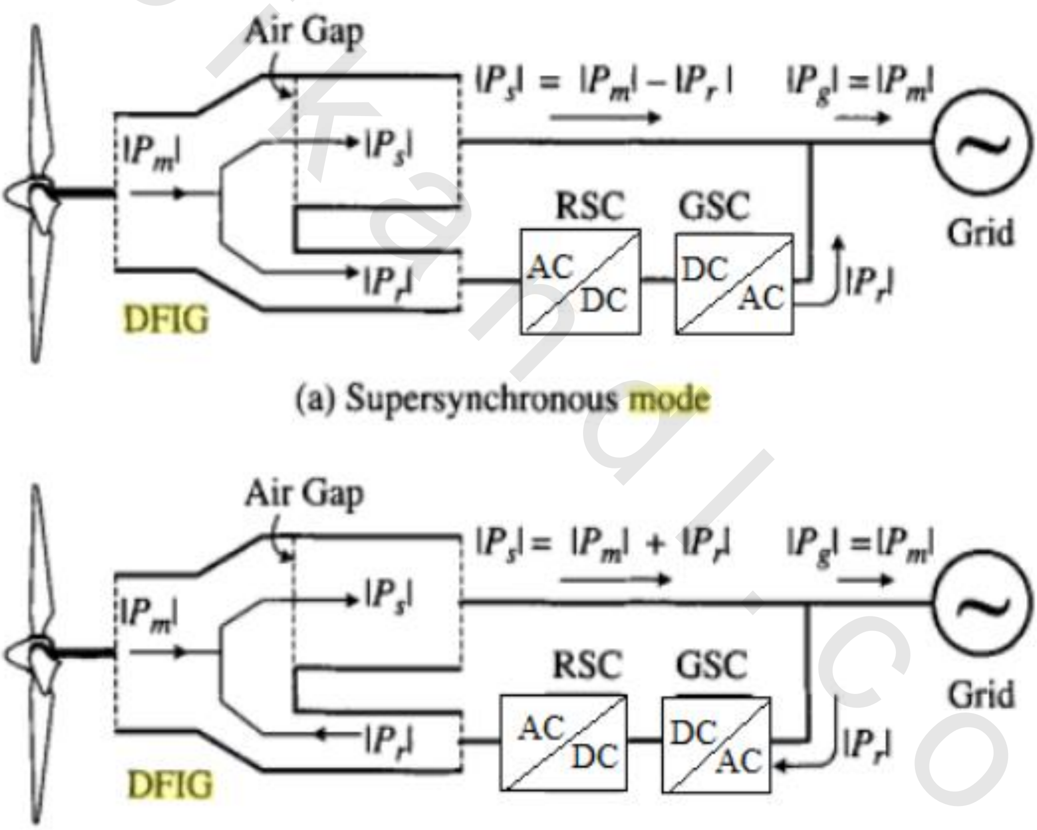

Figure 3 Power flow in DFIG wind energy conversion system

Appendix B
Self-excited Doubly-Fed Induction Generators

Principle of self-excitation

The induction generator can be excited from static charged capacitors or battery figure 4, The utilization of such an idea in the generation of electrical power was realized in recent years and growing interest in the use of other energy sources. This has been motivated by concern to reduce pollution by the use of renewable energy resources such as wind, solar, tidal and small hydro potential .Owing to its many advantages, the self-excited induction generator has emerged from among the known generators as a suitable candidate to be driven by wind power. Some of its advantages are small size and weight, robust construction, absence of separate source of excitation and reduced unit and maintenance cost. Besides its application as a generator, the principle of self-excitation can be used in dynamic braking of a three-phase induction motor. Therefore, methods to analyze the performance of such machines are of considerable practical interest. The terminal capacitance on such machines must have a minimum value so that self-excitation is possible. This value is affected by machine parameters, its speed and load condition.

Methods of self-excitation

The Doubly fed induction machine (DFIM), is an induction machine with both stator and rotor windings. A large amount of recently installed windmills is variable-speed turbines, and they use electronics converters in order to operate at different speed rates. The DFIG is one of the main techniques used in variable speed windmills. The DFIG is used to supply electrical energy to stand-alone loads. The initial excitation for the system start up could be provided by a battery bank. The battery could be kept charged afterward using the energy flow in the dc link. Another possibility is to use a charged capacitor in the dc link for the self -excitation of the machine, generating the required stator voltage. Then, the control strategy of the line side converter or, in this case, the stator-side converter, could regulate the required dc-link voltage. The initial charge of the capacitor or the dc battery voltage must be the same as the output of the uncontrolled rectifier and can be calculated as follows:-

$$V_{dc} = \frac{3*\sqrt{2}}{\pi} * V_L$$

Where:
V_L : the stator line voltage

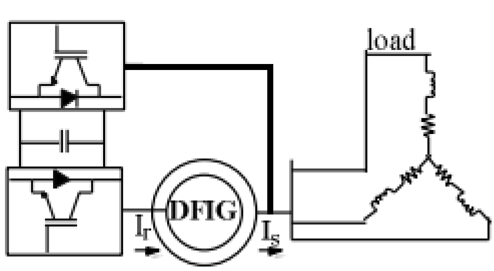

Figure 4 block diagram of self-excited DFIG

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ملخص الرسالة

مقدمة :

اصبحت الطاقة المتجدده في الوقت الحاضر هي مصدر مهم واساسي لتوليد الكهرباء وذلك لما تتميز به من انها طاقة نظيفة وطاقة لا تنضب . من افضل انواع الطاقات المتجددة هي طاقة الرياح.

هناك العديد من المولدات يمكن استخدمها في تحويل طاقة الرياح الي طاقة كهربية ومن افضلها علي الاطلاق هو المولد التاثيري مزدوج التغذية لم يتميز به من قدرة علي العمل علي الشبكة او منفرد ايضا" لانه يمكن ان يعطي طاقة من الجزء الثابت والجزء الدوار.

تقوم هذه الرسالة علي استخدام هذا المولد في تحويل طاقة الرياح الي كهرباء وذلك عن طريق التحكم بالجوامد الالكترونية . يتم ذلك في حالتين اذا كان هذا المولد يعمل بمفرده بدون شبكة او اذا كان هذاا المولد متصل بالشبكة

مكونات الرسالة :

تتكون هذه الرسال من سته فصول :

الفصل الاول : المقدمة

ويعرض انواع الطاقة المتجددة المختلفة وايضا انواع المولدات المستخدمة لتحويل هذه الطاقة الي طاقة كهربية.

الفصل الثاني: محاكاة لمعادلات المولد التاثيري المزدوج التغذية

ويعرض كيفية استخدام برنامج MATLAB في الحصول علي نموذج محاكي للمولد التاثيري المزدوج التغذية .

الفصل الثالث : توصيل المولد بدون شبكة علي الحمل

نقوم في هذا الفصل بشرح كيفية التحكم في المولد بحيث يظل الجهد والذبذبة ثابتين في حالة تغير سرعة الرياح ويتم التحكم عن طريق التحكم في العاكس ١٨٠° .في هذا الفصل ايضا نقوم بعرض النتائج لخاصة بالجزء العملي .

الفصل الرابع : توصيل المولد بدون شبكة علي الحمل باستخدام SVPWM

ايضا نقوم بعرض النتائج الخاصة بتوصيل المولد بدون شبكة ولكن هذه المرة يتم التحكم في العاكس عن طريق SVPWM .

الفصل الخامس : توصيل المولد بالشبكة

ونعرض في هذا الفصل طريقة التحكم في جهد الجزء الدوار وذلك للتحكم في قيمه القدرة الفاعله والغير فاعله الموجوده في الجزء الثابت.

الفصل السادس: الاستنتاج

يقدم هذا الفصل استعراض للنتائج وملخص البحث ومقترحات مستقبلية.

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استيفاء للدراسات المقررة للحصول على درجة

ماجستير العلوم

فى

الهندسة الكهربية

مقدمة من

م./ محمد حسن علي

اشرف عليها

الاستاذ الدكتور / محمد يسري عبد الفتاح

الاستاذ الدكتور / محمد مجدي احمد

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