Analysis, Modelling and Control of Doubly Fed Induction Generators for Wind Turbines[1]

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Abstract

This paper deals with the analysis, modelling and control of a grid connected doubly fed induction generator (DFIG) wind turbine, both during steady-state and transient operations .A mathematical model is derived suitable for modelling both fixed speed and doubly fed induction generator wind turbines. A control structure using standard proportional integral PI controller and a field-oriented control strategy based on a reference frame rotating synchronously with the rotor flux for variable speed wind turbines using doubly fed induction generator and for obtaining injected rotor voltages is described and simulated.

The modelling of the machine considers operating conditions below and above synchronous speed, which are actually achieved by means of a double sided converters joining the machine rotor to the grid. The control strategy effectively decouples the active and reactive powers generated by the machine and provides a means of controlling the power factor of the generator.

The simulation results of the grid connected and modelled doubly fed induction generator wind turbine with such a control strategy shows the energy production of the system during different wind conditions and shows how such a control strategy provides possibility to control the overall system power factor.

[1] For the paper in Arabic see pages (165-166).

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Introduction

Wind energy is one of the most important and promising source of renewable energy all over the world ,mainly because it reduces the environmental pollution caused by traditional power plants as well as the dependence on fossil fuel, which have limited reserves.
Electric energy, generated by wind power plants is the fastest developing and most promising renewable energy source. Off-shore wind power plants provide higher yields because of better conditions.
At the same time there has been a rapid development of related wind turbines technology.
Wind turbines are designed to produce electrical energy as possible and therefore they are generally designed to yield maximum output at wind speeds around 15 meters per second. The case of stronger winds it is necessary to waste a part of the excess energy of the wind in order to avoid damaging the wind turbine. All wind turbines are therefore designed with some sort of power control [1]. The control of the power extracted from the wind can be done in several ways. Stall and pitch control (or a combination) seem to be the prevalent methods in modern wind turbines.
Variable speed induction generators and particularly Doubly Fed Induction Generators (DFIG) are more and more used for wind energy conversion. This allows for operating the turbine at variable speed enhancing the conversion efficiency. The concurrent option is presently based on full AC-DC-AC conversion with a gearless mechanical implementation. The size of the power electronic package is reduced to 30-50% when considering DFIG. That’s why this option is often selected.
So the main purpose of this paper is the analysis of the DFIG for a wind turbine application both during steady-state operation and transient operation. In order to analyse the DFIG during transient operation both the control and the modelling of the system is of importance.

Wind Turbine Model

Several models for power production capability of wind turbine have been developed and can be found throughout the bibliography[1].

The mechanical power P_{mech}, captured by wind turbine , depends on its power performance coefficient C_p given for a wind velocity V and can be represented by:

$$P_{mech} = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 V^3 \qquad (1)$$

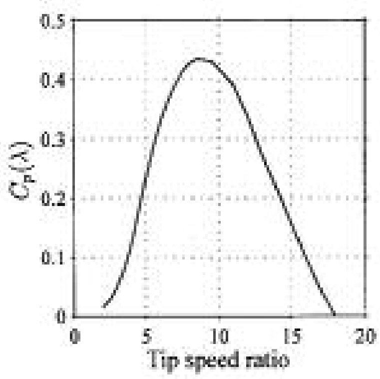
Where ρ and R correspond to the air density and the radius of the turbine propeller, respectively.

The power performance coefficient C_p can be described as the portion of mechanical power extracted from the total power available from the wind, and it is unique for each turbine. This C_p power performance coefficient depends on the pitch angle β and is a function of the tip-speed-ratio λ which is given by:

$$\lambda = \frac{\omega_r R_r}{V} \qquad (2)$$

Where ω_r represents the rotational speed of the wind turbine.

Fig(1) shows a typical relationship between the power performance coefficient and the tip-speed-ratio. It should be noted that there is a value of λ to ensure a maximum of C_p . Thus , it can be stated that , for a specified wind velocity, there is a turbine rotational speed value that allows capturing the maximum mechanical power attainable from the wind.



Fig(1)

A typical wind turbine characteristic with the optimal power extraction-speed curve plotted to intersect the $C_{p\max}$ points for each wind speed is illustrated in Fig.(2) .It appears from Fig.(2) that at wind speed above and below the rated wind speed, the energy capture does not reach the maximum value[1]. The power output is plotted against the rotor's angular velocity at a constant pitch angle. Each curve represents a different wind speed.
It can be seen from Fig.(2) that the rotor speed must be adapted if the wind speed changes, in order to extract the maximum power. Thus, variable-speed and pitch controlled wind power plants are dominating the market nowadays.

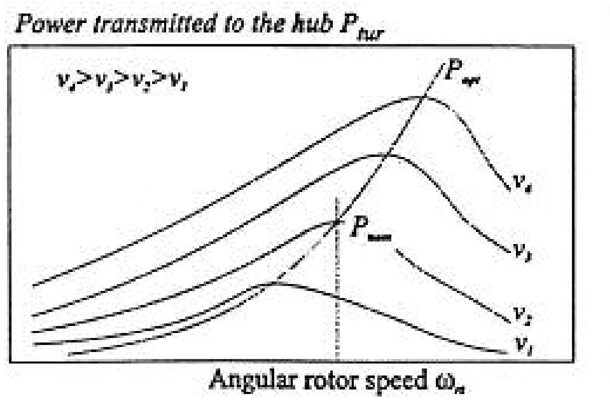


Fig.(2).

Fig.(3) shows an example of how the mechanical power, derived from the $C_p(\lambda,\beta)$ curve , and the rotor speed vary with the wind speed for a variable-speed wind turbine. The rotor speed in the variable-speed area is controlled in order to keep the

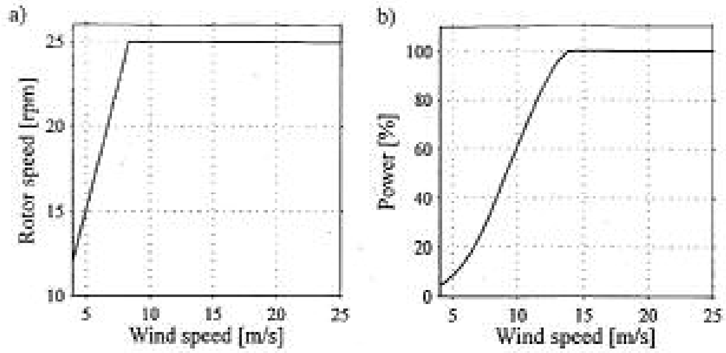


Fig.(3). Typical characteristic for a variable-speed wind turbine. a) Rotor speed as a function of wind speed. b) Mechanical power as a function of wind speed.

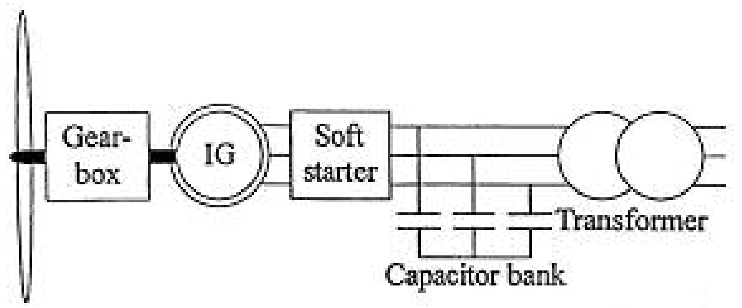
optimal tip speed ratio, λ, i.e., C_p is kept at maximum as long as the power or rotor speed is below its rated values. As mentioned before, the pitch angle is at higher wind speeds controlled in order to limit the input power to the wind turbine, when the turbine has reached the rated power [1]. As seen in Fig.(3-a) the turbine in this example reaches the rated power , 1 p.u., at a wind speed of approximately 13m/s. There is also the possibility to optimize the radius of the wind turbines rotor to suit sites with different average wind speeds. For example, if the rotor radius, R , is increased, the output power of the turbine is also increased, according to (1).

Wind Turbine Systems

Wind energy conversion schemes may be designed with either synchronous or asynchronous generators, and with various forms of direct or indirect grid connection using power electronics converters to provide electricity at a frequency to match as that of the grid. A power electronic converter enables efficient conversion of the variable frequency output driven by a variable speed wind turbine, to a fixed frequency appropriate for the grid or a load.

Wind turbines can either operate at fixed speed or variable speed.

For fixed speed wind turbines , the (generator) induction generator is directly connected to the electrical grid according to the Fig.(4).Since the speed is almost fixed to the grid frequency and most certainly not controllable ,it is not possible to store the turbulence of the wind in form of rotational energy. Therefore for a fixed-speed system , the turbulence of the wind will result in power variations ,and thus affect the power quality of the grid. Investigations with fixed speed turbines have shown that depressed voltage , resulting from short circuits in the connecting networks , can lead to generator overspeed if the network short circuit level to generating capacity ratio is too low. The induction generators may then depress the voltage further , causing instability due to high levels of reactive power being absorbed . But a reason for the prevalent use of fixed speed wind turbines is the simple and reliable generator construction that for small wind turbines seems to be the most competitive concept in terms of cost per Kilowatt-hour.



Fig(4). Fixed-speed wind turbine with an induction generator

For a variable speed wind turbine , the generator is controlled by power electronic equipment .The system presented in Fig.(5) consists of a wind turbine equipped with a converter connected to the stator of the generator .The generator could either be a squirrel cage induction generator or a synchronous generator. The gearbox is designed so that maximum rotor speed corresponds to rated speed of the generator.
Synchronous generators or permanent-magnet synchronous generators can be designed with multiple poles which implies that there is no need for a gearbox as in Fig.(6).

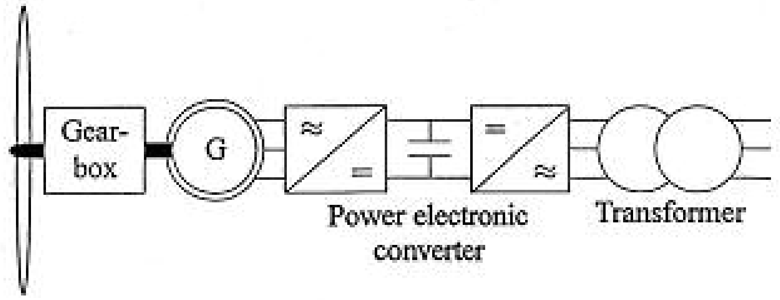


Fig.(5). Variable-speed wind turbine with a synchronous/induction generator

There are several reasons for using variable speed operation of wind turbines. The main reason is their ability to supply power at constant voltage and frequency while the rotor speed varies .Also the possibilities to reduce stresses of the mechanical structure, acoustic noise reduction and the possibility to control active and reactive power. Most of the major wind turbine manufactures are developing new larger wind turbines in the 3-to-5 MW range. These large wind turbines are all based on variable speed operation with pitch control using a direct driven synchronous generator (without gearbox) Fig.(6) or doubly fed induction generators (DFIG) Fig.(7). Fixed- speed induction generators (FSIG) with stall control are regarded as unfeasible for these large wind turbines.

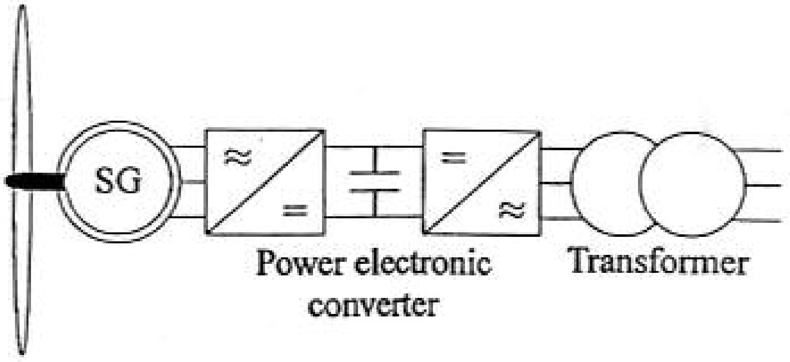


Fig.(6).Variable-speed direct-driven(gear-less) wind turbine with a synchronous generator (SG)

Today , doubly fed induction generators (DFIG) are commonly used by the wind turbine industry for larger wind turbines[5,6,7].

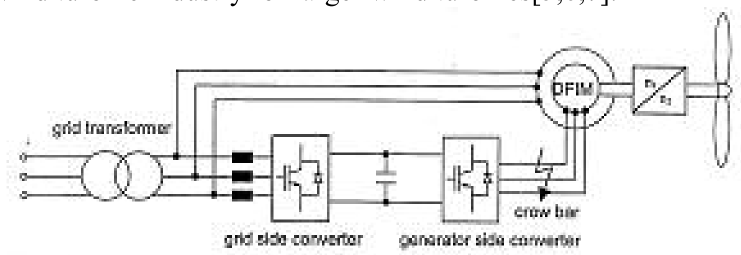


Fig.(7). Variable-speed wind turbine with a doubly-fed induction generator(DFIG)

The attractiveness of the DFIG stems primarily from its ability to handle large speed variations around the synchronous speed. The major advantage of the DFIG shown in Fig.(7) which has made it popular, is that the power electronic equipment only has to handle a fraction (20-30)% of the total system power. This means that the losses in the power electronic equipment can be reduced in comparison to power electronic equipment that has to handle the total system power as for a direct driven synchronous generator , apart from the cost saving of using a smaller converters. The energy production can be increased for a variable speed wind turbine in comparison to a fixed speed wind turbine. The DFIG concept also provides possibility to control the overall system power factor.

The system in Fig.(7) consists of a wind turbine with doubly fed induction generator.

This means that the stator is directly connected to the grid, while the rotor winding is connected via slip rings to a converter. This system has recently become very popular
as generators for variable speed wind turbines.

The system is typically two AC/DC IGBT based voltage source converters (VSC) linked by DC bus. The machine and converters are protected by voltage limits and an overcurrent 'crowbar'[5,7,9].

The converter system enables variable speed operation of the wind turbine by decoupling the power system electrical frequency and the rotor mechanical frequency.

One control system is to use converter C1 to provide speed control together with terminal voltage and power factor (PF) control for the overall system. Converter C2 is used to maintain the DC bus voltage and provide a path for rotor power to and from the AC system at a unity factor.

Dependent upon the rotational speed of the DFIG , power can be delivered to the grid through the stator and the rotor , while the rotor can also absorb power. If the DFIG runs at a sub-synchronous speed, the rotor absorbs power and a fraction of the stator power enters the rotor circuits. In contrast, if the DFIG runs at super-synchronous speeds, the rotor produces power and power is delivered to the grid via the stator and rotor circuits.

Model implementation

Development of the induction machine model

The general procedure followed to create the electrical model was similar for both the Fixed Speed Induction Generator (FSIG) and the Doubly Fed

Induction Generator (DFIG). The operating principle can be analysed using the general theory of electrical machines and the well known $\alpha-\beta$ model [2,3] as shown in Fig.(8).

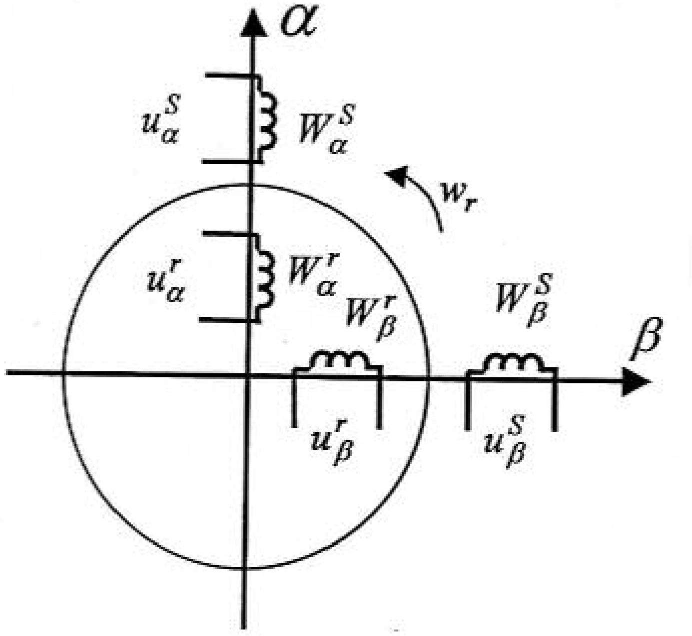


Fig.(8)

The equations describing the induction machine in a $\alpha-\beta$ reference form are:

Stator voltages:

$$u_{s\alpha} = R_s i_{s\alpha} + L_s \frac{di_{s\alpha}}{dt} + M\frac{di_{r\alpha}}{dt}$$
$$u_{s\beta} = R_s i_{s\beta} + L_s \frac{di_{s\beta}}{dt} + M\frac{di_{r\beta}}{dt} \qquad (3)$$

Rotor voltages:

$$u_{r\alpha} = R_r i_{r\alpha} + L_r \frac{di_{r\alpha}}{dt} + M \frac{di_{s\alpha}}{dt} + \omega_r (L_r i_{r\beta} + M i_{s\beta})$$
$$u_{r\beta} = R_r i_{r\beta} + L_r \frac{di_{r\beta}}{dt} + M \frac{di_{s\beta}}{dt} - \omega_r (L_r i_{r\alpha} + M i_{s\alpha}) \qquad (4)$$

Where

$i_{s\alpha}, i_{r\alpha}$ denote the stator and rotor currents respectively in axis α ,

$i_{s\beta}, i_{r\beta}$ are stator and rotor currents in axis β

R_s, R_r are stator and rotor resistance

L_s, L_r, M stator , rotor leakage inductances and magnetising inductance , Respectively

We rewrite these equations in the form of using them to simulate the machine.

$$\frac{di_{s\alpha}}{dt} = \frac{1}{L_s} u_{s\alpha} - \frac{R_s}{L_s} i_{s\alpha} - \frac{M}{L_s} \frac{di_{r\alpha}}{dt}$$
$$\frac{di_{s\beta}}{dt} = \frac{1}{L_s} u_{s\beta} - \frac{R_s}{L_s} i_{s\beta} - \frac{M}{L_s} \frac{di_{r\beta}}{dt}$$
$$\frac{di_{r\alpha}}{dt} = \frac{1}{L_r} u_{r\alpha} - \frac{R_r}{L_r} i_{r\alpha} - \frac{M}{L_r} \frac{di_{s\alpha}}{dt} - \omega_r (i_{r\beta} + \frac{M}{L_r} i_{s\beta}) \qquad (5)$$
$$\frac{di_{r\beta}}{dt} = \frac{1}{L_r} u_{r\beta} - \frac{R_r}{L_r} i_{r\beta} - \frac{M}{L_r} \frac{di_{s\beta}}{dt} + \omega_r (i_{r\alpha} + \frac{M}{L_r} i_{s\alpha})$$

The electromagnetic torque T is given by :

$$T = \frac{3}{2} PM (i_{r\alpha} i_{s\beta} - i_{s\alpha} i_{r\beta}) \qquad (6)$$

Where P represents the number of pole pairs.

The rotor speed ω_r is given by:

$$\frac{d\omega_r}{dt} = \frac{P}{J} (T - T_c) \qquad (7)$$

Where T_c represents the load torque.

The stator side active and reactive powers are respectively:

$$p_s = u_{s\alpha} i_{s\alpha} + u_{s\beta} i_{s\beta} \tag{8}$$
$$Q_s = u_{s\alpha} i_{s\beta} + u_{s\beta} i_{s\alpha}$$

The rotor side active and reactive powers are respectively

$$p_r = u_{r\alpha} i_{r\alpha} + u_{r\beta} i_{r\beta}$$
$$Q_r = u_{r\alpha} i_{r\beta} + u_{r\beta} i_{r\alpha} \tag{9}$$

These equations constitute the basis for constructing the block diagram of an
induction machine.

Both fixed speed (squirrel cage) and doubly-fed (wound rotor) machine constructions are represented by one set of equations, differing only by the representation of rotor voltage (i.e. short-circuited or injected voltage).

Control Scheme

The DFIG control structure is shown in Fig.(9). It contains two control loops. The outer one controls both the stator side active and reactive powers, so that the power factor set point value demanded by the electric energy distribution company is complied with as accurately as possible. On the other hand, the inner one controls the rotor current direct i_d^r and quadrature i_q^r components expressed according to the reference frame fixed to the stator flux-linkage space phasor [2,5,7,10].

The primary stage of speed control scheme was developed using a standard proportional integral PI controller to calculate a reference value i_q^r (ref) as shown in Fig(9).The actual machine current i_q^r , was calculated by the equations (10) and according to the Fig.(10).

Comparing the reference variable to the actual machine current , an error signal required for controlling the speed of the machine was obtained.

The secondary stage of the controller was again constructed using the primary stage reference current , but now compared to the direct component i_d^r of the measured rotor current.

Since the rotor side current components need first to be changed from their natural

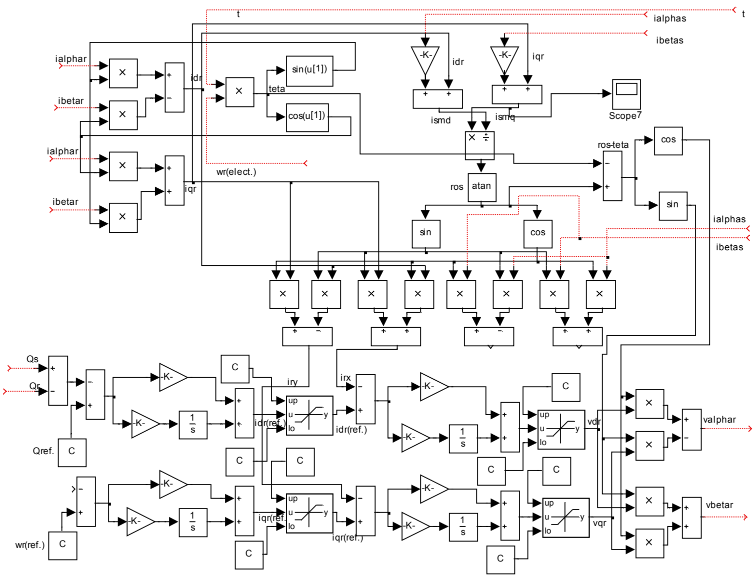


Fig.(9) Control structure of DFIG

axes to the stationary reference frame, it is necessary to measure the rotor angle θ_r as is shown in Fig.(10).

The equations to be followed are given next:

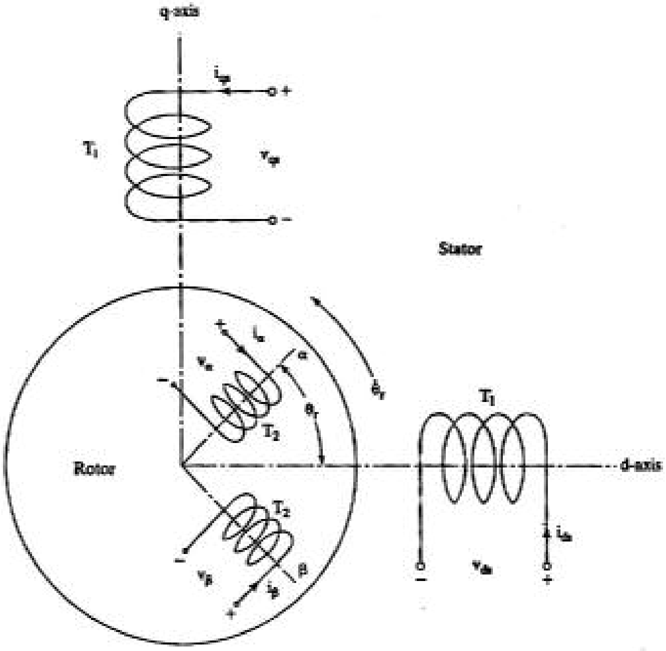


Fig.(10) Stator and rotor windings of a two phase induction machine

$$i_d^r = i_\alpha^r \cos\theta_r - i_\beta^r \sin\theta_r$$
$$i_q^r = i_\alpha^r \sin\theta_r + i_\beta^r \cos\theta_r$$
(10)

Estimation of The stator flux linkage space phasor ρ_s angular position with respect to the stationary direct axis, Fig.(11), the direct and quadrature-axis stator magnetising current components expressed in the stationary reference frame are given by:

$$
\begin{aligned}
i_{msD} &= \frac{L_s}{M} i_\alpha^s + i_d^r \\
i_{msQ} &= \frac{L_s}{M} i_\beta^s + i_q^r \\
\rho_s &= arctg \frac{i_{msQ}}{i_{msD}}
\end{aligned}
\tag{11}
$$

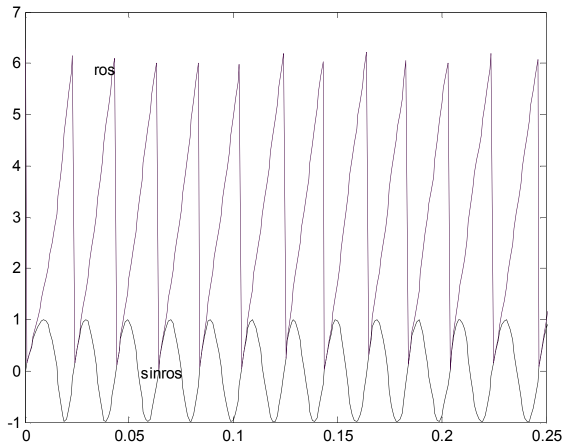


Fig.(11)

The expressions of the rotor current space phasor in the reference frame fixed to the stator flux linkage space phasor, so as to compare its i_x^r and i_y^r components with their corresponding $i_x^r(ref.)$ and $i_y^r(ref.)$ set-point values are given as shown below:

$$
\begin{aligned}
i_x^r &= i_d^r \cos\rho_s + i_q^r \sin\rho_s \\
i_y^r &= -i_d^r \sin\rho_s + i_q^r \cos\rho_s
\end{aligned}
\tag{12}
$$

Based on the errors in both current components , the voltage v_d^r and v_q^r components and therefore v_α^r and v_β^r components to be applied to the rotor side are generated by means of two identical PI controllers , Fig.(9), as shown below:

$$v_\alpha^r = v_d^r \cos(\rho_s - \theta_r) - v_q^r \sin(\rho_s - \theta_r)$$

$$v_\beta^r = v_d^r \sin(\rho_s - \theta_r) + v_q^r \cos(\rho_s - \theta_r)$$

(13)

It is required to design the outer loop control law, which is responsible for providing the power generation process with the desired power factor. It should be noted that, once the outer control-loop is put on operation, only wind speed changes can cause the generated active power to vary, since rotor angular velocity, which establishes, depends on wind speed. Thus the over all control-system designed allows the generator to work properly either under subsynchronous or supersynchronous conditions.

Protection of the DFIG system

The response of wind turbines to grid disturbances is an important issue, especially since the rated power of wind turbine installations steadily increases. Faults in the power system, machine or converter devices may result in high voltages or currents that damage the equipment. When the whole turbine would be disconnected from the grid, it can become difficult to control the mechanical rotation of the wind turbine, as it is not possible any longer to develop an electrical torque to counteract the mechanical torque provided by the wind power. Suitable protection is therefore provided in wind turbine systems to minimise the effects of possible abnormal operating conditions.

Preliminary investigations of the steady-state stability margins of the DFIG have shown that power factor and speed control can assist in maintaining stability during power system disturbances. The steady-state modelling of the FSIG discussed in[6] shows the effect of the voltage variation on the torque-slip characteristics. A reduction in terminal voltage results in a reduced peak pull-out torque. If the applied generating torque is maintained, throughout the reduced voltage, the rotor speed will increase. This may lead to machine instability when the terminal voltage and the pull-out torque recovers if the rotor has accelerated past the peak torque. The terminal voltage support, provided by the power factor control capacitors in FSIG wind turbines, is reduced with the square of the voltage. In contrast, the DFIG reduces terminal voltage variations during power system disturbances by implementing a power factor control strategy independent of the terminal voltage. This is provided that the DC capacitor is large enough to hold its voltage and converter C2 continues to operate correctly. Maintaining the peak torque reduces the risk of instability as the rotor accelerates but does not go beyond the pull-out torque. Controlling i_q^r to limit the rotor speed in the DFIG model also assists in post-fault stability as the rotor acceleration during the network fault is reduced compared to the FSIG.

In the literature there are some different methods to modify the DFIG system in order to accomplish voltage sag ride-through proposed. In [8] anti-parallel thyristors is used in the stator circuit in order to achieve a quick (within 10 ms) disconnection of the stator circuit, and thereby be able to remagnetize the generator and reconnect the stator to the grid as fast as possible. Another option proposed in [6,9] is to use an active 'crowbar', which can break the short circuit current in the crowbar. This 'crowbar' consists of a diode bridge that rectifies the rotor phase currents and a single thyristor in series with resistance Rcrow as it is depicted in Fig.(12).

The thyristor is turned on when the DC link voltage U_{DC} reaches its maximum value, $U_{DC} \geq U_{DC\max}$. Simultaneously the rotor circuit is disconnected from the rotor side frequency converter and connected to the crowbar. The rotor remains connected to the crowbar until the main circuit breaker disconnects the stator from the network.

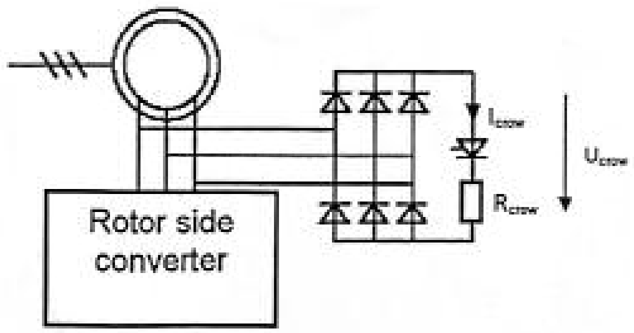


Fig. (12) Diode bridge crowbar

Simulation Results

Simulation of DFIG Control

A 4-pole 30 KW doubly-fed induction generator wind turbine and control model was simulated using the MATLAB program[4].

Fig.(13) shows the block scheme of the modelled DFIG and the control system.

The dynamic performance of the DFIG system was modelled by applying mechanical torque to the generator rotor, representative of step changes in wind velocity. A typical wind turbine characteristic with the optimal power extraction-speed curve plotted to intersect the $C_{p\max}$ points for each wind speed is illustrated in Fig. (14). If the control strategy is applied to maintain P_{opt}, since the rotor speed ω_r is proportional to the wind speed V, the power increases with V^3 and ω_r^3 , and the corresponding generator torque with V^2 and ω_r^2. The complete generator torque-speed characteristic, which was applied for the controller model, is shown in Fig.(15) and Fig.(16) for two different wind velocities.

The simulation results when running the DFIG wind turbine and its overall control system model is presented.

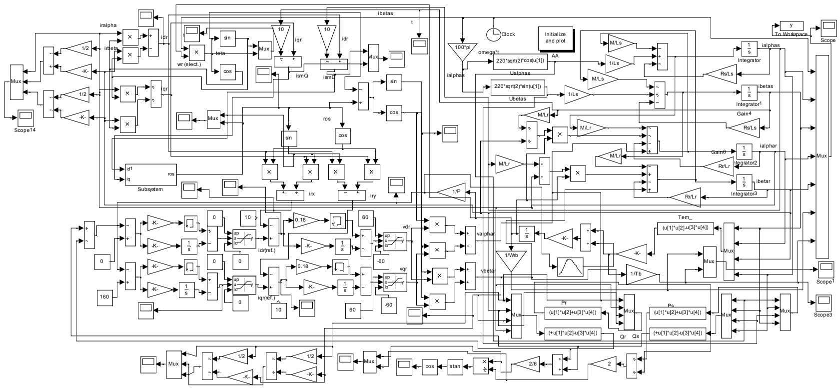


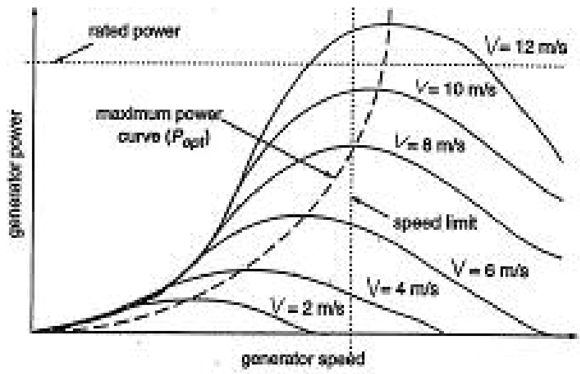
Fig.(13) Block scheme of the modelled DFIG and the control system

Some results obtained when simulating the described model are provided in Figures below.

These results correspond to a test carried out in which keeping wind conditions constant having mean speeds of 12m/s and 8m/s respectively.

Fig.(17) and Fig.(18) show the generator speed and torque produced on its shaft.

Fig. (19) and Fig.(20) show the three phase voltages applied to the rotor side through the converter and the resulting rotor three phase currents.



Fig(14) Maximum power extraction control strategy curve

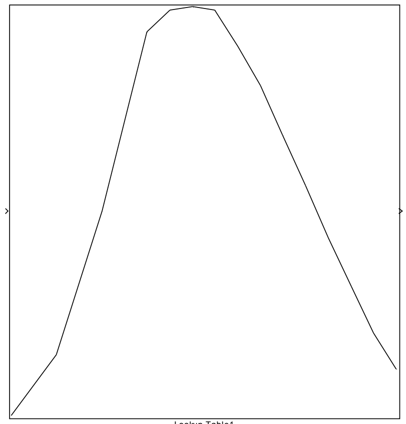


Fig.(15) Applied torque-speed characteristic at wind speed 12m/s

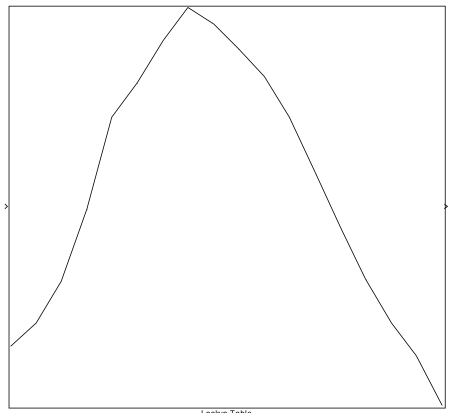


Fig.(16) Applied torque-speed characteristic at wind speed 8m/s

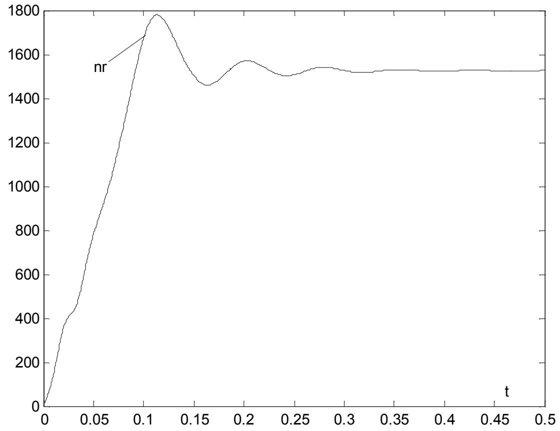


Fig.(17) Generator speed at wind speed 12m/s

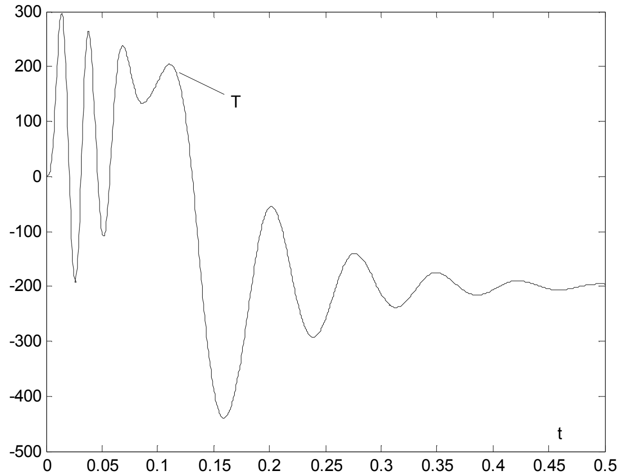


Fig.(18) Generator torque at wind speed 12m/s

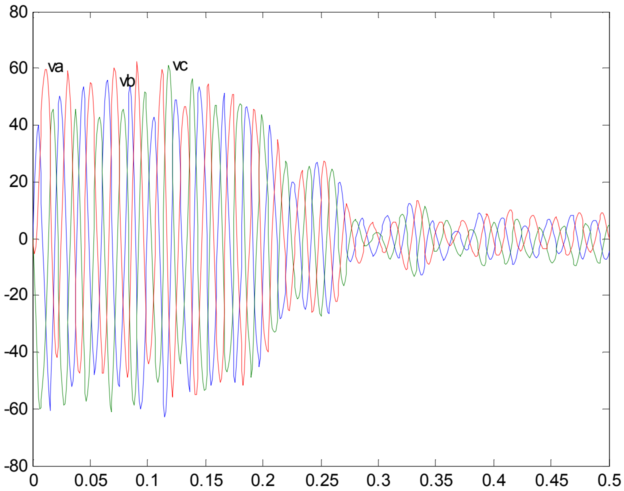


Fig.(19) Three phase voltages applied to the rotor at wind speed 12m/s

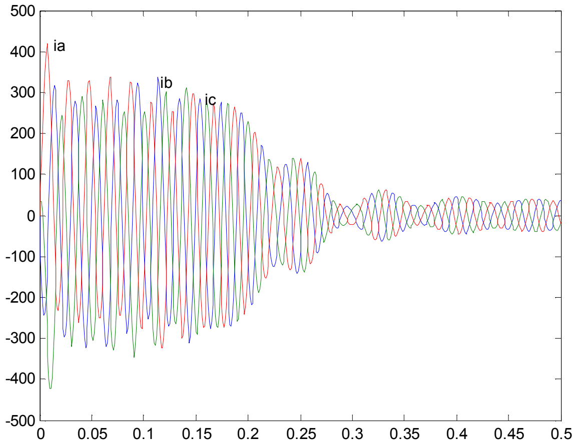


Fig.(20) Rotor three phase currents at wind speed 12m/s

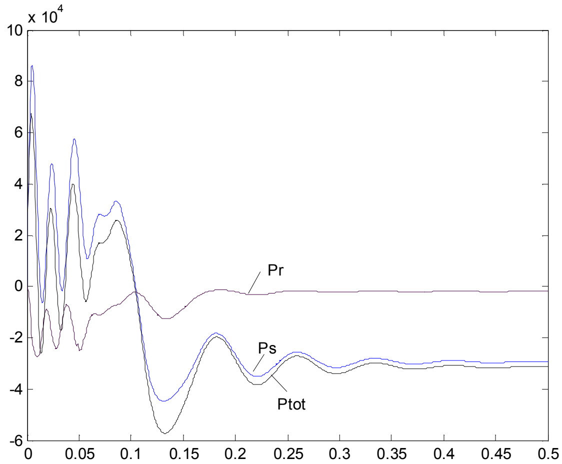


Fig.(21) Generated active powers at wind speed 12m/s

On the other hand, the generated active and reactive powers and the power factor in this case , respectively can be clearly observed in Figs.(21-22-23), where both generated active and reactive powers have been assumed to be negative. It is clear, that according to this wind velocity and the applied torque to the generator rotor , the DFIG system generates its optimum power 32KW when the generator speed is 1530 rpm, and the power factor of the system $Cos\varphi \approx 1$.

Thus for another torque-speed characteristic or torque applied , where wind velocity is 8 m/s , the obtained results by this control system are shown in Figs.(24-28) , where we can observe from Fig.(24) , that the speed which gives the optimum generated power 26KW, is about 1440 rpm , which is below the synchronous speed.

i.e. for a specified wind velocity , there is a turbine rotational speed value that allows capturing the maximum power attainable from the wind.

In addition Figs.(26-27) prove that below the synchronous speed, the rotor side $\Pr$ power flows from the grid to the DFIG , where as at supersynchronous speeds , it flows in the opposite direction.

As was mentioned above , the over all control-system designed , allows the generator to work properly either under subsynchronous or supersynchronous conditions and even if working conditions and consequently the optimum of active power to be generated vary because of changes in wind speed, the designed control structure is capable of keeping track of the desired power factor in the wind generator.

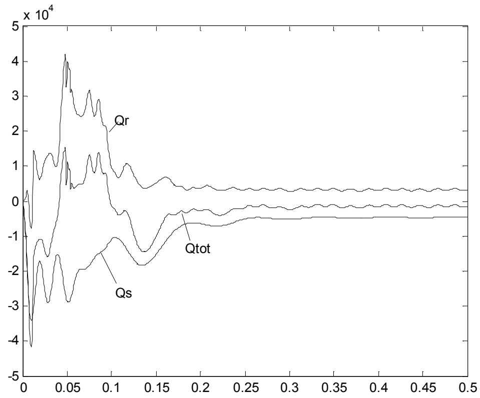


Fig.(22) generated reactive powers at wind speed 12m/s

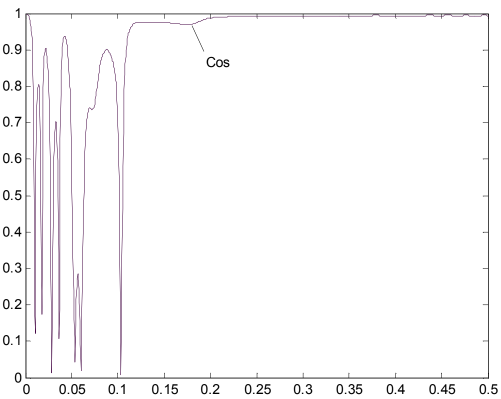


Fig.(23) Power factor at wind speed 12m/s

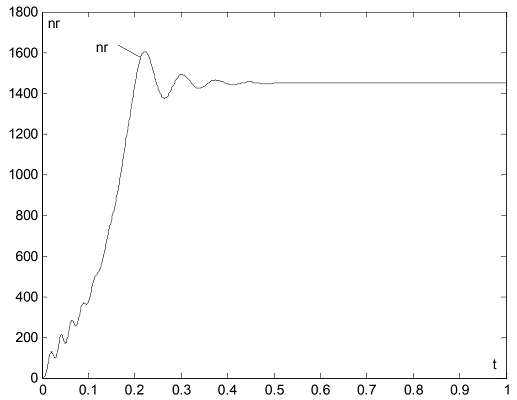


Fig.(24) Generator speed at wind speed 8m/s

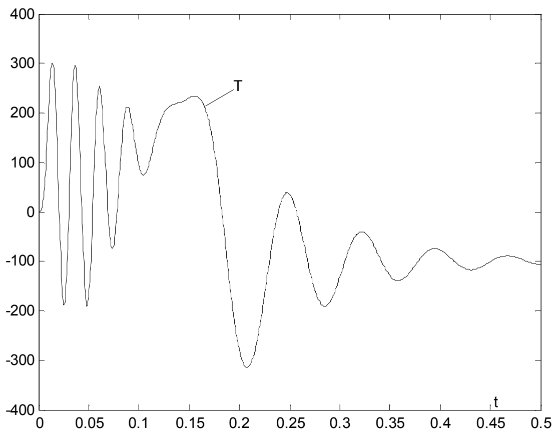


Fig.(25) Generator torque at wind speed 8m/s

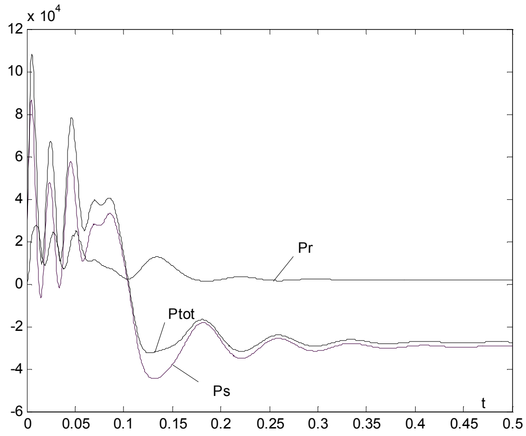


Fig.(26) Generated active powers at wind speed 8m/s

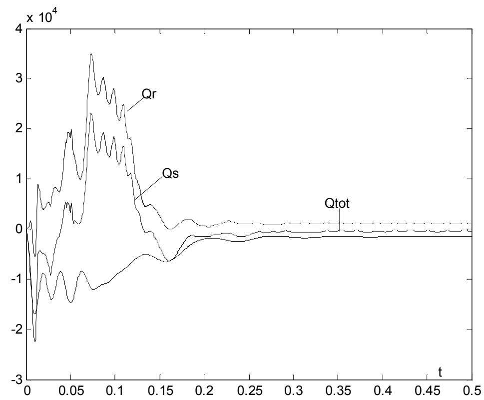


Fig.(27) Generated reactive power at wind speed 8m/s

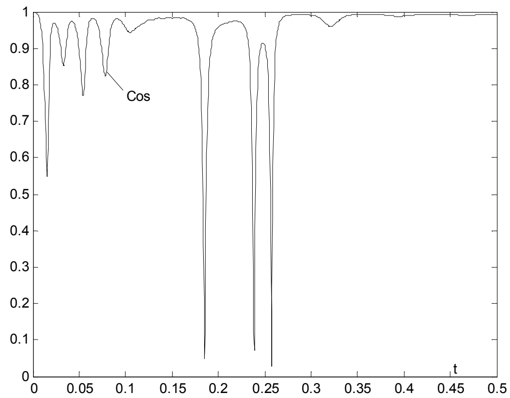


Fig.(28) Power factor at wind speed 8m/s

Conclusion

1-The mechanical efficiency in a wind turbine is dependent of the power performance coefficient. The power performance coefficient of a rotating wind turbine is given by the pitch angle and the tip speed ratio. Adjustable speed will improve the system efficiency since the turbine speed can be adjusted as a function of wind speed to maximize output power.

2-To develop adjustable speed one possible solution is a doubly fed induction generator. Fixed speed generators have a number of drawbacks. The reactive power and therefore, the grid voltage level cannot be controlled, the blade rotation causes power variations and therefore, causes voltage variations from 1 to 2 Hz in the grid. Most of the drawbacks that are mentioned are avoided when variable speed wind turbines are used. These turbines improve the dynamic behaviour of the turbine and reduce the noise at low wind speeds. The power production of variable speed turbines is higher than for the fixed speed turbines, as they can rotate at the optimal rotational speed for each wind speed.

3-A machine model is derived suitable for modelling both fixed speed (FSIG) and doubly fed induction generator (DFIG) wind turbines.Both fixed speed (squirrel cage) and doubly fed (wound rotor) machine constructions are represented by one set of equations, differing only by

the representation of rotor voltage (i.e. short circuited or injected voltage).
4-Control schemes using standard proportional integral PI controller for variable speed wind turbines, using doubly fed induction generators (DFIG) are described and simulated.
5-A full speed control strategy is described and modelled for an optimal power extraction scheme.
6-The modelling of the machine and the control system considers operating conditions below and above synchronous speed, which are actually achieved by means of a double sided converter joining the machine rotor to the grid. In order to decouple the active and reactive powers generated by the machine , stator-flux oriented vector control is applied. The wind generator mathematical model developed in this paper is used to show how such a control strategy offers the possibility of controlling the power factor of the energy to be generated.
7-The simulation results of a grid connected wind driven doubly fed induction generator (DFIG) are presented where they show the transient behaviour of the doubly fed induction generator under different conditions of wind speed. The results prove that, below the synchronous speed the rotor side active power flows from the grid to the DFIG, whereas, at supersynchronous speeds, it flows in the opposite direction.
8-The torque transmitted in the shaft varies with different speed of control. The proportional plus integral (PI) controller has two parameters, the proportional gain constant and the integral time constant. A large proportional constant gives large gain and a small integral time constant gives fast control. Simulations show that fast control of the electric torque gives oscillations in the torque that transmits through the shaft when a change in torque at the turbine occurs. Pulsations will be damped with a large proportional gain constant in the speed controller. A large gain constant in the speed controller makes the electromagnetic torque to vary more and it starts tracking the torque pulsations from the turbine. When the electromagnetic torque has pulsations the power will contain the same pulsations. When choosing the gain constant in the speed controller a choice between pulsations in the torque transmitted in the shaft or pulsations in the power from the generator must be done.

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