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NEW TRENDS IN WIND ENERGY MODELING AND WIND TURBINE CONTROL

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Abstract- Energy planning through optimization techniques is not a new concept, although different new models have been proposed and used over the last 30 years. Environmental concern over the use of conventional sources has reached an alarming stage, thus alternatives sources is imminent. Renewable sources such as wind have gain popularity and demand over the last decade. Renewable sources of electrical energy, which have been lately promoted, are causing problems in distribution and transmission operation networks globally on-shore wind power has seen considerable growth in all grid systems. In the coming decade off-shore wind power is also expected to expand rapidly. Wind power is variable and intermittent over various time scales because it is weather dependent. Therefore wind power integration into traditional grids needs additional power system and electricity market planning and management for system balancing. This extra system balancing means that there is additional system costs associated with wind power assimilation. In this paper, wind energy is reviewed and opened for further discussion. Wind economy, the energy climate relations, wind turbine technology, wind industry, wind control for the wind turbine applications and the current status of installed wind energy capacity all over the world reviewed critically with further enhancements and new research trend direction suggestions. This paper deals with the modeling of Doubly Fed induction Generator (DFIG) cooperating with wind turbine. The wind turbine and the DFIG models are presented step by step. Overall control system of the DFIG is modeled in details in program ATP-EMTP.

Keywords: Wind Energy, Greenhouse Effect, Induction Generator, Wind Turbine, AC/AC Converter.

I. INTRODUCTION

Energy is available in two different alternatives, nonrenewable (coal, fuel, natural gas) and renewable energy (RE) (solar, wind, hydro, wave) sources. Especially, after the industrial revolution, in the 19th century, first coal and then fuel oil are used as primary energy sources for the needs of modern communities. Wind energy is welcomed by the society, practical, economical and environmentally friendly alternative. After the 1973 oil crisis, the RE sources started to appear in the agenda and hence the wind energy gained significant interest. Energy sources with huge and renewable raw materials have the advantage in the long run. Atmospheric environment is polluted due to thermoelectric power plants, and petroleum materials since the industrial revolution. The pollution crises are the catalysts for the search and development of RE sources.

Continuing to use fossil fuels is bound to pollute the atmosphere, and consequently, unwanted greenhouse emissions and climate change effects will come to dominate every part of the earth. Currently the fastest developing energy source technology is the wind energy. Because wind energy is renewable and environment friendly, systems that convert wind energy to the electricity have developed rapidly. Wind power produces about 1.5% of worldwide electricity use and is growing rapidly, having doubled in the three years between 2005 and 2008. Several countries have achieved relatively high levels of wind power penetration, such as 19% of stationary electricity production in Denmark, 11% in Spain and Portugal, and 7% in Germany and the Republic of Ireland in 2008. As of May 2009, 80 countries around the world are using wind power on a commercial basis [1].

The amount of water usage is often of great concern for electricity generating systems as populations increase and droughts become a concern. All thermal cycle plants require a great deal of water for condensing, and the amount of water needed will be reduced with increasing boiler temperatures. Wind turbine technology with wind energy economics and wind systems are evaluated. Wind energy current states are given year by year for some countries where electricity generation by wind energy increases in an unprecedented manner. So at same time, there has been a rapid development wind technology [3, 4]. The main advantage of the DFIG include: wide range of control of the output power extracting from the wind, separate active and reactive power control and relatively fast response to significant grid disturbances [5, 6].

II. MAIN JUSTIFICATIONS OF WIND ENERGY

Engineering economics is a specialized subject. Engineering economics is not theoretical, and it is not concerned with balance sheets or profit- loss statements. Rather it is a pragmatic study of costs which involve decision- making regarding future income and expenses. Engineering economics involves planning and good business judgment. Note that as with the other technology assessments, grid connection costs and related energy and emissions are not considered. The remoteness of many wind farms does often mean that new grid connections are required and studies often calculate the greenhouse requirements of these connections.

While calculating costs, several internal cost factors have to be considered [7]. Capital costs- tend to be low for fossil fuel power stations; high for renewable and nuclear; very high for waste to energy, wave and tidal, Photovoltaics (PV) and solar thermal.

- Operating and maintenance costs - tend to be high for nuclear, coal, and waste-to-energy and low for renewable and oil and gas fired peaking units.
- Fuel costs- high for fossil fuel and biomass sources, very low for nuclear and renewable, possibly negative for waste to energy.
- Expected annual hours run- as low as 3% for diesel peakers, 30% for wind, and up to 90% for nuclear.
- Revenue recovered from heat sales can be offset against running costs, and reduces the net costs in the case of Cogeneration and District heating schemes.

To evaluate the total cost of production of electricity, the streams of costs are converted to a net present value using the time value of money. The part of a basic load represents approx. 64% of the electricity production in total. The costs of electricity production for the mid-load and peak load are considerably higher. There is a mean value for the costs of electricity production for all kinds of conventional electricity production and load profiles in 2010 which is 10.9 €ct to 11.4 €ct per kWh. The RWI (Rheinisch- Westfälischen Institute) calculated this on the assumption that the costs of energy production would depend on the price development of crude oil and that the price of crude oil would be approx. 23 US$ per barrel in 2010. In fact the crude oil price is about 80 US$ in the beginning of 2010. This means that the effective costs of conventional electricity production still need to be higher than estimated by the RWI in the past. The following Table 1 arises for the costs of electricity production in newly constructed power plants in 2010.

Table 1. Arise for the costs of electricity production

ENERGY SOURCE	COSTS OF ELECTRICITY PRODUCTION €CT/KWH
Nuclear Energy	10.70 – 12.40
Brown Coal	8.80 – 9.70
Black Coal	10.40 – 10.70
Domestic Gas	10.60 – 11.80
Wind Energy Onshore	4.97 – 9.61
Wind Energy Offshore	3.50 – 15.00
Hydropower	3.47 – 12.67
Biomass	7.71 – 11.55
Solar Electricity	28.43 – 39.14

The major processes required for the installation and operation of a wind farm are outlined in Figure 1. [8]. The most process in development of a wind farm is the turbine construction (60-85% of cost [9-10], consisting of the rotor, nacelle and tower. Although these components are often constructed separately, standard technology is used, and requirements reported in the literature and industry are by turbine.

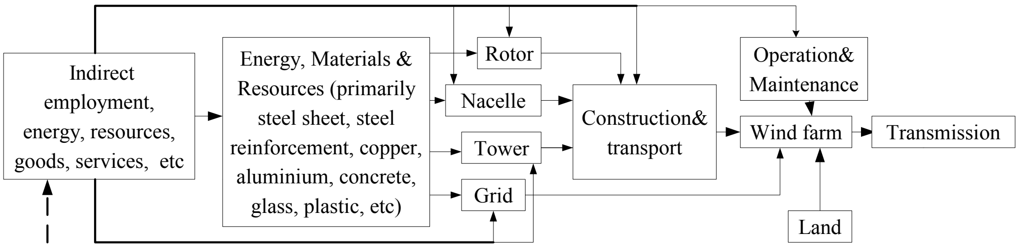

Figure 1. Major processes required for wind farm development and operation

The foregoing sources and assumptions are used to develop base, high and low cases for a nominal rated 1.5 MW_{el} wind turbine (Table 2). The material intensity factor increases and reduces the embodied energy in the material inventory by 20%. The base case here can be considered current state of the art equipment installed at good, but not extreme site.

Table 2. Main parameters for the wind power cases

MAIN PARAMETERS	BASE	HIGH	LOW
Grid Losses (%)	5%	9%	3%
Wind Speed (M/S)	6	5	7
Electricity Out (Gwh/Year)	4.10	3.03	5.03
Capacity Factor (%)	31.2%	23.1%	38.1%
Lifetime (Years)	25	20	30
Transport Distance (Km)	250	400	150
Material Intensity Factor	1	1.2	0.8

A trend to replace older and smaller wind turbines with larger, more efficient, quieter and more reliable designs gives higher power outputs from the same site often at a lower density of turbines per hectare. A number of technologies are under development in order to maximize energy capture for lower wind-speed sites. These include: optimized turbine designs; larger turbines; taller towers; the use of carbon- fibre technology to replace glass reinforced polymer in longer wind-turbine blades; maintenance strategies for offshore turbines to overcome difficulties with access during bad weather/ rough seas; more accurate aero-elastic models and more advanced control strategies to keep the wind loads within the turbine design limits.

III. ENVIRONMENTAL EFFECTS

Compared to the environmental effects of traditional energy sources, the environmental effects of wind power are relatively minor. Wind power consumes no fuel, and emits no air pollution, unlike fossil fuel power sources.

A. Global Climate Change and Greenhouse Effect

Global climate change and greenhouse effect the history of the planet shows that climate changes occur from time to time in different parts of the world. There are some differences between present day climate change and other times. Historical climate changes resulted from natural phenomena and they affected some parts of the world. Today climate change occurs due to human activities [12].

The greenhouse effect can be defined briefly as an atmospheric temperature increase, due to gas emitted by human activities. Emissions of the main anthropogenic greenhouse gas, CO_2, are influenced by: size of the human population, amount of energy used per person, and level of emissions resulting from energy use.

B. Energy Production and Greenhouse Gases

As mentioned earlier, half of the greenhouse gases due to CO_2. The production of CO_2 is dependent on human attitudes, especially, towards energy production. CO_2 productions for each energy source are given in Figure 2. It is seen that highest CO_2 values are produced by non-conventional energy sources as wind and nuclear energy sources have minimum levels. Nuclear energy produces dangerous radioactive gases and wastes [13].

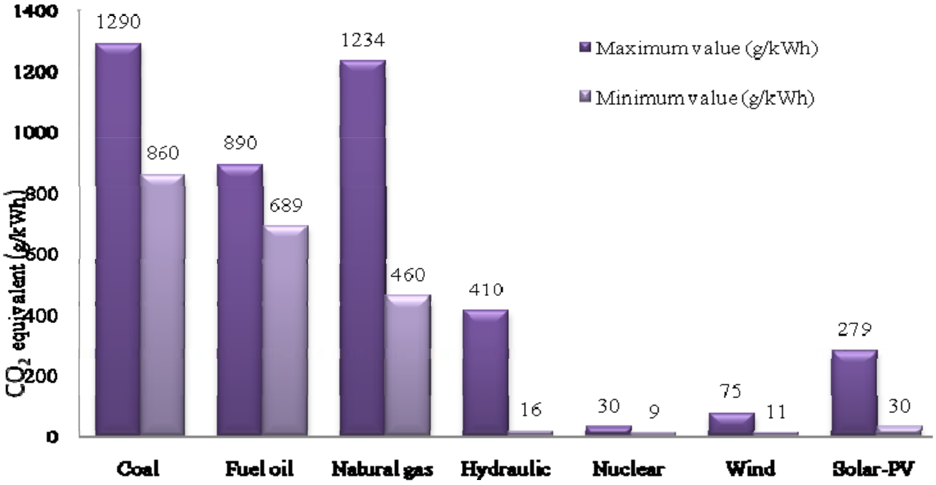

Figure 2. CO_2 emissions production for all energy sources [8]

C. Developing International and Technical Policy to Protect the Climate

One of the most effective protocols was developed in Kyoto in December 1997, a very important milestone to establish an international framework for climate change policy in the 21st century. A policy is expected to be adopted regarding quantified emissions limitations and reduction these objectives are some of the key elements of the protocol [14]. The Kyoto Protocol has been discussed from several perspectives, a scientific [15], and economic perspective [16] discussions of the necessary and sufficient conditions for reducing CO_2 emission intensity and achieving the Kyoto Protocol [17].

In addition to developing international policy to protect the climate, technically RE sources are considered and wind energy has the greatest capacity to increase RE sources. At the end of 2010, worldwide nameplate capacity of wind-powered generators was 159.2 gigawatts (GW). These turbines save carbon, nitrogen oxide and sculpture dioxide, and main gases responsible for acid rain. Wind energy reduces emissions from polluting gases because every unit of electricity produced by wind power replaces a unit of electricity generated by other means. These are usually coal-fired plants, which tend to be taken 'off-line' when supply exceeds demand. Coal-fired power stations typically emit around 800–1200 g of CO_2 for every unit (kWh) of electricity they produce. Therefore, each unit of electricity produced by wind energy avoids an equivalent amount of emissions.

Combined with other renewable technologies and efficient energy use, wind power is crucial in reducing global climate change, acid rain and other environmental problems, because it produces no carbon dioxide, and hazardous or radioactive wastes.

It is well known that wind energy is one of the cleanest and most environmentally friendly energy sources, and unlike fossil fuels, the wind will never be depleted. All forms of energy production have an environmental impact, but the impacts of wind energy are low, local, and manageable. The production of blades, the nacelle, the tower, etc. the exploration of the material and the transport of equipment need to energy consumption. In addition to energy consumption, scrap metals remain when these devices have outlived their usefulness. These environmental impacts are negligible when compared with conventional energy sources. The significance of wind energy originates from its friendly behavior to the environment. Due to its clean, wind power is sought wherever possible for conversion to electricity with the hope that air pollution from fossil fuels will be reduced [18, 19].

D. Water Usage

The amount of water usage is often of great concern for electricity generating systems as populations increase and droughts become a concern. Still, according to the U.S. Geological Survey, thermoelectric power generation accounts for only 3.3 percent of net freshwater consumption with over 80 percent going to irrigation. General numbers for fresh water usage of different power sources are shown below [20].

Table 3. Fresh water usage of different power sources

WATER USAGE (GAL/MW-H)			
Power Source	Low Case	Medium/Average Case	High Case
Nuclear Power	400	400 to 720	720
Coal	300		480
Natural Gas	100		180
Hydroelectricity		1,430	
Solar Thermal		1,060	
Geothermal	1,800		4,000
Biomass	300		480
Solar PV		30	
Wind Power	0.5	1	2.2

All thermal cycle plants require a great deal of water for condensing, and the amount of water needed will be reduced with increasing boiler temperatures. Coal, being able to burn at high temperatures is thus more efficient and uses less water, while nuclear is more limited by material constraints and solar is more limited by potency of the energy source. Thermal cycle plants, however, also have the option of using seawater if located on the seacoast. Such a site will not have cooling towers and will be much less limited by environmental concerns of the discharge temperature due to the fact that dumping heat will have very little effect on something with such a comparatively large thermal mass. This will also not deplete the water available for other uses. Nuclear power in Japan for instance, uses no cooling towers at all because all plants are located on the coast. Also, if dry cooling systems are used, significant water from the water table will not be used. Other, more novel, cooling solutions exist, such as sewage cooling at the Palo Verde Nuclear Generating Station.

Hydroelectricity's main cause of water usage is both evaporation and seepage into the water table.

According to table 3, Wind need to limited water consumption.

IV. NEW DESIGN TRENDS

Making a wind turbine may seem simple, but it is a big challenge to produce a wind turbine that [21]:
- Meets specifications for standard electricity generation with each unit operating as an unattended power station.
- Competes economically with other energy sources.

Technology trends can be categorized into three areas:
- Trends that increase output power performance while increasing long term life- extracting more power from available wind.
- Trends in manufacturing that lower turbine costs- competition is driven by the total installed cost.
- Trends in diagnostic tools that reduce turbine downtime including ease of maintenance.

A. Rotor Blade Technology Trends

With the wind turbines we convert wind into energy. The most important part in a wind turbine is the rotor blade. Because of the shape of the rotor blade becomes the power from the air flow a turning movement. The rotor blade is connected to the main axel. The turning movement is accelerated by gears in the gear cast. Then there's one axel that drives on the generator to arouse the electricity. Longer, lighter, and stronger is the blade for tomorrow, room for manufacturing innovation. A very complex "airplane wing" design. Turbine blade has up to 6 critical surfaces compared to 1. Rotor Mass Reduction is a key factor in improving performance

B. Tomorrow's Towers May Change

Today's towers are aesthetically pleasing and relatively easy to manufacture, but growing in cost with rising costs in steel materials. Lattice structures may come back. Concrete structures are being widely considered. Taller, lighter and lower cost is the goal for tomorrow.

C. Control Technologies

A critical part of today's research and study for Power Engineering. Possibly the most significant improvements to come is in this area. Wind and wind turbulence is the most challenging to predict. Yet the most critical is to control for the wind turbine.

D. Drive Train Design Trends

Improved lubrications- synthetic oils use of advanced analytical design tools to refine designs including an overall systems approach, lighter weight turbines, and reduced weight.

E. Turbine Configuration

Direct Drive and Permanent Magnet Generators (PMG's) a significant reduction in gearing, but also many new design challenges. Permanent Magnet Generators are potentially greater power efficiency, Long term reliability increase. Traditional Turbine Configuration has a drive train. A new trend in Turbine Configuration cancelled to drive train (Figure 3).

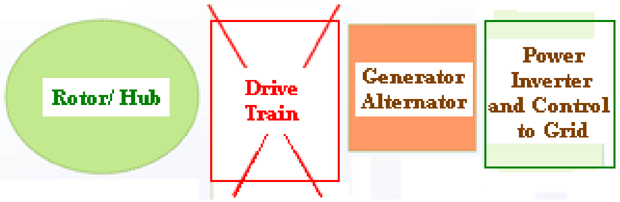

Figure 3. A new trend in turbine configuration

V. MATHEMATICAL MODEL OF GENERATOR AND WIND TURBINE

Functions approximation is a way of obtaining relatively accurate representation of a wind turbine. It is made by using a few parameters which represent model of wind turbine. It is current source, capacitor and resistance. Equation described behavior of wind turbine is the following:

$$J_m \frac{d\omega_r}{dt} + D_m \omega_r = T_m - T_e \tag{1}$$

where, on the basic of duality principle, mechanical variables are represented by adequate electrical quantities:

a) Inertia constant J_m, [kg.m^2]- capacitance C, [F]
b) Friction coefficient D_m, [N.m/(rad/s)]- conductance $1/R$, [1/Ω]
c) Mechanical torque Tm, [N.m]- current i, A
d) Angular velocity ω_r, [rad/s]- voltage u, [V]

Therefore, the instantaneous value of voltage ω_r [v] is equivalent to the rotor angular velocity [rad/s]. The current at the machine input represents the torque shaft, which is balanced with the electromagnetic torque.

$$T_e = \frac{3}{2} p(\psi_d i_q - \psi_q i_d) \tag{2}$$

where;
p- number of machine pair of poles
ψ_d, ψ_q, i_d, i_q - electromagnetic flux and current, respectively, in d and q coordinate.

Structure of the considered model is shown in Figure 4. This model is fed up from the both sides. The stator winding of the generator is directly connected to the grid and rotor windings are fed from the grid using voltage source converter AC/AC.

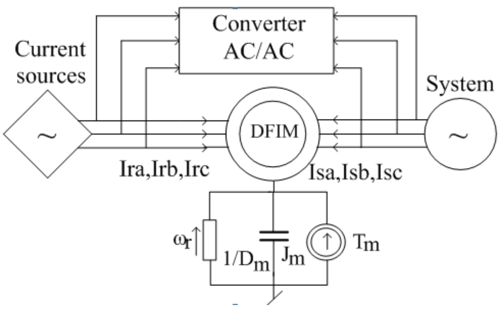

Figure 4. Structure of the considered model

In order to simplified phenomena analysis in electric machine, was introduced classic theory of rotating fields and the well known d-q model, as well as both three-to-two and two to three axes transformations. Stator side current and voltage components are referred to the stationary reference frame, while the rotor side current and voltage components are referred to a reference frame rotating at rotor electrical speed ω_r. Figure 5 presents vector diagram of the machine.

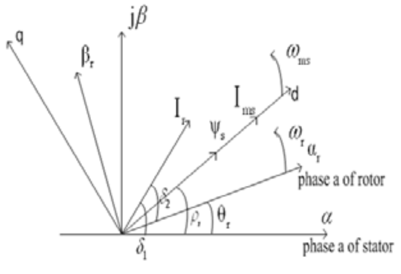

Figure 5. The machine vector diagram

Any three phase stator or rotor electrical magnitude x can be expressed according natural reference frame-stationary if it is a stator side and rotating at rotor electrical speed ω_r if it is a rotor side-direct, quadrature and zero-sequence components as follows

$$\begin{bmatrix} X_d \\ X_q \\ X_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \tag{3}$$

where x represents the stator or rotor side voltage, current or flux-linkage. The Clarke's inverse transformation allowed obtain three phase value from direct, quadrature, and zero components as follow

$$\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} X_d \\ X_q \\ X_0 \end{bmatrix} \tag{4}$$

VI. OVERALL MODEL OF DFIG

Structure of the considered model is shown in the Figure 6. For simplicity the phase current sources in the rotor circuit was presented by using controlled current sources. This current is applied only by starting simulation and is switched-off after 0.0001s.

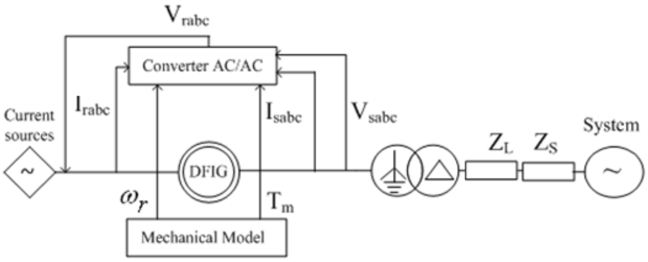

Figure 6. Structure of the considered model

The control procedure for determination of needed voltage in the rotor circuit was realized in the form of MODELS module (block Converter AC/AC in Fig.3). There are 3-phase signals at the input of this block: current at both sides of the generator and voltage of stator and at the output 3-phase voltage source control signal. This method allows regulate wind turbine only by using signals measured in both sides of generator. The electrical parameters of machine are shown in Table 4.

Table 4. Electrical parameters machine

Parameters [Ω]	Value [Ω]
R_s Resistance stator	0.0017
X_{ls} Inductance stator	0.0172
X_m Inductance magnetizing	0.7391
R_r Resistance rotor	0.0055
X_{lr} Inductance rotor	0.0172

Dynamical parameters of model are defined as follows;

$$L_m = \frac{X_m}{2\Pi f_s} \tag{5}$$

$$L_{ls} = \frac{X_{ls}}{2\Pi f_s} + L_m \tag{6}$$

$$L_{lr} = \frac{X_{lr}}{2\Pi f_s} + L_m \tag{7}$$

Parameters of system are following
U_S=20 kV
Impedance of system; R=0.18 Ω; X=1.13 Ω
Transmission line parameters;
R_L=0.5 Ω; X_L=0.37 Ω
Transformer;
S_T=1.8 MVA
ϑ_T=20000/690 (V/V)

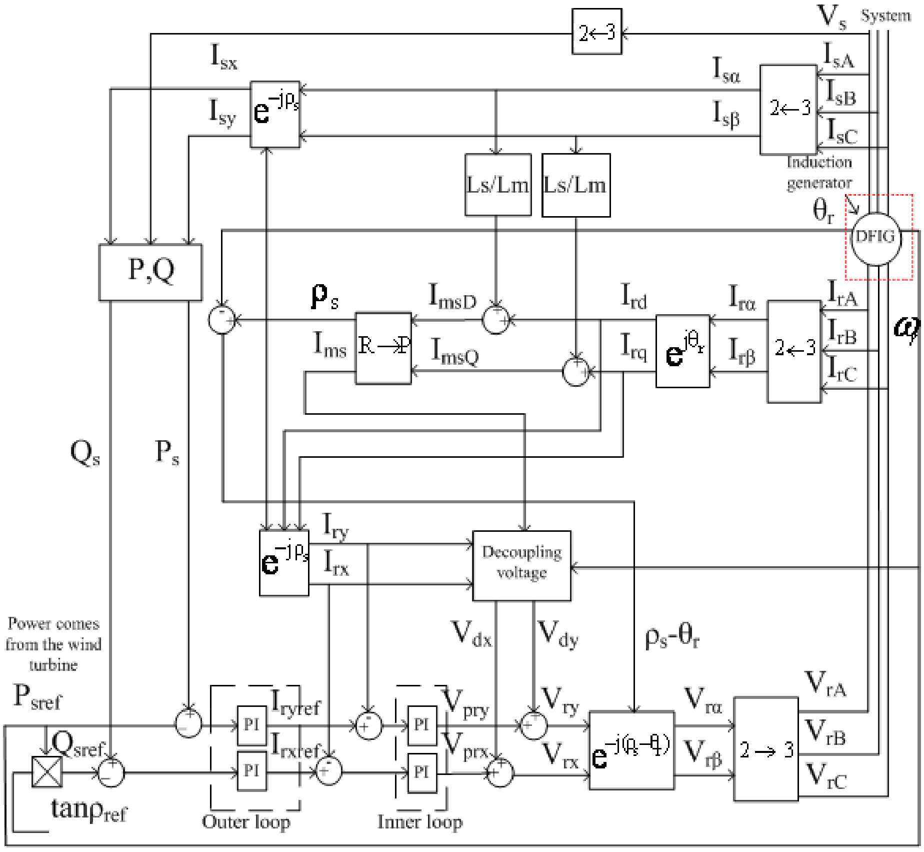

Figure 7. Overall control of DFIG

VII. OVERALL CONTROL OF DFIG

Overall control of DFIG is presented in the Figure 7. As the rotor position is concerned, in the non-sector application this variable can be estimated on the bases of measured quantities: the rotor current L_r and the stator current I_s and voltage U_s. From the Figure 2, we can conclude, that position of the rotor is determined by the angle

$$\theta_r=\delta_1-\delta_2 \tag{8}$$

The angle δ_2 can be obtain from the measured 3-phase current rotor by using Clarke's transformation.

$$I_{rr\alpha}=(2.I_{Ar}-I_{Br}-I_{Cr})/3 \tag{9}$$

$$I_{rr\beta}=(I_{Br}-I_{Cr})/\sqrt{3} \tag{10}$$

and finally;

$$\delta_2 = arctg(\frac{I_{rr\beta}}{I_{rr\alpha}}) \tag{11}$$

For the determination angle δ_1 we can use adequate components of measured stator quantities

$$\delta_1 = arctg(\frac{I_{r\beta}}{I_{r\alpha}}) \tag{12}$$

where;

$$I_{r\alpha} = \frac{X_s I_{s\alpha} + R_s I_{s\beta} + U_{s\beta}}{X_m} \tag{13}$$

$$I_{r\beta} = \frac{X_s I_{s\beta} - R_s I_{s\alpha} - U_{s\alpha}}{X_m} \tag{14}$$

and $X_m = \omega_s L_m$; $X_s = \omega_s L_s$, $I_{s\alpha}$, $I_{s\beta}$, $U_{s\alpha}$, $U_{s\beta}$ are the stator current and voltage space vector components calculated from measured quantities, similarly as in (9) and (10) equation.

Estimation phase angle of stator-flux-linkage space phasor ρ_s demanded obtain rotor current changed from their natural axes to the stationary reference frame. For this equations is necessary measure the rotor angle θ_r;

$$I_{rd} = I_{r\alpha}\cos(\theta_r) - I_{r\beta}\sin(\theta_r) \tag{15}$$

$$I_{rq} = I_{r\alpha}\sin(\theta_r) + I_{r\beta}\cos(\theta_r) \tag{16}$$

Direct and quadrature axis stator magnetizing current components respectively, expressed in the stationary reference frame, can be calculated as follow;

$$I_{msD} = \frac{L_s}{L_m} I_{s\alpha} + I_{rd} \tag{17}$$

$$I_{msQ} = \frac{L_s}{L_m} I_{s\beta} + I_{rq} \tag{18}$$

and finally;

$$\rho_s = arctg\left(\frac{I_{msQ}}{I_{msD}}\right) \tag{19}$$

Direct and quadrature axis rotor current components respectively, expressed in the stator- flux oriented reference frame, can be represented by

$$I_{rx} = I_{rd} \cdot \cos(\rho_s) + I_{rq} \cdot \sin(\rho_s) \tag{20}$$

$$I_{ry} = I_{rq} \cdot \cos(\rho_s) - I_{rd} \cdot \sin(\rho_s) \tag{21}$$

On basis space vector current stator expressed in axis *x*, *y* (reference to the direct and quadrature axis rotor components) can computed active and reactive power obtain from the machine;

$$P_S = \frac{3}{2} \cdot |\overrightarrow{V_S}| \cdot I_{SY} \tag{22}$$

$$Q_S = \frac{3}{2} \cdot |\overrightarrow{V_S}| \cdot I_{SX} \tag{23}$$

where:

$$I_{sx} = \frac{L_m}{L_s} \cdot (I_{ms} - I_{rx}) \tag{24}$$

$$I_{sy} = -\frac{L_m}{L_s} \cdot I_{ry} \tag{25}$$

Equations (24) and (25) confirm dependence, that components current stator in axis *x*, *y*, I_{sx} and I_{sy} should be proportionally to the current rotor in the same axis I_{rx}, I_{ry}.

It means that, the stator side-active and reactive power may be governed separately just by controlling the stator current I_{sx} and I_{sy} components, respectively.

In scheme control contains two cascaded control-loops. The outer one (current regulator) serve to the control power obtain from generator and decrease about reference power, which come from turbine.

$$I_{ry}ref = P_s - P_{sref} \tag{26}$$

$$I_{rx}ref = Q_s - Q_{sref} \tag{27}$$

The inner-loops, which has aim to control voltage rotor as result decoupling with signal voltage came from stator, cause voltage stability and control power.

$$V_{pry} = I_{ry}ref - I_{ry} \tag{28}$$

$$V_{prx} = I_{rx}ref - I_{rx} \tag{29}$$

In order to improve decoupling between x and y axes, the V_{pry} and V_{prx} decoupling voltage components given above are added to V_{drx} and V_{dry} in the following way;

$$V_{rx} = V_{drx} + V_{prx} \tag{30}$$

$$V_{ry} = V_{dry} + V_{pry} \tag{31}$$

where:

$$V_{drx} = -X_{s1} \cdot L_{pr} \cdot I_{ry} \tag{32}$$

$$V_{dry} = (2\pi f - \omega_r) \cdot L_r \cdot I_{rx} - X_{s1} \cdot (I_{ms} - I_{rx}) \tag{33}$$

where;

$$L_{pr} = \frac{L_{lr} + L_m - L_m{}^2}{L_{ls} + L_m} \tag{34}$$

$$X_{s1} = (2\pi f - \omega_r) \cdot L_{pr} \tag{35}$$

An inner control loop consists of a current regulator, which controls the magnitude and phase of the voltage generated by the converter. Expression of V_{rx} and V_{ry} according to the rotor natural reference frame as follows:

$$V_{r\alpha} = V_{rx} \cdot \cos(\lambda) - V_{ry} \cdot \sin(\lambda) \tag{36}$$

$$V_{r\beta} = V_{rx} \cdot \sin(\lambda) + V_{ry} \cdot \cos(\lambda) \tag{37}$$

where;

$\lambda = \rho_s - \theta_r$ is a different between phase angle of stator flux-linkage space phasor with respect to the direct-axis of the stationary reference frame and angle of rotor. On basic expression (3) we can compute voltage rotor in three phase.

VIII. SIMULATION RESULTS

The model was prepared by using of ATP-EMTP program (Figure 8) [22]. Power of the generator is equal 2MWA. Some simulation results are presented. Figure 9 presents compared active and reactive power of generator and obtained from the wind turbine. This parameters are covered, so it’s mean that regulators applied in model operate very well. The range of the changing of power load of the machine is very wide.

Figure 10 shows rotor angular velocity, which is varies according to changing generator load.

Figure 11 shows Rotor current, which is varies according to changing generator load. Figure 12 shows Rotor voltage is depends on load of generator and is changing appropriate to the power of wind turbine (P_{sref}, Q_{sref}).

IX. CONCLUSIONS

In this review paper, wind engineering subjects are explained in Main Justifications. Additionally, wind turbine technology with wind energy economics and wind systems are evaluated. Wind energy current states are given year by year for some countries where electricity generation by wind energy increases in an unprecedented manner.

This paper presents a detailed model for a wind turbine based on DFIG, so that special attention is paid to the description and design overall control system. This control system of DFIG allows governing independently stator side or net active and reactive power. In this model range of changes of generator load is very wide. Simulation result obtain during investigate this model are very satisfactory.

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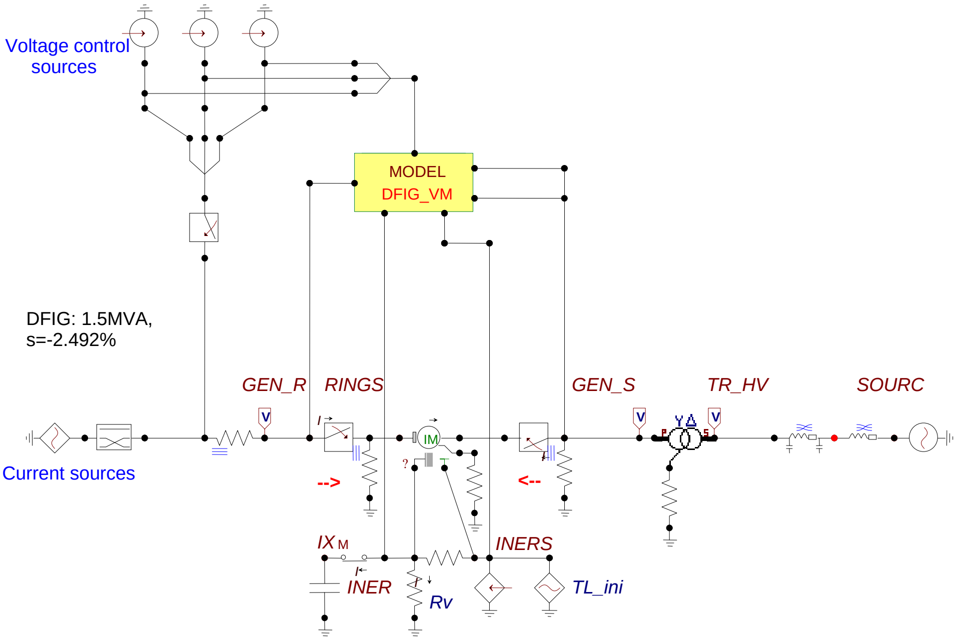

Figure 8. Circuit diagram in ATP-EMTP

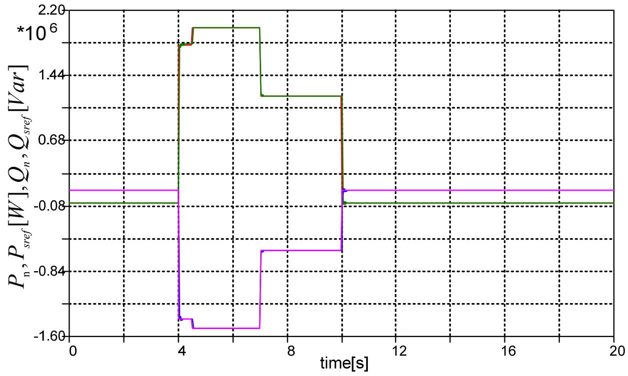

Figure 9. Compare active P_n and reactive Q_n power of the generator and P_{ref} and Q_{ref} come from wind turbine

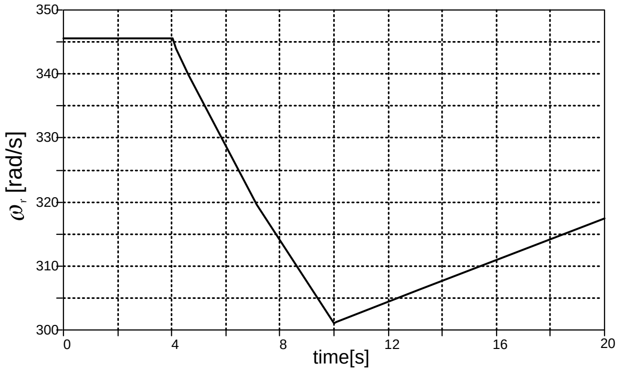

Figure 10. Rotor angular velocity

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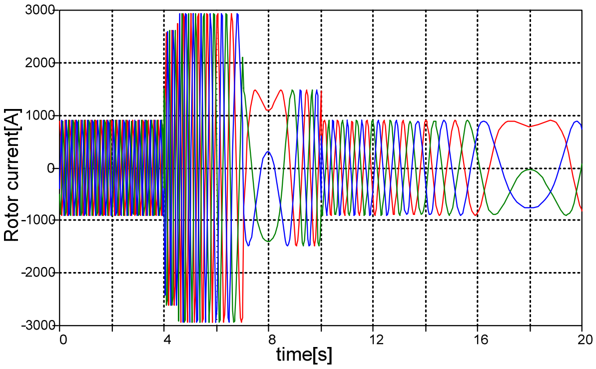

Figure 11. Rotor current

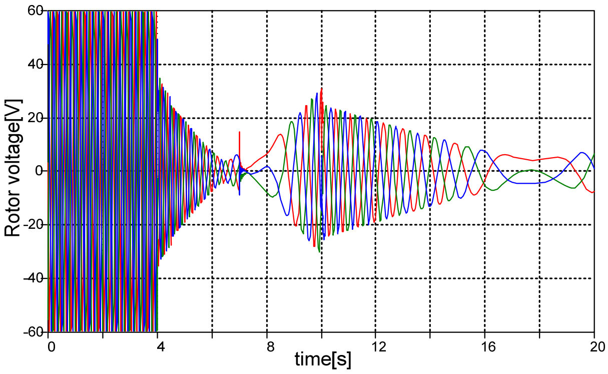

Figure 12. Rotor voltage

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