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Advanced electric drives in the wind turbine conversion chain

Actionarile electrice avansate in lantul de conversie al turbinelor eoliene

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Rezumat: *Creșterea consumului de energie și al emisiilor de gaze cu efect de seră (GES) are consecințe din ce în ce mai grave asupra mediului, societății și economiei, atât la nivel global, european, cât și național. În acest context lupta pentru măsuri de combatere a efectelor schimbărilor climatice impune stabilirea de strategii energetice și ecologice. La nivel european s-a stabilit neutralizarea emisiilor de gaze cu efect de seră până în 2050, îmbunătățirea eficienței energetice și promovarea surselor regenerabile de energie. Utilizarea resurselor eoliene, în special a turbinelor eoliene cu generatoare sincrone cu magneți permanenți și a diverselor actuatoare electrice avansate - convertoare de mare putere, se accentueaza tot mai mult.*
Această lucrare este un studiu bibliografic elaborat al compoziției, tehnologiilor și configurațiilor de ultimă generație a lanțului de energie eoliană a unui parc eolian. Sunt abordate și studiate tendințele actuale ale diferitelor topologii din lanțul de conversie a energiei eoliene disponibile în literatură.

Cuvinte cheie: actuatoare electrice avansate, conversie de energie, configurație electrică.

Abstract: *The increase in energy consumption and emissions of greenhouse gases (GHG) has increasingly serious consequences on the environment, society and the economy, both at the global, European and national level. In this context, the fight for measures to combat the effects of climate change require the establishment of energy and ecological strategies. At the European level, the neutralization of greenhouse gas emissions by 2050, the improvement of energy efficiency and promotion of renewable energy sources have been established. The use of wind resources, especially wind turbines with permanent magnets synchronous generators and various advanced electrical actuators - high power converters, is increasingly emphasized.*

This paper is an elaborate bibliographic study of the state-of-the-art wind power chain composition, technologies and configurations of a wind farm. The current trends of the different topologies in the wind power conversion chain available in the literature are addressed and studied.

Keywords: advanced electric actuators, energy conversion, electrical configuration.

1. Introduction:

The development of power electronics and control electronics led to the emergence of an informational flow that complemented the existing electrical drive systems, bringing them to the level of advanced electrical drives [1].

The main purpose of an electric drive is to drive, electrically, working machines, mechanical devices, in our case to an electric generator. Another role of an actuation is that of matching the motor/electric generator to the mechanical load and to the electrical network [2, 3].

Advanced Electric Actuators (AEAs) power electronic devices to (digitally) control this power conversion process [4].

The electric drive system (SAE) will therefore represent the set of devices that transform electrical energy into mechanical energy and control this energy.

Electric drives have the largest share in electricity consumption. It is stated that over 60% of the electricity produced is used in electric drives [1].

The advantages of using AE in various industries: reliability, precision, speed, improving the quality of dynamic processes, reducing consumption by 30-50%, compatibility of AE with power and information systems, fine adjustments, starting, stopping and reversing the direction of rotation, high efficiency, easy maintenance [5].

Among the most important fields of use of AEA would be: - renewable energies, the technological industry, the automotive industry, the military industry, the aeronautical industry, the cement industry, the metallurgical industry, electrified transport, info gadgets, home applications, etc. [3, 6].

The importance of AEA in the field of renewable energies is maximum. Today's turbines, represented in figure 1, are able to transform a large amount of wind energy into electricity. This is due to blades that are developed using cutting-edge aerodynamic analysis and performance-enhancing electronics.

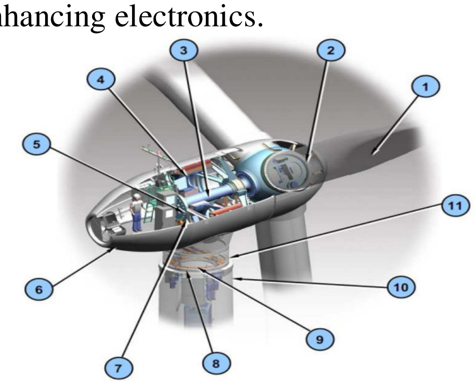


Fig.1 Representation of the main components of a wind power plant:1-blade, 2-blade system orientation, 3-main transmission system, 4-electric generator, 5- bracking rotor system, 6-nacelle, 7-bracking system, 8-rotor system orientation, 9-braking system of the braking device [7]

The main elements of a wind energy conversion system are shown in figure 2: the turbine rotor with the component blades, and the gearbox, which may be missing in the case of using synchronous generators, participates in the conversion of wind energy into mechanical power. The electric generator, which can be synchronous or asynchronous (induction), transforms mechanical energy into electrical energy that will be processed with the help of high-power converters to be transmitted to a step-up transformer from where it is taken over by the network [8].

2. Advanced electric drives. Topologists, classifications

The advanced electric drives are composed of the following parts, described in figure 2.1: electric generator, electronic power converter, current and position sensors, unit controller.

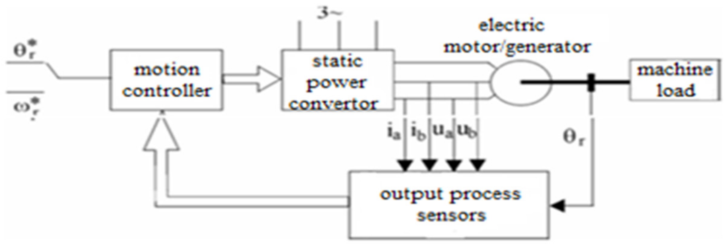


Fig. 2.1. The basic topology of an advanced electric drive [5].

The drive controller can also be motion – speed and/or position controller, more or less the same for all types of electric drives and the electric controller that deals with current and voltage (or link flux and torque) control within a converter [3].
Electrical sensors (observers) refer to voltage, current, flow measured (or calculated) state variables while motion sensors (observers) mean position and/or speed and torque according to measured (or calculated) state variables [3].

The electrical controller generally has electrical input sensing (observer) from both the power supply and the PEC output. The motion controller generally only handles motion sensor (observer) outputs. On the other hand, electrical controller commands are related to power source-side energy conversion performance commands (unity power factor, harmonic elimination) while motion controller commands are related to motion control commands (speed, position, torque) managed through an interface from a local digital controller. As expected, the electrical and motion controllers are mixed together in the hard and soft drive controller. So far both the drive controller and the interface are made by high-performance digital signal processors (DiP). Electric controllers tend to be more specific and have applications for different electric drives [3].

High power converter

It is a regulation system that transforms the single-phase supply voltage into a three-phase voltage system where the voltage and frequency are variable, obtained by pulse width modulation (PWM), as shown in figure 2.2. The adjustment of the parameters specific to the static converter are set by means of a galvanically isolated serial communication (SCI).

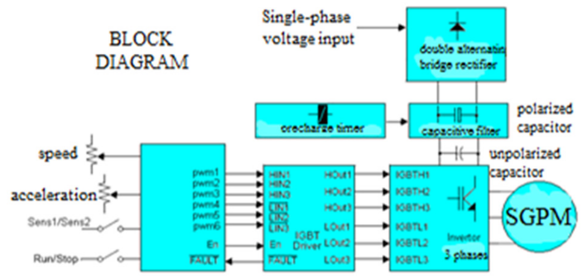


Fig. 2.2. Block diagram representation of the static converter [9]

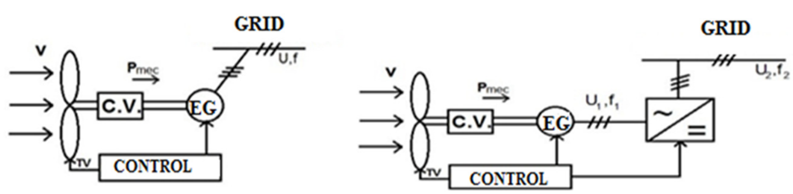
3. Topologies of the advanced electric drives of wind power plants

The configuration of the wind power plants includes a multitude of constructive variants with advanced electric actuators, which will be presented below.

Depending on the type of connection of the electrical generators to the electrical network we have:

- direct: cheap, but with low energy yield, as can be seen in figure 3.1a;
- indirectly: more expensive as a result of the cost of static equipment, but with higher efficiency because driving strategies can be realized that tend to operate at the points of maximum power, at variable wind speeds figure 3.1b, presented in [10].

Direct connection implies rigid connection to the alternating current (usually three-phase) of the network. The indirect connection to the network involves passing the current from the generator through a series of electronic devices that have the role of adjusting the current to match that of the network. In the case of asynchronous generators, this is achieved by simply connecting to the network [10].



a) b)

Fig. 3.1. The type of connection of the SGPM to the grid: a) direct connection; b) indirect connection [10].

Currently, the wind control systems that operate at wind speeds that vary significantly over time are built in the second variant, and those that operate at an approximately constant wind speed, in the first variant. In the absence of the fixed voltage and frequency network, the energy provided by the electric generator can be stored in the electric accumulators (AE), from figure 3.2:

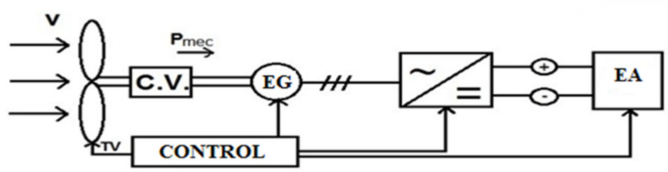


Fig 3.2. Wind system charging on electric accumulators [10]

In the absence of wind, the energy needed by the consumers is given from the AE. In this case, power fluctuations do not create problems for electric consumers, because the voltage at AE is approximately constant.

In this classic topology representing the conversion of wind energy into electrical energy, the turbine shaft can be directly connected to the gearbox or the generator. The generator with permanent magnets is chosen because the sliding contacts are eliminated, which leads to the reduction of the size of the generator, simplifies their maintenance, low price. The connection diagram is shown in figure 3.1 below [11].

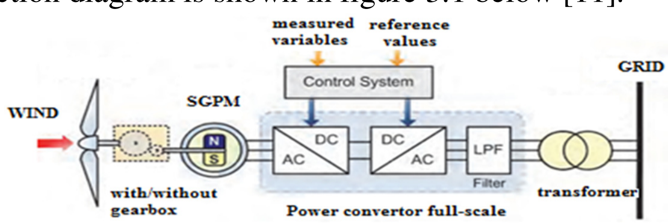


Fig. 3.1 Common model of energy conversion of a wind power plant [11]

The SGPM is connected with a high-power converter, the generator can completely disconnect from the grid and operate at full speed. In the full converter concept, the converter ensures the decoupling of the generator and the mechanical transmission from the mains. This type of converter being efficient and complex, but has a high price which makes the price of the whole conversion system quite high. The electrical energy that is produced is passed through cables to the base, where a step-up transformer is placed [11, 13]. All the generated power goes through the converter to the grid.

In this constructive options in figure 3.2, the high-power converter is connected to the SGPM and provides protection against faults occurring in the wind turbine network. In SGPM the frequency varies according to the wind speed, which allows the wind turbine to operate at variable wind speeds being a great advantage for the system, therefore a Chopper converter is required [14].

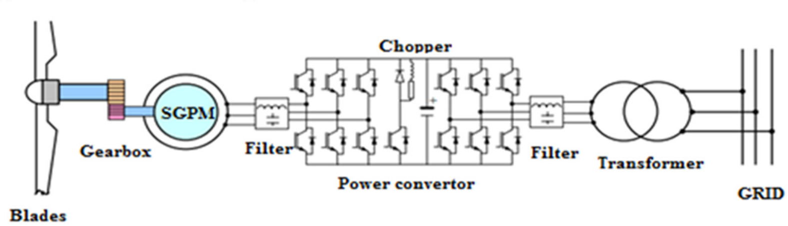


Fig. 3.2. Topology of a wind power plant conversion chain [14]

In order to efficiently control the electric generator but also the flow of active and reactive power to the network, a Chopper type converter is chosen. The rotor-side converter ensures the regulation of the rotation speed in a wide range, while its grid-side converter transfers the active power to the grid and tries to cancel the reactive power consumption.

A great advantage of this topology is that it allows the integration of considerable capacities in the network.

The disadvantage of this switching strategy is the double switching losses, as the two power transistors are switched simultaneously (instead of one at a time) [14].

The configuration in figure 3.3 is suitable if one wants to use the maximum power point tracking (MPPT) control strategy based on the perturbation and observation (PO) method in low power wind turbines by maximizing the output power. It presents the advantage of increasing the output power by more than 50% improving the performance of wind systems, by eliminating the oscillation problems that occur due to power fluctuations when it reaches the maximum value [15].

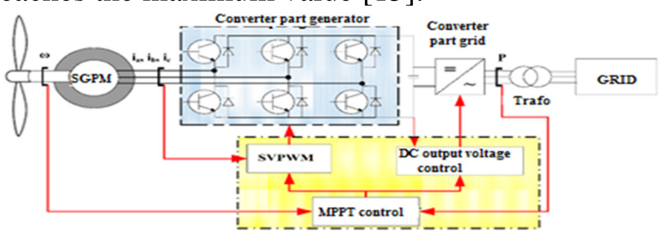


Fig. 3.3 Electricity conversion scheme [15]

The system comprises a wind turbine, SGPM, a rectifier, MPPT and an inverter. The turbine transforms the wind into mechanical energy, the SGPM transforms the mechanical energy into electrical energy, and the rectifier ensures the transformation of the electrical voltage from a.c. in d.c. This is due to the fact that the speed of the rotor increases with the increase in wind speed, which also affects the power generated.

In addition, MPPT maximizes the output power of the wind turbine system and the inverter converts direct current into alternating voltage. Applying this scheme to the wind system, especially at high wind speeds, has significant results in increasing SGPM voltage and power [15].

In figure 3.4, a high-speed static converter participates in the wind-electric energy conversion.

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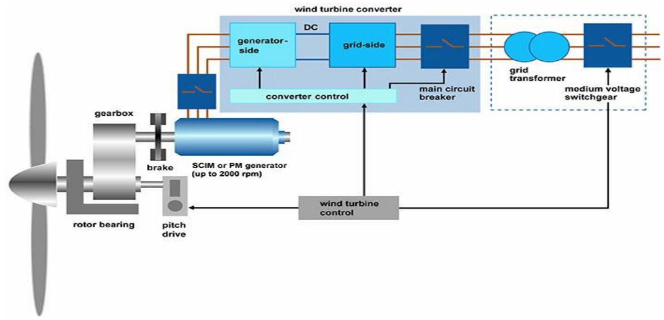

Fig. 3.4 The wind conversion chain having a high speed converter [16].

HSFC High Speed Converter - provides SGPM speed and torque control. This type of converter presents the advantages: small size of the SGPM, small volume of the converter.

Using a SGPM in a wind system results in high power density and small dimensions with the highest efficiency at all speeds, providing the maximum annual energy production at the lowest lifetime cost [16].

The two-level converter is an ac-dc-ac converter, with six unidirectionally driven insulated gate bipolar transistors (IGBTs) used as the rectifier and the same number of unidirectionally driven IGBTs used as the inverter.

In this energy conversion of the wind system, the rectifier is connected between the SGPM and the capacitor bank as seen in figure 3.4. The inverter is connected between this bank of capacitors and a second-order filter, which in turn is connected to the power grid [17, 18].

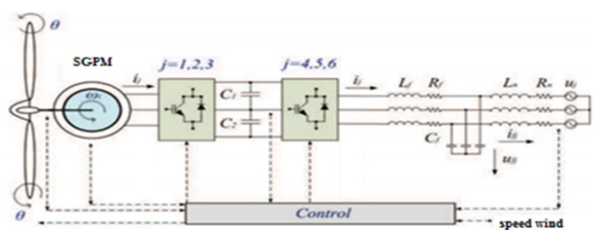

Fig. 3.4 Turbine conversion using a multilevel converter with capacitors [18]

With this configuration, it is desired to obtain a sinusoidal voltage through several voltage levels having voltages with capacitors as a source. They are used for wind power plants of medium or high power.
Among the advantages are the reduction of switching losses of the converter by up to 25% compared to the simple one, the efficiency of the converter is greatly improved.
A disadvantage of this type of capacitor is the voltage imbalance between the top and bottom capacitors, but also unequal stress on the semiconductor devices.
The matrix converter is an ac-to-ac converter with nine isolation bi-directionally driven bipolar gate transistors (IGBTs). The matrix converter is connected between a first order filter and a second order filter. The first-order filter is connected to a SGPM, while the second-order filter is connected to the mains. The configuration of the

simulated wind energy conversion system with the matrix converter is presented in figure 3.5 [18].

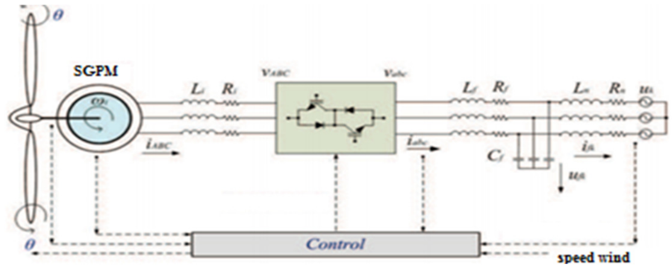

Fig. 3.5. Turbine conversion using a matrix converter [18]

This conversion has the advantages:
- compared to classic converters, they have reduced dimensions and dimensions, due to the absence of DC-link capacitors;
- the absence of the DC-link capacitor increases the efficiency and lifetime of the converter;
- the switching losses of the matrix inverter are reduced compared to the back-to-back one;
- the sinusoidal waveforms of the input and output currents show negligible harmonics;
- the thermal stresses are reduced compared to the classic converter.

Disadvantages of this energy conversion:
- the maximum output voltage of the matrix converter is 0.866 times higher than the input voltage;
- due to the absence of the DC link, there is no decoupling between the input and output of the converter;
- the modulation technique and switching control are more complicated than those of conventional inverter PWM;
- the protection of the matrix converter in fault situations is weak.

For applications of medium or high power wind power plants, three types of multilevel converters can be used: fixed Neutral Point (CPN), Fly capacitor (CF), series converters with H bridge (CSPH).

The CPN multilevel converter shown in figure 3.6 is a power converter that can operate in inverter or rectifier mode [19].

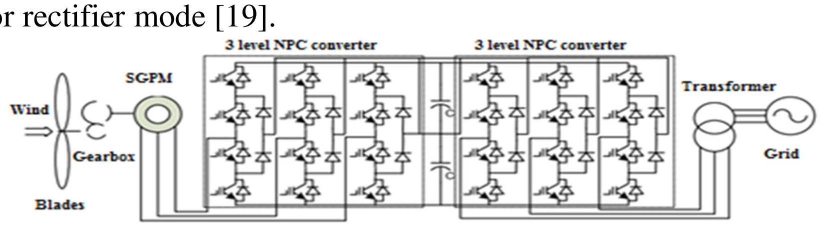

Fig. 3.6 Wind power generation system based on multilevel converter fixed at neutral point [19]

At the CPN converter the d.c. voltage of the bus is divided into voltage levels by series capacitors, the neutral point is connected to the midpoint of the DC connection, which allows this topology to form back-to-back connections. CPN is a three-level back-to-back converter.

Through this energy conversion, the CPN converter is intended to improve its operation in stationary and transient conditions. When n is large enough, the number of diodes required will make the system impossible to implement; the number of diodes required for each phase will be (2n-4). Therefore, this topology is not suitable for high power applications.

CPN has advantages:

- the CPN converter has the capacity to handle high voltage;
- reduced switching losses;
- high efficiency compared to other types of converters;
- reduces the filter elements, which affect the dynamic response of the converter.

Limitations of CPN converters:

- requires semiconductor devices;
- between the upper and lower DC-link capacitor the voltage is unbalanced [19].

This wind-energy conversion shown in figure 3.7 is composed of a voltage Z converter or Z source converter, and is the power converter supplied with "impedance". It is mainly used for power conversions d.c.-d.c., a.c.-d.c., a.c.-a.c. and d.c.-a.c. This converter offers a new type of power conversion, compared to the classic one.

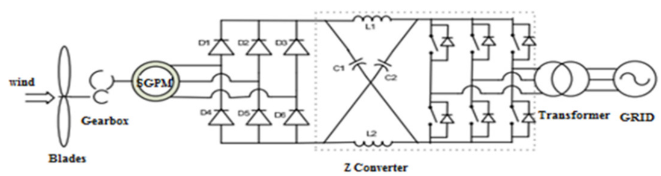

Fig.3.7 Energy conversion configuration with a Z-converter [19]

Inductors L1 and L2 and capacitors C1 and C2 are linked in an X-shape, being used to provide an impedance source that connects the converter to the DC source, load or other converter.

In order to increase the performance of a wind conversion system, the behavior of the Z converter in stationary and transient mode is analyzed, especially due to its low cost and high efficiency. It also has other advantages: fewer components than the classic converter, smaller dimensions, the output voltage differs from the input voltage.

Disadvantages: it requires high voltage Z capacitors which increases the cost of the converter as well as its size, it can cause overvoltages which leads to the destruction of the device, it is a unidirectional converter [19].

In this variant, the fuzzy logic controller shown in figure 3.8 is usually used to adjust the pitch angle of the blade. This technique is based on human experience using a set of rules determined by applying linguistic variables instead of numerical ones [20].

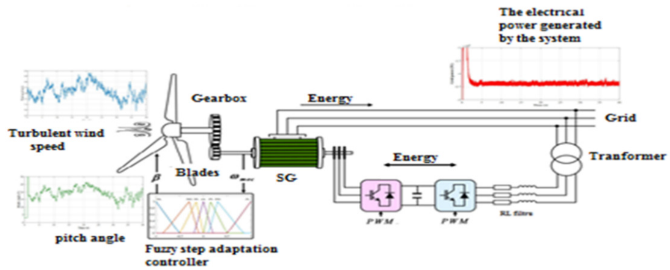

Fig. 3.8 Wind conversion system with Fuzzy controller [20]

The fuzzy logic process has three main phases: fuzzification, inference, defuzzification.

Making comparisons between three types of CLF configurations: CLF with initial parameters, optimized CLF, adaptive CLF and two classic control methods: the classic PI controller and the programmed PI controller, it was found that the Fuzzy optimized CLF and the PI controller have the same results, being able to replace one controller with the other.

Advantages: improves the quality of power produced by the wind system, achieves precise regulation of generator speed and electrical power and mitigates the effects of mechanical loads compared to other controllers, as well as the ability to produce more energy annually.

4. Conclusions:

Some representative examples from the existing configurations for modern wind power plants were selected from the specialized literature.

Internationally, there is a growing trend of using permanent magnet synchronous generators in wind power plant applications due to the significant advantages: sliding contacts are eliminated, which leads to a reduction in the size of the generator, simplifies their maintenance, low price, but above all because it works at variable wind speeds.

The quality of the electricity supplied in the power grid is influenced by the location of the wind power plant and the choice of the common point of connection to the grid. The closer the wind power plant is located to the consumers, the higher the quality of the electricity supplied to the network.

The wind conversion system that has the electronic part provided by a full-scale converter, being a complex converter, provides SGPM with the possibility to completely disconnect from the grid to operate at maximum speed although its cost is high. If we opt for an HSFC converter we will have SGPM speed and torque control, being a low volume converter which helps to reduce the footprint and SGPM and to the whole wind system it offers the maximization of energy production at a reduced price over the lifetime of the converter.

If you choose to use a chopper-type power converter in the energy conversion, the losses are doubled due to the two transistors in its composition that switch simultaneously.

Control strategies are used to increase the performance of the wind system. The MPPT control method is often used in conjunction with other control methods. When used with the PO (perturb and observe) method, over 50% improvement in system performance is found as well as raising the output voltage and power at the SGPM. If the TSR+MPPT method is chosen, a higher quality of the output voltage and a fast response time are obtained.

The latest generation converters include the multilevel, matrix, multilevel CPN, or Z type used in applications for medium to high power wind power plants, which improve the efficiency of the entire wind system. Due to their characteristics, switching losses are reduced, they have reduced geometric dimensions compared to classic ones, the lifetime of the converter is increased, the number of filter elements is also reduced, they can have high prices compared to classic capacitors.

If one opts for the wind turbine variant equipped with a fuzzy logic controller, the SGPM speed will result in a higher quality power, the speed and electrical power of the SGPM being regulated quite precisely, and the annual energy production is high.

There are a multitude of combinations for wind energy conversion, from which one essential thing emerges, namely that there is no universally valid variant that is satisfactory from all points of view.

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