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Electric conversion device for wind turbines assembled with commercial components.

State of the art

Electricity production by means of wind generators, especially by horizontal-axis wind turbines, has greatly developed in the past 20 years.

Turbine components basically consist of a rotor, a nacelle containing transmission unit and the generator, the supporting tower. The rotation device necessary to direct the rotor towards the wind is placed between the tower and the nacelle and may be active (engine) or passive (vane).

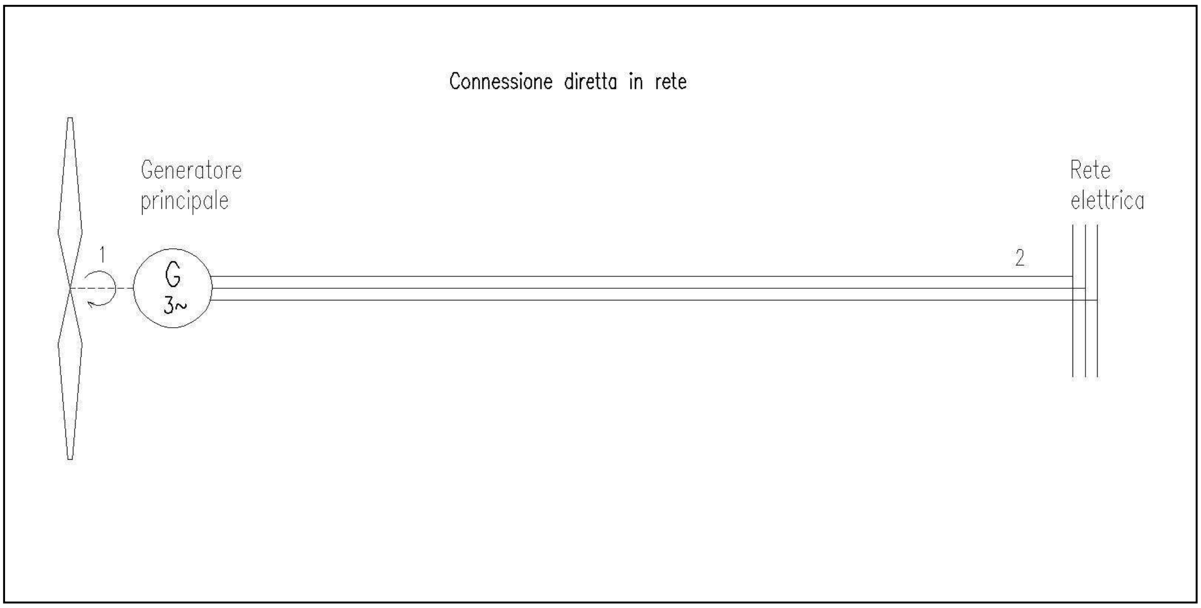
The energy produced is normally conferred to the grid by means of appropriate grid connection devices.

There are two kinds of turbines: using fixed speed or variable speed rotors. Optimization of aerodynamic efficiency of the rotor blades has been achieved in both cases with different types of technology.

In the fixed speed system the generator (usually the asynchronous induction type) can be directly connected to the grid and for this reason it must rotate at the speed near the grid's synchronous speed. As optimal aerodynamic efficiency of the rotor blades is only achieved at a certain incidence angle with the wind, the turbine will reach optimal efficiency only at a specific wind speed rate.

The next picture shows the grid connection outline of this kind of generator: the wind causes rotation of the rotor which is coupled to an asynchronous generator (main generator) by means of appropriate transmission devices (here not shown). The main generator is directly connected to the grid.

Grid direct connection

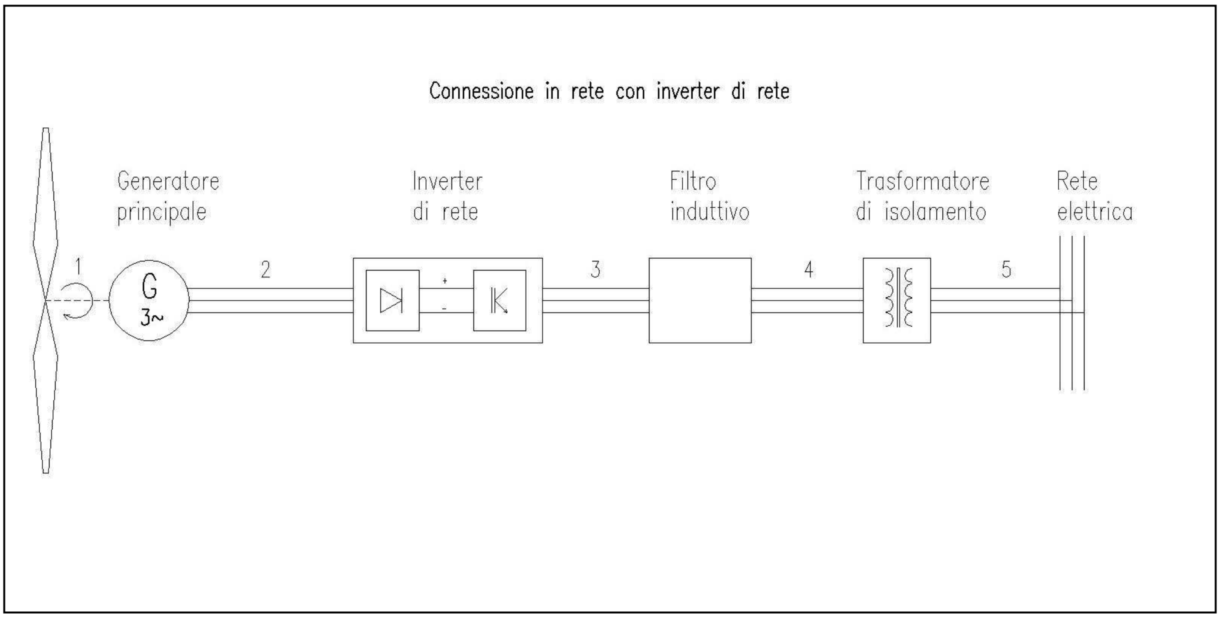


In order to operate, as the fixed frequency of the three phase voltage (point 2) is determined by the grid, the generator is required to rotate at a frequency that is almost identical to the grid (allowing for a small difference due to the necessary 'slip' that is typical of asynchronous electric machines). For this reason, the wind rotor will be forced to rotate at a steady speed pratically equal to grid frequency speed.

In the past, efficiency has been increased by using two separate generators having different power: the smaller generator, built for low rotation speed, is used for reduced wind speed; the larger generator, built for higher rotation speed, is used for high wind speeds. This solution represents an adaptation that allows the rotor to rotate at two different speeds (fixed), therefore efficiency optimization is only partial.
An alternative method is to make an adjustment of the blade angle (pitch) to assure that the incidence angle of the wind on the blades be always optimal depending on the wind speed, even though the rotation speed is constant. The system is nevertheless expensive and mechanically complex.

In variable speed systems, the rotor is made to always rotate at the speed that will reach the optimal incidence angle; the generator (either synchronous or asynchronous) rotates at variable speed and generates electrical energy with variable frequency. For this reason direct connection to the grid is not possible. In order to connect to the grid, a conversion device must be inserted to transform variable speed electrical energy (and voltage) produced by the generator to a 50 Hz frequency electric energy that is synchronous to the grid.
In actual fact, solid state electronic conversion systems used are very efficient but also costly and very sensitive to damage due to electric trouble on grid (caused for instance by lightening).
The next picture shows the grid connection outline for this kind of generator: the wind causes rotation of rotor which is coupled to an asynchronous generator (main generator) by means of appropriate transmission devices (here not shown), to either synchronous or asynchronous generator (provided with excitation systems).

Grid connection by means of grid inverter



There will be a three-phase voltage variable both in voltage and frequency, for the number of rotations of the wind rotor (point 2).
The grid inverter rectifies the voltage transforming it in a DC voltage; DC voltage is then re-transformed by means of PWM in a sinusoidal three-phase current (point 3) at the frequency and phase that are identical to that of grid voltage (point 5).
Filter and transformer are indispensable to block frequency components that are different from those on the grid, including possible DC components.

These electronic power conversion devices are normally expensive because not mass-produced. Instead, they are designed and built for specific applications thus without the benefits of large scale economy featured for commercial electronic devices.

The above mentioned devices are not connected to the grid unless officially approved for safety.

Furthermore, direct grid connection of sophisticated electronic devices make them more sensitive to failure caused by grid disturbances and overloads.

Invention description

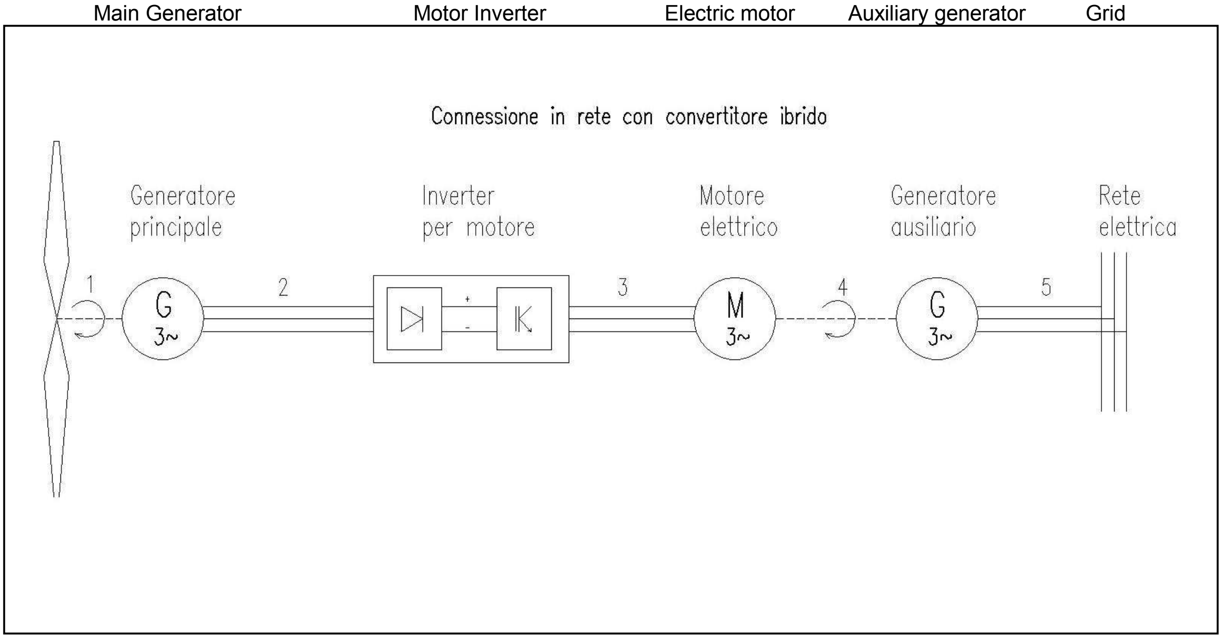
The basic idea of the invention a conversion device assembled using commercial components of proven reliability, easily available an relatively inexpensive.

The invention featured in the 55 kW version consists in:

- One main generator either synchronous or asynchronous (in this case provided with excitation systems).
- One 55 kW commercial frequency converter for electric asynchronous motors (motor inverter)
- One 55kW asynchronous motor (auxiliary electric motor)
- One 45 or 55kW asynchronous motor, employed as generator, directly controlled by the auxiliary motor (auxiliary generator)

Grid connected hybrid converter

Main Generator | Motor Inverter | Electric motor | Auxiliary generator | Grid



The drawing shows the grid connection principle of this type of conversion system: the wind causes the rotor to rotate, connected by the hub with appropriate transmission units (not shown) to the generator. In point 2 there will be a three-phase voltage, variable in value and frequency according to the number of rotations of the wind rotor.

The motor inverter operates in the same way as the above described grid inverter: it rectifies the variable frequency voltage transforming it in an internal DC voltage, which is then re-transformed a pulse modulated current, PWM, as to reach proximal sinusoidal three-phase current (point 3) at a frequency and phase that are identical to that of grid voltage (point 5). The motor that utilizes this type of energy does not need transformers or filters of any kind. The motor is mechanically coupled (point 4) to the auxiliary asynchronous generator, which is directly connected to the grid. This mechanical coupling warrants total isolation of entire turbine electrical system from the grid.

The commercial frequency converter for asynchronous motor (motor inverter) is designed to control a three-phase asynchronous motor with variable frequency that is independent from the grid and can be set over a wide interval (generally from 0 to 120 Hz when the grid frequency is fixed at 50 or 60 Hz). This way the motor can be made to rotate at any rate of speed.

In our system the electric energy produced by the main generator (variable frequency) can be used to feed the commercial frequency converter (motor inverter) because it is internally transformed by it to a DC voltage and is therefore independent from frequency.

Regardless of the frequency value (and therefore from the RPM) of the main generator, the inverter can control the auxiliary motor with a variable and freely adjustable frequency. In this particular case the inverter can control the auxiliary motor so that the auxiliary generator will supply the required power once it has been connected to the grid.

The asynchronous motor used as auxiliary generator is directly connected to the grid; an asynchronous motor, forced to rotate at a slightly higher speed than that at the corresponding grid frequency acts like a generator thus supplying all the more power in relation to the rotation speed exceeds that of synchronicity.

The system's global efficiency is equal to the efficiency result of the three chain constituents:

EFFtot = EFFinverter x EFFaux_motor x EFFaux_generator

The motor inverter efficiency is equal to about 96%.

Since the motors nowadays available in so called EFF1 class have relatively high efficiency (about 95.3 for a 55kW motor) the combination of the two motors will have approx 91% efficiency, so that the overall net efficiency is about 87.2%.

By comparison, the efficiency of the system using the grid inverter would be equal to the product of the three chain constituents:

EFFtot = EFFinverter x EFFfilter x EFFtransformator

Inverter efficiency is equal to about 96%, as for the above mentioned case.

Filter system efficiency is about 99%.

Transformer efficiency is about 97.5%

Global efficiency theoretically equals about 92.6%. Actually, the share of power necessary for ventilation or air conditioning of the box that contains the system needs to be subtracted from this figure which therefore amounts to an estimated 1.5-2% reduction.

Therefore, overall net efficiency amounts to about 91%.

The electro-mechanic solution does not need ventilators or electrical air conditioning systems since it utilizes the motors already in use and their mechanical ventilation.

The difference between the two solutions, in terms of theoretic overall efficiency, is lower than 4%, compared to greater reliability and to commercial costs that can be reduced by 40%.

With this method we have the following advantages:

- Same simple direct grid connection of fixed speed systems.
- High aerodynamic efficiency that is typical of systems with variable speed rotor.
- Excellent immunity to disturbance from grid, with consequences only on the auxiliary generator (the only component connected to the grid) which is an extremely sturdy and reliable component that is designed to stand significant overloads without suffering any damage.
- It is not necessary to use filtering devices or specific protection devices to connect the system to the grid.
- It is not necessary to use an isolation transformer to connect the system to the grid.
- It is not necessary to be approved to connect the system to the grid, unlike for custom solid state systems.
- Forced ventilation electrical system is not needed. These systems cause efficiency loss and have a relatively short life (ventilators must be replaced every three years).

The small residual disadvantage in terms of efficiency is compensated by lower costs, at least until the market price of custom static converters will maintain the current rate.