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Stability Investigation of HV Networks in presence of large Wind Farms

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***Abstract*- This paper carries out a stability analysis of HV networks in presence of large wind farms. In particular, wind generators at partially variable rotation speed will be deeply analyzed in comparison with the fix rotation speed ones. The transit of a wind plant at variable speed from the doubly-fed functioning to classic asynchronous one will be studied to evaluate the system stability. Many simulations will be carried out, considering different generator start rotation speeds.**

I. Introduction

Renewable energy sources are spreading abroad, considering both strategic and environmental concerns. In this context the wind energy is always more important and the operators are planning to invest in the wind farms diffusion. For this reason it is necessary to evaluate the consequences of new wind farms connection to the HV networks, that will be modified in its structure and dynamic behavior. In order to study the influence of the different factors on the system stability and on the wind production loose due to the faults, it is important to evaluate which kind of technology has been adopted. The two wind generators typologies more used are at fix rotation speed and at partially variable rotation speed. In this article the second one has been deeply analyzed, considering its structure and the internal protections of the wind plants.

In particular, the transit of a wind plant at variable speed from the doubly-fed functioning to classic asynchronous one will be analyzed to evaluate the system stability. This operation will be simulated considering the nominal voltage and different generator start rotation speeds.

The study has been developed considering a wind farms of 200MW connected to transmission grid at 63 kV through a 20 kV underground medium voltage line.

II. Wind generator at partial variable rotation speed

A. *Wind generator with variable step*

Many of the wind generators today available on market have the possibility to rotate the turbine blades around their longitudinal axis, varying the pitch angle. A such wind generator is characterized by a curves family of the coefficient of performance $C_P(\lambda)$, where λ is the ratio between the wind and the peripheral blade speeds. Each curve refers to a specific value of the pitch angle β, that is the rotation of the rotor blades. The typical shapes of this curves family are reported in Figure 1.

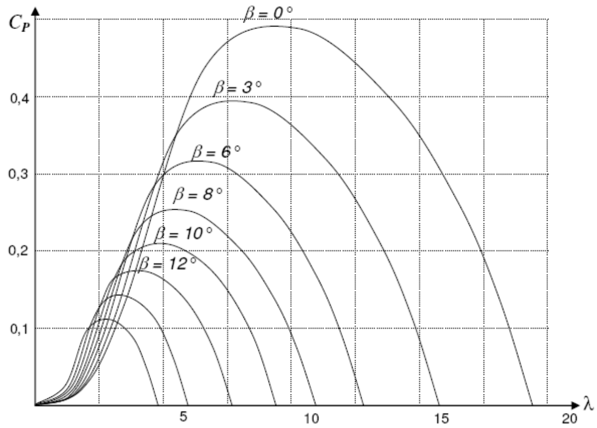

Figure 1: $C_P(\lambda)$ shapes for various pitch angles β

The possibility to regulate the blades pitch allows a better control of the wind generator behavior. In particular, the pitch angle regulation is a way to limit the mechanic power absorbed by the plants when the wind speed is too high (greater than the nominal speed).

B. *Wind generator at partial variable rotation speed*

A way for a better exploitation of the wind energy is the use of variable rotation speed generators. The wind plants at partial variable rotation speed often employ asynchronous generators with wound rotor. The rotor presents a three phase windings, electrically accessible through a slip rings and brushes system.

The stator is directly connected to the transformer and it is fed at constant frequency (50Hz), while the rotor windings are fed through a power electronic converter, Figure 2.

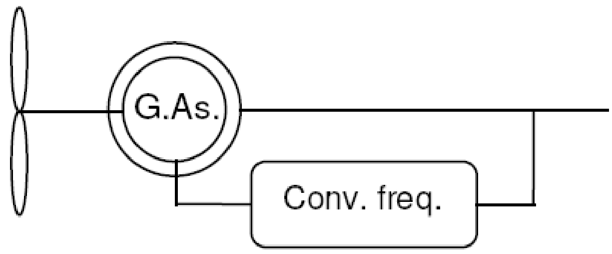

Figure 2: Principle scheme of a wind generator at partial variable rotation speed

The asynchronous generator is, in this case, doubly fed (at the stator and at the rotor). For this reason this configuration is normally named as "doubly fed induction generator (DFIG)".

The speed variation is realized regulating the electric power absorbed by the rotor. The relationship between the power absorbed by the rotor and the slip s is the following:

$$P_{rot} = s \cdot T_{em} \Omega_{\sin}$$

This relationship can be easily obtained from the basis formula describing the asynchronous machine behavior:

$$P_{rot} = s \cdot P_{traf} = \frac{s}{1-s} P_{mech} = \frac{s}{1-s} T_{em} \Omega = s \cdot T_{em} \Omega_{\sin}$$

The synchronism speed can be considered constant, because the stator windings are fed at the net frequency. Supposing the electromagnetic torque constant and equal to the load mechanic torque, the slip of the machine is proportional to the electric power absorbed by the rotor: $P_{rot} = K \cdot s$

When the machine works as generator ($T_{em}>0$), a speed greater than the synchronous one is obtained (and consequently a negative slip). This working regime is named supersynchronism. Vice versa, in a conventional induction machine a smaller speed than the synchronous one is obtained (and consequently a positive slip), giving power to the rotor ($T_{em}<0$). This working regime is named subsynchronism. The main characteristic of the DFIG is to produce a positive electromagnetic torque ($T_{em}>0$) also in subsynchronism condition thanks to the rotor frequency control provide by the electronic power converter.

For the rotor feeding, different converters types can be used. The most employed solution is a front-end converter constituted by an IGBT rectifier and an inverter connected in cascade. The connection is voltage imposed and the control strategy is PWM. The principle scheme circuital is reported in Figure 3.

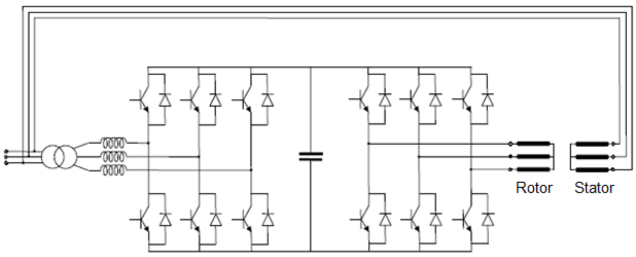

Figure 3: circuital scheme of a doubly-fed generator feeding

The main advantage of the wind generators at partial variable rotation speed is the possibility to use a reduced power electronic converter that is less expensive. On the contrary, they have to use asynchronous machine with wound rotor and slip rings and brushes for the electric contact among the rotor windings and the power converter. This means a higher generator cost and the necessity of frequently maintenance operations for the brushes fretting.

III. INTERNAL PROTECTIONS OF THE WIND PLANTS

As explained before, in the wind plants at partial variable rotation speed, asynchronous generators with wound rotor, doubly-fed at stator and rotor, are used. The rotor is fed by two series IGBT electronic converters, connected in parallel to the machine stator.

The electronic disposal used in the converters cannot tolerate too high over currents. For this reason the rotor supply system has to contain a specific protection that can disconnect the converters and short-circuit the generator rotor. This wind plants types have two different protection level against the low voltages (Figure 4):

- generators protection (stator protection): this protection, that is the same of the used in the wind plant at fix rotation speed) disconnects the wind plant from the net when the voltage remains lower than the limit value for a time longer than the protection restart time.
- converters protection (rotor protection): this protection immediately disconnects the converters and short-circuits the machine rotor windings as soon as the voltage gets down the limit value. The limit value of this protection can be different from the stator protection one.

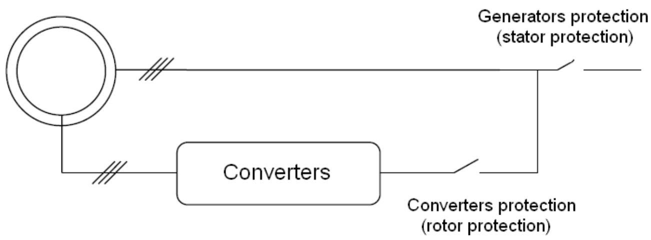

Figure 4: internal protection system of a wind farm with doubly-fed generator

The limit values of these protections impact on the dynamic behavior of the wind plant during the voltage drops due to the faults. The choice of these values can be done following different strategies that have important consequences on the disconnection of the wind plant from the net.

IV. THE STUDIED CASE

The studied case considers a wind farm of 200 MW, that is a high value that can introduce dynamic stability problems to the net.

In particular, the transit from the doubly-fed (variable rotation speed) to the classic asynchronous operation (fix rotation speed) has been analyzed.

The wind farms have been connected to transmission grid at 63 kV through a 20 kV underground medium voltage line as reported in Figure 5.

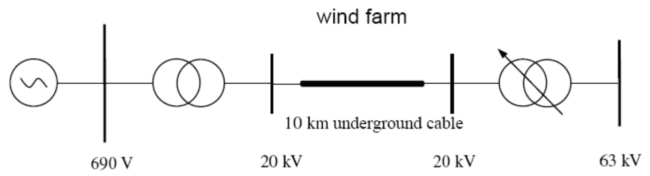

Figure 5: Electric scheme considered in this study

All the wind generation systems connected to the same 63 kV node of the net have been grouped and modeled in one generator. The length of the connecting cables is equal to the mean distance between the considered generation stations and the 63 kV nodes and it is equal to 10 km. The cable numbers have been calculated in function of the rated power of the connected farm, considering for each cable a rated power of 25 MVA.

V. Simulation of the Transit from Doubly-Fed Functioning to Classic Asynchronous One

As told before, the rotor protection immediately trips closing the slip rings in order to short-circuit the rotor windings. In this condition the generator has to transit from the doubly-fed functioning to classic asynchronous one. This transient can have different consequences, depending from the generator start speed that is directly subordinated to the wind speed and then to the supplied power.

In the following, the transit of a wind plant at variable speed from the doubly-fed operation to classic asynchronous one in case of unfaulted network is studied. The generator rotor will be roughly short-circuited, without the trip of the converters protections. This procedure will help to better understand the wind plant dynamic behavior during the voltage collapse due to the faults, case in which the protections can really trip.

This operation has been simulated considering the rated voltage, unfaulted network and different generator rotation speeds.

A. Initial Slip equal to 5.5%

This case considers the roughly short-circuit of the rotor windings al time t = 1s, network rated voltage and an initial speed equal to 3164rpm, to which corresponds an initial slip of 5.47%, Figure 6. When the rotor windings are short-circuited, the induction machine begins the classic asynchronous operation, therefore it starts to absorb reactive power from the net.

The reactive power absorption is high since the initial slip is greater than the rated one during the classic asynchronous operation. Moreover this power is not compensated because in this kind of plant no power factor compensators are installed. Consequently the voltage at the machine terminals fall down causing the electromagnetic torque decrease that becomes less than the mechanic one. In this condition the rotor masses accelerate due to torque unbalance causing the loss of stability.

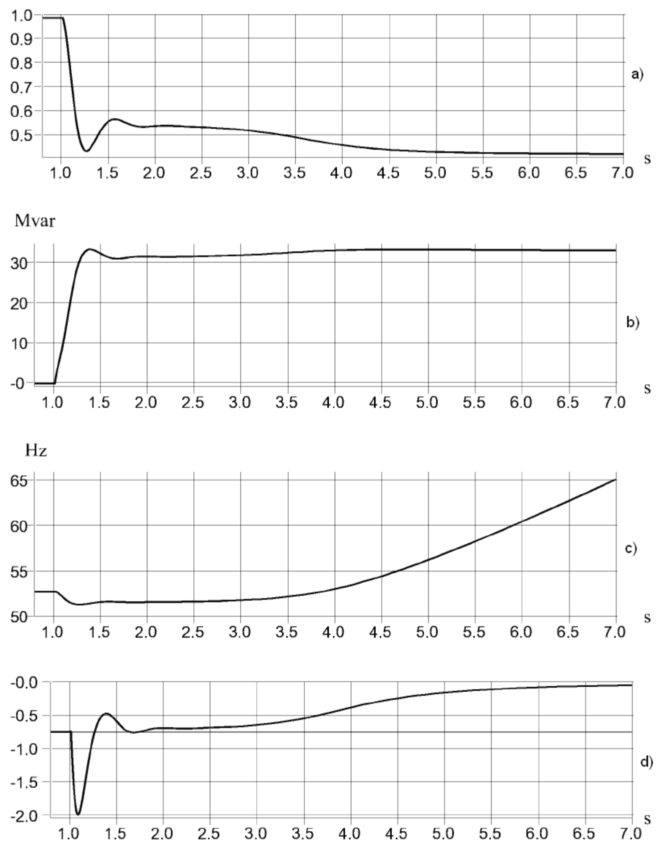

Figure 6: Transit from the doubly-fed functioning to classic asynchronous one with a start speed of 3164rpm: a) voltage, b) reactive power, c) speed, d) electric couple (dark line) and mechanic couple (light line)

B. Initial Slip equal to 5.4%

Now we consider the same previously case, but with an initial rotor speed equal to 3163rpm, to which corresponds an initial slip of 5.43%, Figure 7. In this case the reactive power absorption, after the converters disconnection (t = 1s), is quite less than the previous one because the initial speed is also quite smaller. This little difference is sufficient to maintain the induction generator in the stability region.

Form Figure IV.5 it is possible to note that the reactive power absorption by the generator just after the converters disconnection is much greater than those one absorbed when the transient is finished. Indeed, the induction machine find a new stable operation point characterized by a rotation speed equal to 3018rpm to which correspond a slip of 0.6%, much smaller than the initial one.

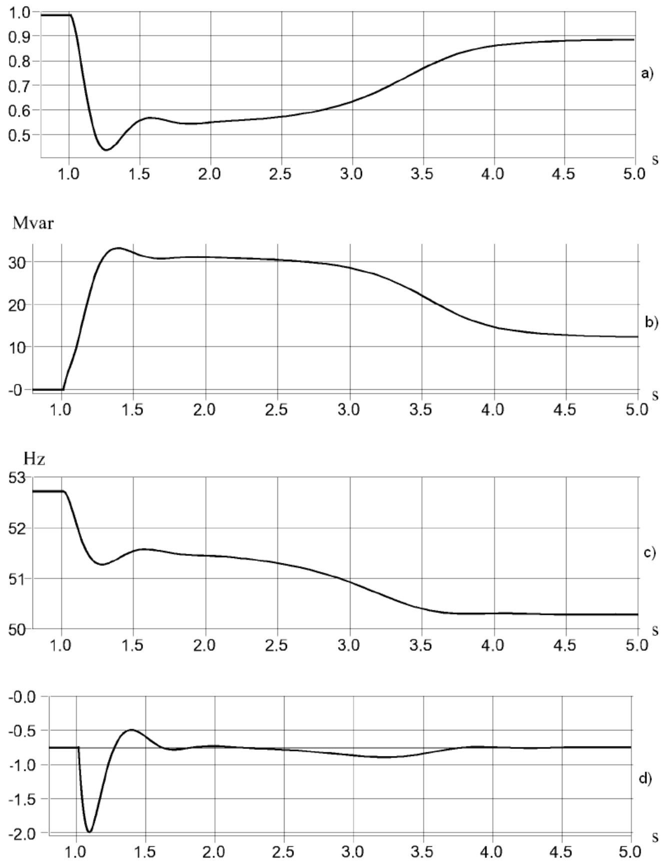

Figure 7: Transit from the doubly-fed functioning to classic asynchronous one with a start speed of 3163rpm: a) voltage, b) reactive power, c) speed, d) electric couple (dark line) and mechanic couple (light line)

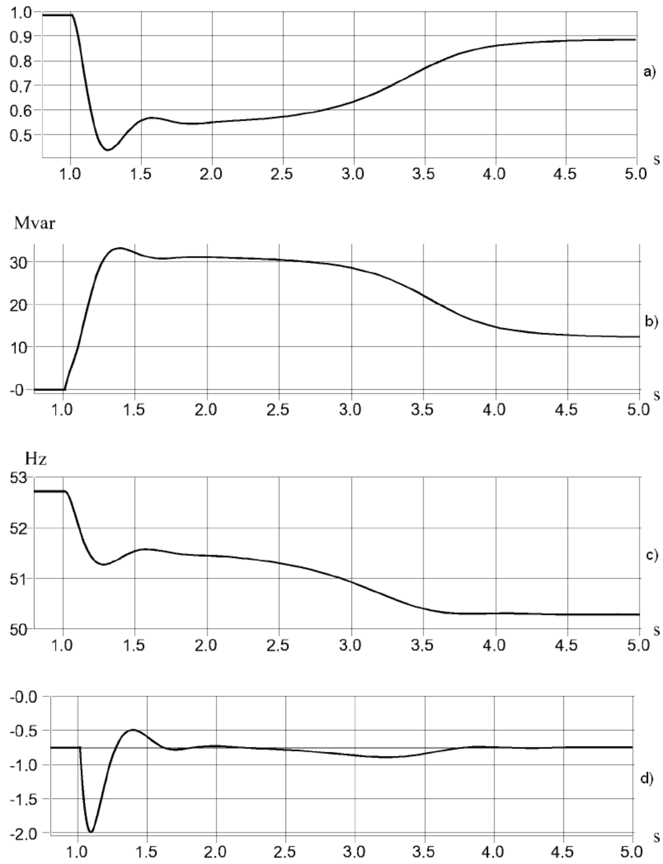

Figure 8: Transit from the doubly-fed functioning to classic asynchronous one with a start speed equal to the nominal one: a) voltage, b) reactive power, c) speed, d) electric couple (dark line) and mechanic couple (light line)

C. Initial Slip equal to 15% (nominal speed)

Figure IV.6 shows the consequences of the converters disconnection at the rated power, that is when the wind turbine rotates at its maximum speed with a slip of 15%, Figure 8.

This slip value is very high compared with the typical values that assume an induction generator with the short-circuited rotor windings. Therefore, when the converters are disconnected and rotor windings are closed, the generator operation become instable with greater voltage oscillation at its terminals that cause variable reactive power absorption and electromagnetic torque fluctuation.

In all the presented cases it is possible to note that in the first time of the transient after the converters disconnection, the electromagnetic torque is much greater than the mechanical one provided by the wind turbine.

In fact, the high slip value and the sudden absence of the rotor excitation voltage causes high reaction currents in the stator and rotor windings that tend to keep constant the magnetic flux in the gap. As a consequence a great value of the electromagnetic torque is produced. If the initial slowing down is not enough to bring the system in stable operation region, it starts to accelerate until the loss of synchronism.

D. Comparison and considerations

From this analysis it is possible to establish that the transit from doubly-fed operation to classic asynchronous one causes the instability on the generator if the initial speed is too high. For the machines considered in these studies, the speed limit is 3162rpm, to which corresponds a slip value equal to 5.4%. At the rated voltage, every transient from doubly-fed to asynchronous operation cases the loss of stability if the initial speed is greater than the limit one above described.

In practice, this limit correspond to a maximum power bound that the power plant can generate, because the rotation speed is correlated to the wind speed and then to the generated electric power. From Figure IV.2 it is possible to deduce that the limit rotation speed occur in correspondence of a wind speed equal to 8.5m/s; while from Figure IV.3 can be determined the maximum power that can be generated, that is about 55% of the rated one.

This fact confirm that also in the case of doubly-fed induction generators, the operation with a power less than the nominal one is more stable. Therefore, the design criteria employed for the fixed rotation speed generators sizing can be applied also for the doubly-fed or hybrid wind power plant planning.

VI. CONCLUSIONS

The paper reports a study about the stability of HV networks in presence of large wind farms. The dynamic behaviour of the wind generation networks has been analyzed considering the use of wind generators at partial variable rotation speed. In particular, the transit of a wind plant at variable speed from the doubly-fed functioning to classic asynchronous one has been analyzed. Many simulations have been carried out, considering different generator start rotation speeds.

The stability following a fault of the wind networks using doubly-fed generators depends from the electronic converters sizing and from the regulation strategy of the internal protection system. If the converters have been sized letting the flowing of significant over-currents following the fault, the wind generators are more stable than the ones that use normal asynchronous machines. But, if the converters are not oversized, they can roughly cut off, therefore it is important to disconnect the wind plant from the network as soon as the rotor protection trips. In this way it is possible to avoid the impairing of the net voltage waveform caused by the system instability. The wind plant can be reconnected to the net, in doubly-fed configuration, as soon as the fault has been isolated.

Moreover, thank to the rotor excitation presence, these kinds of wind plants can provide ancillary services to the net, such as an help to the voltage primary regulation.

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