Rotor flux oriented control on the rotor side of the induction motor

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***Abstract* - In heavy duty drives, in the range of hundreds kW, wound rotor induction motors are widely used. It is the case of cement and minerals industries. Major users make use of tens of such drives, summing hundreds of MW. Due to the large amount of losses which occur at low speeds, the users use the facility given by the wound rotor only for starting, despite the technical capabilities to easily operate at variable speed. Even so, given the range of power, the losses specific to the additional rotor resistors are quite important. As will be shown, these additional looses can arrive to one fifth of the active energy consumed during only the starting process. The paper briefly discusses the existing technologies involved in the variable speed drives based on wound rotor induction machines and proposes a technique for starting which avoids the use of additional rotor resistors and consequently it eliminates the corresponding losses. The technique implies the control on the rotor side of the motor, the stator being directly connected to the grid. This is an important aspect, as generally, in certain applications, the stator rated voltage is quite high (typical 6 kV). The simulations confirm the viability of the technique.**

Keywords - *induction motor, wound rotor, doubly fed, start*

I. INTRODUCTION

For high power (x 100 kW – MW) and heavy duty drives, wound rotor induction motors are generally used. Generally, in this range of power, the stator windings are high voltage ones (6 kV). The classical solution for variable speed drives which involves a controlled V/f source is difficult to be applied for such rated voltage.Our goal is to simulate the usual appearance of papers in the IEEE format.

For existing drives, the control on the rotor side is technically more accessible, knowing that the rated rotor voltage can be ten times smaller than the stator one. Thus, power electronic equipment is easily to be reached.

The paper proposes a solution for starting (and speed adjustment) high power heavy duty wound rotor asynchronous motors drives which would have a maximized efficiency thanks to the elimination of the losses specific to the additional resistors. The method, known as double feeding of the induction machine is presently used, as example, for speed adjustment of the asynchronous generators within the wind generators [1, 2]. The literature does not report the use of this method for starting the drives, knowing that the applications that use such type of motors need high starting torque. The literature [4] signals technical difficulties in using this method for speed ranges around zero (i.e. starting). The paper proposes a solution for extending the speed range down to zero.

The proposed solution dramatically improves the energetic efficiency of the variable speed drives with wound rotor induction machines, mainly during the starting process, grace to elimination of the power dissipation in the additional rotor resistances. It maintains in the same time the drive performances in terms of torque capability.

II. PRESENT TECHNOLOGIES

In the present, for starting (and speed adjustment) of the heavy duty electric drives with wound rotor asynchronous motors, beside the classical solution which involves a variable three-phased additional resistor on the rotor side, two other solutions are used, both of them using additional resistors on the rotor side. Consequently, especially during the starting phase, but also during the speed adjustments mostly in the low speed range, important losses occur.

The first of the two technologies uses an uncontrolled rectifier supplied by the rotor winding. The load of this rectifier is an electronic variable resistor, by the way of a chopper [3].

The second technology (Fig. 1) involves a graduator on the rotor side. The fire angle of the semiconductors adjusts the equivalent additional resistance in the rotor circuit [4].

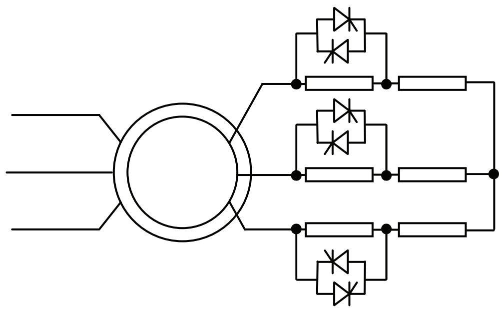

Fig. 1. Technology with graduator.

Two elements are common to the technologies described above:

- the both involves the direct connection of the stator at the power grid; this aspect is mandatory due to the high rated voltage of the stator (6 kV);

- the both use additional resistors. Besides the disadvantages given by the necessity of the additional resistors themselves (size, occupied space), during the operation, inevitable additional losses occur. The amount of the losses is higher if the drive must perform speed adjustment, especially in the low speed range, as losses are proportional to the slip. The amount of losses is unacceptable for current exploitation purpose.

III. Proposed Technology

In the range of high and very high power, speed adjustment of the wound rotor asynchronous machines can be achieved by applying the double fed principle.

The typical applications of doubly fed induction machines are high power drives (pumps, fans, cement and minerals industries), hydro and wind generators, shaft generators for ships etc. where operating speed range is about ±30% of the synchronous one. Consequently, due to the fact that only the slip energy is circulated by the two converters, only small power is spread by the static converters chain. As example, for a speed range of D=3:1 (0.5Ő1.5 nN), the rated power of the rotor side converter can be just about 0.33 of the machine rated power. This is the main reason why this method is used only for speed adjustment in limited range. If the principle must be used for starting too, the rated power of the converters chain will rise to the rated power of the induction machine.

The classical technology of this principle is the sub synchronous cascade [6]. It allows the regulation of the motor speed, as the name is saying, only below the synchronous speed and it consists in retrieving of the slip energy from the rotor and reinsertion of this energy either in the grid or, as mechanical energy, at the motor shaft.

The real doubly fed principle consists in supplying the rotor winding by a bidirectional converter, the stator being directly connected to the grid (Fig. 2).

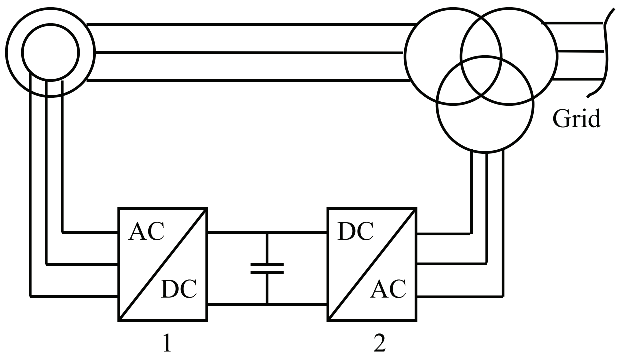

Fig. 2. Speed control by double feeding the asynchronous motor.

Thus, in the case of the sub synchronous cascade, the static converter 1 connected to the rotor windings is an uncontrolled rectifier, the energy corresponding to the induction motor slip being reinserted into the grid by the inverter (converter 2).

For the double fed machine, the both converters are bidirectional ones. In fact the two are fully controlled bidirectional bridges, able to circulate the energy in both directions.

The proposed solution is able to perform speed control on the both sides of the synchronous speed. This is another important facility of the solution, face to the classical sub synchronous cascade. Furthermore, the price of the converter can be more attractive than in the case of V/f converter on the stator side, taking into account the quite different values of the rated voltages on the two sides of the machine.

Another important advantage of this control technology is the short time maximum torque. For doubly fed asynchronous machine, this parameter is much higher than all other electric machines, including induction or permanent magnet machines. This is due to the fact that the increasing of the active current does not directly increase the air-gap flux and consequently the iron saturation. The active current is temporally limited only by the thermal stress of the windings and by the current capability of the rotor side converter.

Continuing with the advantages of the control technology, it must be mentioned the very important facility to control the reactive power changed by the stator with the grid. The term “changed” was used because, with a proper control of the rotor side converter, it is possible not only to cancel the reactive power got by the stator from the grid (unity power factor), but even to inject reactive power into the grid. This is a quite important advantage, taking into account the size and number of such drives in the mining industry, for example.

For motor operation, several reasons are mentioned in the literature which limits the use of this technology only for speed adjustment, not for starting too:

- high rotor to stator winding turn ratio. This generates at low speeds (standstill) very high voltages in the rotor windings, much higher than the rated one;
- if the technology is used for starting and speed adjustment in the low speed range, the rated power of the static converter chain must be designed for the rated power of the motor;
- high instability of the control in the very low speed domain (around zero).

This last aspect is highlighted in the results of the simulation of the 2.2 kW doubly fed induction machine drive. The control was performed by considering rotor flux oriented control on the rotor side of the doubly fed induction machine.

The rotor flux oriented vector control imposes constant active and reactive rotor currents. The reactive rotor current is greater than the rated one and consequently, the stator injects reactive power in the grid.

The active current is smaller than the one needed for balancing the static torque. Consequently, the speed constantly decreases and around 20 rad/sec the system became instable (Fig. 3).

Literature signals as possible alternative the Direct Torque Control on the rotor side [5].

The technique we propose is simply to supply the rotor side of the induction motor by a preset currents inverter.

The simulation diagram (Fig. 4) uses the model of a preset currents voltage source inverter (P3Htg) which injects the necessary currents in the rotor windings. The two orthogonal components of the rotor currents result as outputs of two continuous PI controllers: the direct component is the output of the reactive power controller and the quadrature component is the output of the speed controller.

Some results of the simulation of the system are plotted in Fig. 5. The torque applied to the motor shaft is proportional to the mechanical speed. It attains the rated value at the rated speed.

The start process is imposed to begin at 1 second after the beginning of the simulation. The preset speed of 150 rad/sec is achieved in about 1.2 seconds, the currents controllers being tuned to limit the maximum torque to double of the rated one.

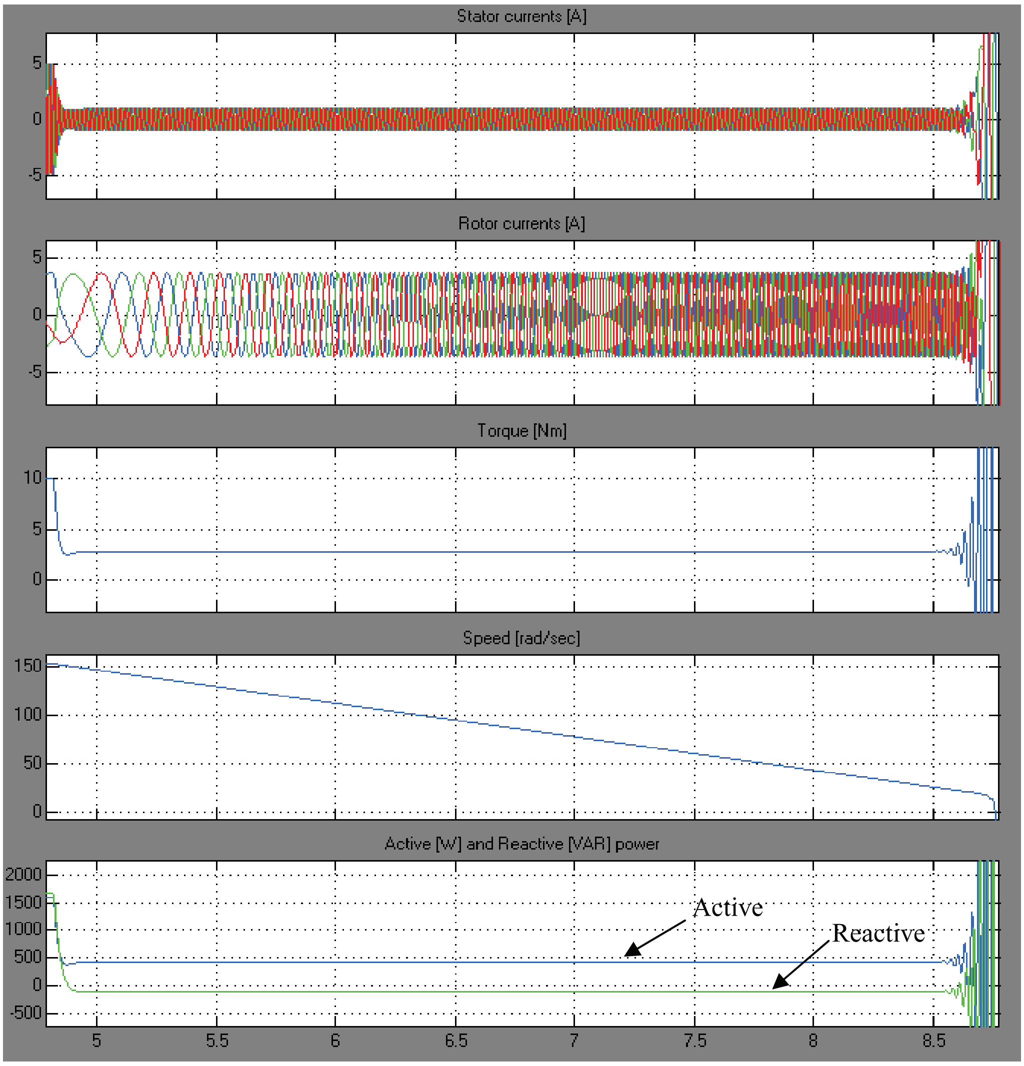

Fig. 3. Behavior of the doubly fed induction machine supplied by voltage source inverter in the low speed range.

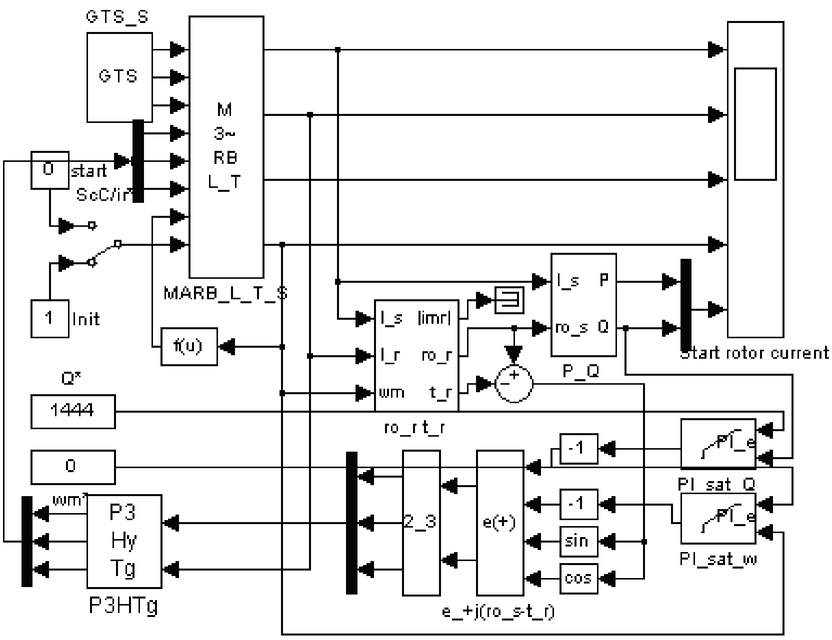

Fig. 4. Doubly fed induction machine supplied by preset currents voltage source inverter.

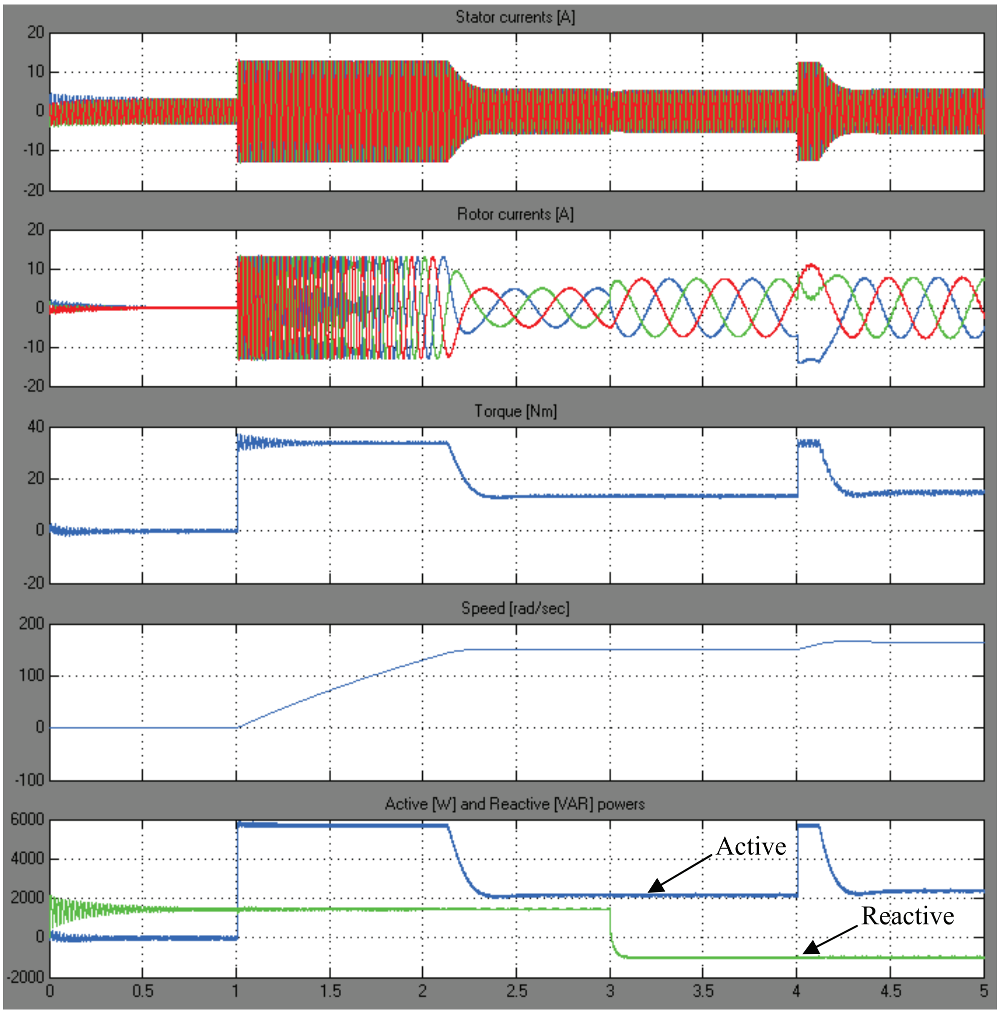

Fig. 5. Behavior of the doubly fed induction machine supplied by preset currents voltage source inverter, controlled on the rotor flux.

No hesitation is present at the very beginning of the starting phase.

At 3 seconds from the beginning of the simulation, a negative 1000 VAR reactive power is imposed i.e. the motor would act as a reactive power generator (traced in the last plot). The reference signs of the variables are considered positive for motor operation.

The hyper-synchronous operation is imposed at 4 seconds after the beginning of the simulation, when the preset speed becomes 165 rad/sec, the synchronous one being 157 rad/sec.

It is notable the very good behavior of the drive during all the phases of the simulation.

Besides the very truthfully behavior, an important disadvantage must be noted. It is the preset current modulation technology of the inverter. It is known that this type of modulation is specially suited for low power applications.

Another mentioned disadvantage of this modulation strategy is the variable switching frequency which has bad influence on the switching losses estimation in the designing phase.

IV. CONCLUSIONS

The paper discusses the existing technologies involved in the variable speed drives based on wound rotor induction machines and proposes a technique for starting which avoids the use of additional rotor resistors and consequently it eliminates the corresponding losses.

It implies the double fed of the induction machine and vector control of the currents injected in the rotor windings. It is shown by simulations that the voltage source inverters determine instability in the low range of the speed. The paper proposes the using of preset currents voltage source inverters which, even have known and notable disadvantages, are capable to truthfully control the drive, especially its start.

Further researches will focus on minimization of the disadvantages of the preset currents modulation strategy.

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