

DIRECT TORQUE CONTROL FOR DOUBLY- FED INDUCTION MACHINE BASED WIND TURBINES

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Abstract

This paper proposes a rotor flux amplitude reference generation control strategy for doubly fed induction machine (DFIM) based wind turbines. It is designed to address perturbations, as voltage dips, by keeping the torque of the wind turbine in control, and considerably decreasing the stator and rotor over currents during faults. A direct torque control (DTC) strategy provides fast dynamic response and also the overall control of the wind turbine. The proposed control strategy does not totally eliminate the requirement of the typical crowbar protection for wind turbines, but during low depth voltage dips it eliminates the activation of this protection. The main objective of this proposed is to control the voltage dips and to reach the constant voltage by using DTC control system it is based upon wind turbines and without crowbar protection. From this paper we can generate a power for different speeds of wind we can get a constant voltage.

Index Terms: doubly fed induction machine (DFIM), direct torque control (DTC), crowbar protection etc.

1. INTRODUCTION

This paper is focused on the analysis on the control of doubly fed induction machine (DFIM) based high-power wind turbines when they operate under presence of voltage dips. Most of the wind turbine manufacturers build this kind of wind turbines with a back-to-back converter sized to approximately 30% of the nominal power. This reduced converter design provokes that when the machine is affected by voltage dips, it needs a special crowbar protection in order to avoid damages in the wind turbine and meet the grid-code requirements. The main objective of the control strategy proposed in this paper is to eliminate the necessity of the crowbar protection when low-depth voltage dips occur. Hence, by using direct torque control (DTC), with the generation of proper rotor flux, during the fault it is possible to maintain the machine to be grid connected, generating power from the wind. And it is also possible to reduce over currents, and eliminate the torque oscillation that causes such voltage dips.

1.1.Crowbar Protection

A crowbar circuit is a protection circuit that short-circuits ("crowbars") the supply line if the voltage or current exceed the limits. In general, the resulting short blows a fuse or triggers other protection effectively disconnecting the supply. It is

achieved by an SCR or other silicon device, or by a mechanical shorting device. It is operated by putting a short circuit or low resistance path across the voltage source. Crowbar circuits are generally implemented using a thyristor or a triac or thyatron as the shorting device.

As triggered, they depend on the current-limiting circuitry of the power supply or, if it fails, the line fuse blows or tripping the circuit breaker.

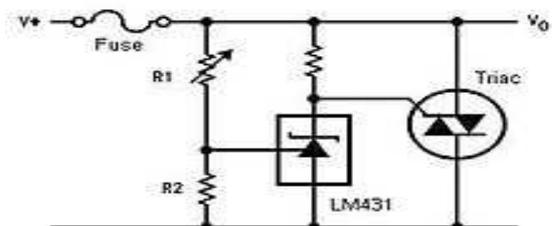


Fig-1 Equivalent Circuit of Crowbar Protection

A crowbar circuit is distinct from a clamp in that, once triggered; it pulls the voltage below the trigger level, usually close to ground. A clamp prevents the voltage from exceeding a preset level. Thus, a crowbar will not automatically return to normal operation when the overvoltage condition is removed, power must be removed entirely to stop its conduction.

An active crowbar is a crowbar that can remove the short circuit when the transient is over thus allowing the device to resume normal operation. Active crowbars use a transistor, gate turn off (GTO) thyristor or forced commutated thyristor instead of a thyristor to short the circuit. Active crowbars are commonly used to protect the frequency converter in the rotor circuit of doubly fed generators against high voltage and current transients caused by the voltage dips in the power network. Thus the generator can ride through the fault and quickly.

The advantage of a crowbar over a clamp is that the low holding voltage of the crowbar lets it carry higher fault current without dissipating much power (which could otherwise cause overheating). Also, a crowbar is more likely than a clamp to deactivate a device (by blowing a fuse or tripping a breaker), bringing attention to the faulty equipment. Although this power supply overvoltage protection circuit is widely used, it does have some limitations. Most of these are associated with the zener diode. The zener diode is not adjustable, and these diodes come with at best a 5% tolerance.

An over voltage crowbar protection circuit using a silicon controlled rectifier or SCR Power supplies are normally reliable, but if they fail then they can cause significant damage to the circuitry they supply on some occasions. The SCR overvoltage crowbar protection circuit provides a very simple but effective method of protecting against the certain types of power supply failure.

2. CONTROL OF DOUBLY-FED INDUCTION GENERATOR

Doubly-fed electric machines are electric motors or electric generators that have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and electrical system. Doubly-fed machines are useful in applications that require varying speed of the machine's shaft for a fixed power system frequency.

As the penetration of large scale wind turbines into electric power grids continues to increase, electric system operators are placing greater demands on wind turbine power plants. One of the most challenging new interconnection demands for the doubly fed induction generator (DFIG) architecture is its ability to ride through a short-term low or zero voltage event at the point of common coupling (PCC), resulting from a fault on the grid. During extreme voltage sags high per unit currents and shaft torque pulsations occur unless mitigating measures are taken.

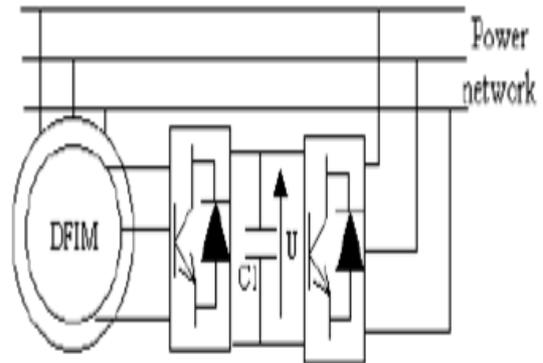


Fig-2 Double Fed Induction Generator

The wound-rotor doubly-fed electric machine is the only electric machine that operates with rated torque to twice synchronous speed for a given frequency of excitation (i.e., 7200 rpm @ 60 Hz and one pole-pair versus 3600 rpm for singly-fed electric machines). Higher speed with a given frequency of excitation gives lower cost, higher efficiency, and higher power density.

In practice, the classical wound-rotor doubly-fed "induction" electric motor or generator system has known issues of instability, high maintenance and inefficiency of an integral multiphase slip-ring assembly, and discontinuity about synchronous speed where induction ceases to exist. A practical wound-rotor doubly-fed electric machine system that does not rely exclusively on asynchronous (i.e. induction) principles while symmetrically motoring or generating over its entire speed range has never materialized from the electric machine establishment, despite years of research to find an evolutionary brushless, synchronous, and stable control technology. Consequently the wound-rotor doubly-fed induction electric machine has been forced into antiquity, except in large installations where efficiency and cost are critical over a limited speed range, such as wind turbines.

When the DFIG is connected to a network, connection must be done in three steps which are presented below the first step is the regulation of the stator voltages with the network voltages as reference. The second step is the stator connection to this network. As the voltages of the two devices are synchronized, this connection can be done without problem. Once this connection is achieved, the third step, is the power regulation between the stator and the network.

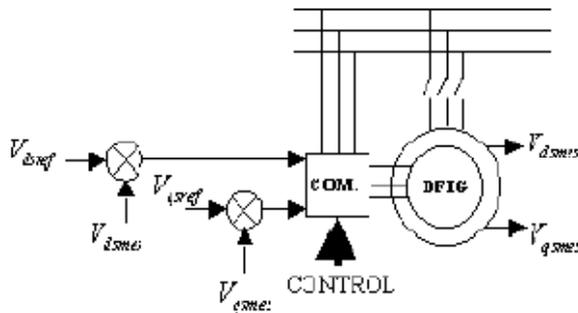


Fig-3: Without Stator Connection

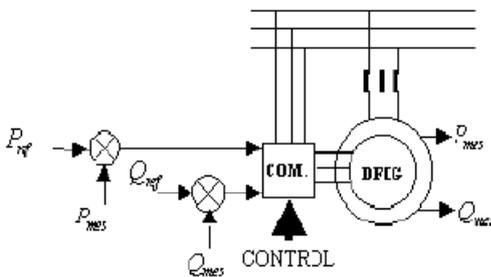


Fig-4: With Stator Connection

The electronic controller, a frequency converter, conditions bi-directional (i.e., four quadrant), speed synchronized, and multiphase electrical power to at least one of the winding sets (generally, the rotor winding set). Using four quadrant controls, which must be continuously stable throughout the speed range, a wound-rotor doubly-fed electric machine with two poles (i.e., The electronic controller, a frequency converter, conditions bi-directional (i.e., four quadrant), speed synchronized, and multiphase electrical power to at least one of the winding sets (generally, the rotor winding set). Using four quadrant controls, which must be continuously stable throughout the speed range, a wound-rotor doubly-fed electric machine with two poles (i.e., one pole-pair) has a constant torque speed range of 7200 rpm when operating at 60 Hz.

Due to the lack of damper windings used in synchronous machines, the doubly fed electric machines are susceptible to instability without stabilizing control. Like any synchronous machine, losing synchronism will result in alternating torque pulsation and other related consequences.

2.1 Direct Torque Control (DTC)

Direct Torque Control (DTC) is a method that has emerged to become one of the possible alternatives to the known Vector

Control of Induction Motors. This technique gives a good performance with a simpler structure and control. However, the evolution of AC variable speed drive technology has been driven partly by the desire to emulate the excellent performance of the DC motor, such as fast torque response and speed accuracy, while using rugged, inexpensive and maintenance free AC motors. DTC offers direct control the stator flux and the torque by selecting the appropriate inverter switching state.

A variety of techniques have been proposed to overcome some of the drawbacks present in DTC. Some solutions proposed are: DTC with Space Vector Modulation (SVM), the use of a duty-ratio controller to introduce a modulation between active vectors chosen from the look-up table and the zero vectors, use of artificial intelligence techniques, such as Neuro-Fuzzy controllers with SVM. These methods achieve some improvements such as torque ripple reduction and fixed switching frequency operation. However, the complexity of the control is considerably increased.

A different approach to improve DTC features is to employ different converter topologies from the standard two-level VSI. Some authors have presented different implementations of DTC for the three-level Neutral Point Clamped (NPC) VSI. This paper presents a new control scheme based on DTC designed to be applied to an Induction Motor fed with a three-level VSI. The major advantage of the three-level VSI topology when applied to DTC is the increase in the number of voltage vectors available. This means the number of possibilities in the vector selection process is greatly increased and may lead to a more accurate control system, which may result in a reduction in the torque and flux ripples

3. WIND ENERGY GENERTION SYSTEM BASED ON THE DFIM

3.1. Proposed System

Fig3.1 shows the wind turbine generation system together with the proposed control block diagram. The DFIM is supplied by a back-to-back converter through the rotor, while the stator is directly connected to the grid. This letter only considers the control strategy corresponding to the rotor side converter. The grid-side converter is in charge to keep controlled the dc bus voltage of the back-to-back converter and the reactive power is exchanged through the grid by this. As can be noticed from, the DFIM control is divided into two different control blocks. A DTC that controls the machine’s torque (T_m) and the rotor flux amplitude ($\psi_{r/l}$) with high dynamic capacity, and a second block that generates the rotor flux amplitude reference, in order to handle with the voltage dips.

When the wind turbine is affected by a voltage dip, it will need to address three main problems:

- 1) From the control strategy point of view, the dip produces control difficulties, since it is a perturbation in the winding of the machine that is not being directly controlled (the stator).
- 2) The dip generates a disturbance in the stator flux, making necessary higher rotor voltage to maintain control on the machine currents.

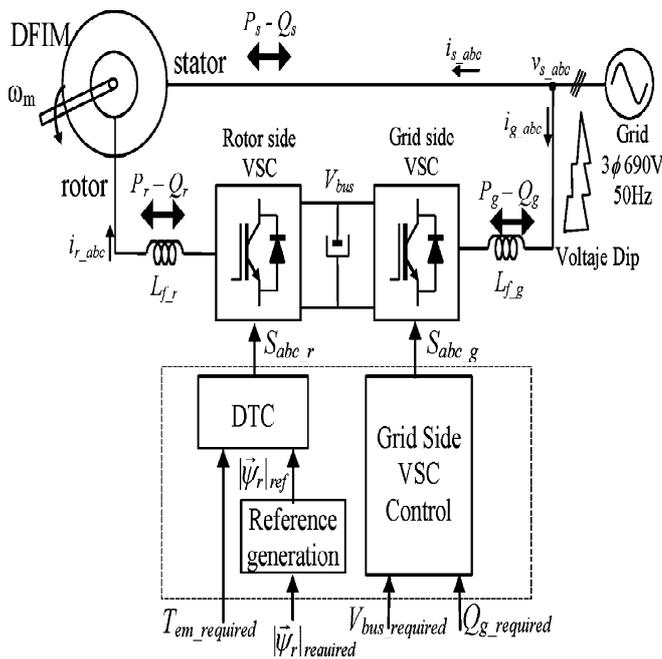


Fig-5: Wind Energy Generation System Based on the DFIM.

- 3) If not special improvements are adopted, the power delivered through the rotor by the back-to-back converter, will be increased due to the increase of voltage and currents in the rotor of the machine, provoking finally, an increase of the dc bus voltage.

Taking into account this, depending on the dip depth and asymmetry, together with the machine operation conditions at the moment of the dip (speed, torque, mechanical power, etc.), implies that the necessity of the crowbar protection is inevitable in many faulty situations. However, in this letter, a control strategy that eliminates the necessity of the crowbar activation in some low depth voltage dips is proposed.

As depicted in the proposed rotor flux amplitude reference generation strategy, adds a term ($\Delta|\psi_r|$) to the required reference rotor flux amplitude according to the following expression:

$$\Delta|\psi_r| = |\psi_s| - \frac{|\vec{v}_s|}{\omega_s}$$

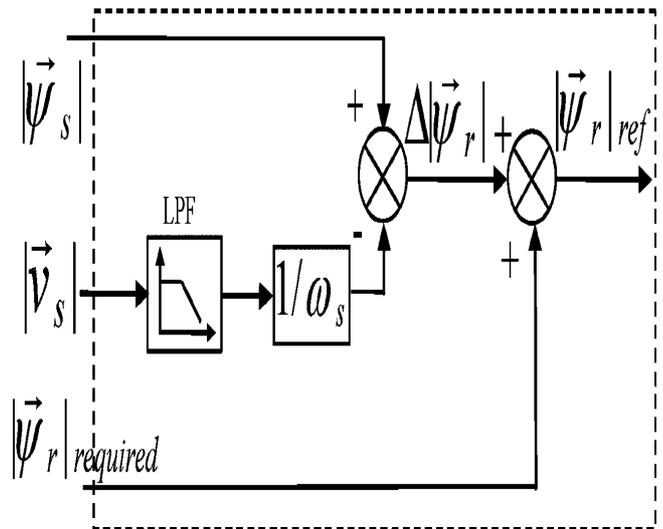


Fig-6: Rotor Flux Reference Generation Strategy

4. RESULTS & DISCUSSIONS

The simulated wind turbine is a 2 MW, 690 V, $N_s/N_r = 1/3$ and two pair of poles DFIM. The main objective of this simulation validation is to show the DFIM behavior or when a low depth [in this case 30%, as in symmetric voltage dip occurs with and without the proposed flux reference generation strategy and at nearly constant speed. The simulations are performed in MATLAB/Simulink. During the dip, it is desired to maintain the torque controlled to the required value (20%), allowing to eliminate mechanical the stator flux amplitude. It must be pointed out that DTC during faults is a well-suited control strategy to reach quick flux control dynamics, as well as to dominate the situation, eliminating torque perturbations and avoiding mechanical stresses. Consequently, the proposed control schema maintains the stator and rotor currents under their safety limits, avoiding high over currents, either in the voltage fall or rise stresses to the wind turbine. This issue is achieved, as shown in only if the oscillatory rotor flux is generated. For this purpose, the rotor flux is generated according to the block diagram of, generating an equivalent oscillation to

However, as predicted in theory, it is hard to avoid a deterioration of the quality of these currents. Nevertheless, if the rotor flux is maintained constant, the currents will go further till their limit values, as, provoking in a real case, a disconnection of the wind turbine or an activation of the crowbar protection. Moreover, by mitigating the over currents of the rotor, the back-to-back converter is less affected by this perturbation, producing short dc bus voltage oscillations, as illustrated Finally, it can be said that the proposed control is useful at any operating point of the wind turbine, as well as at any type of faults (one phase, two phases, etc.). The performance will be limited only, when the rotor voltage required is higher than the available at a given dc bus voltage.

4.1 Output Results without Reference

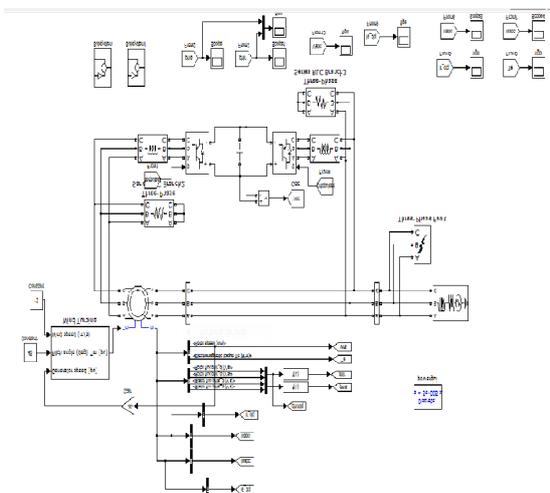


Fig-7: DTC for DFIM based wind turbines under voltage dips and without reference

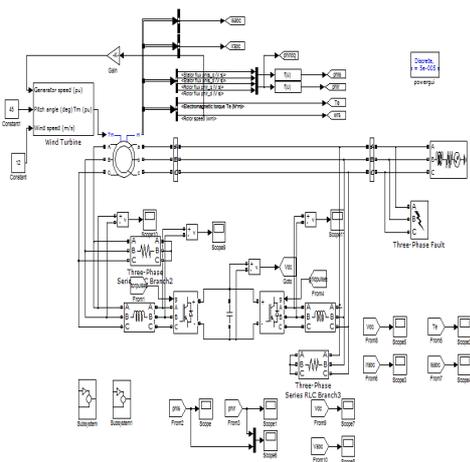


Fig-8: DTC for DFIM based wind turbines under voltage dips and with reference

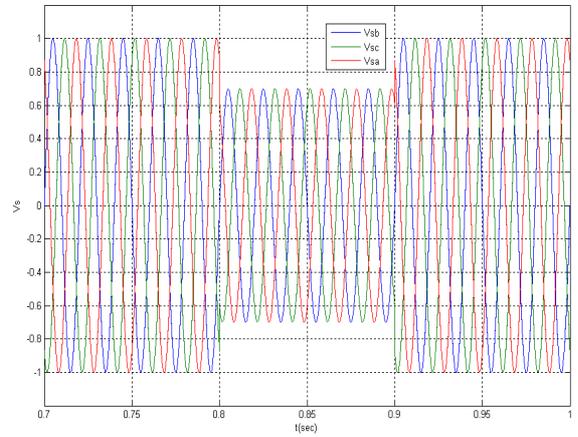


Fig-9(a): Voltages

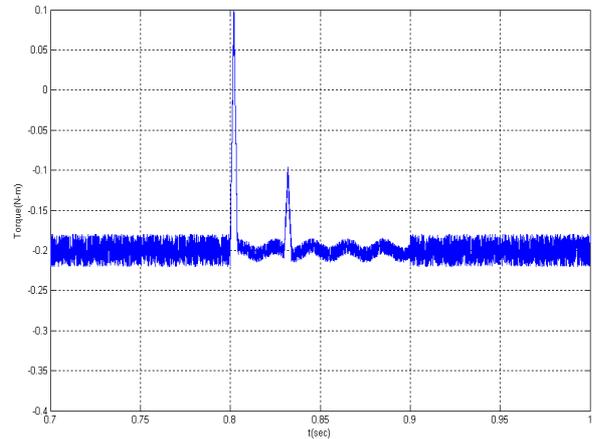


Fig-9(b): Torque

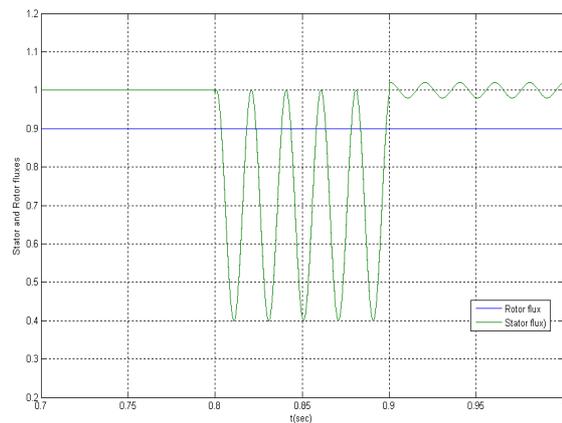


Fig-9(c): Stator and Rotor Fluxes

4.2 Output Results with Reference

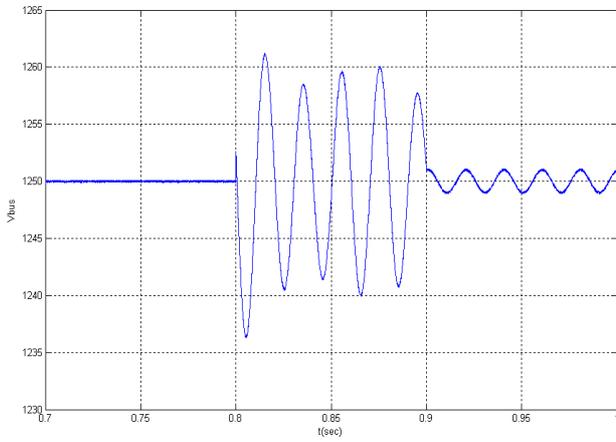


Fig- 10(a): DC Voltages

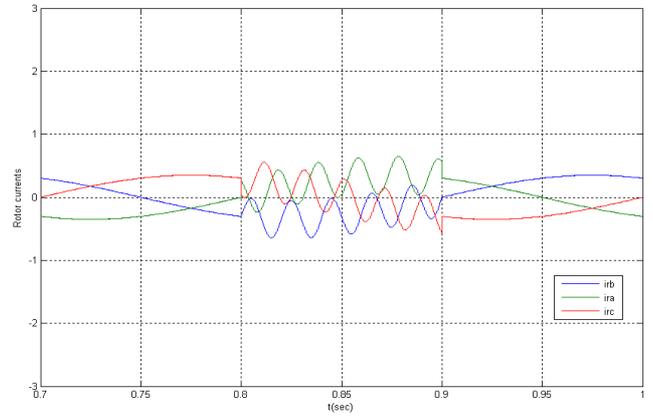


Fig-10(d): Rotor Currents

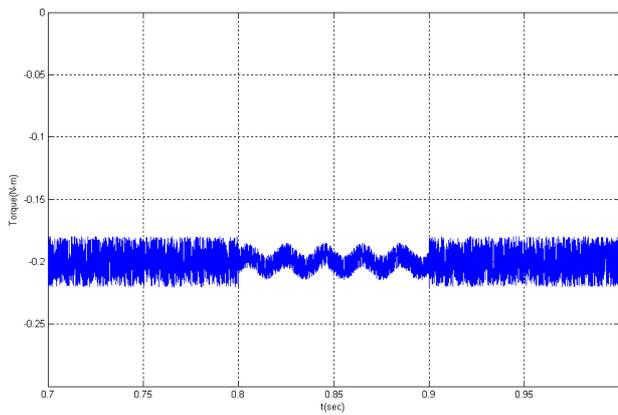


Fig-10(b): Torque

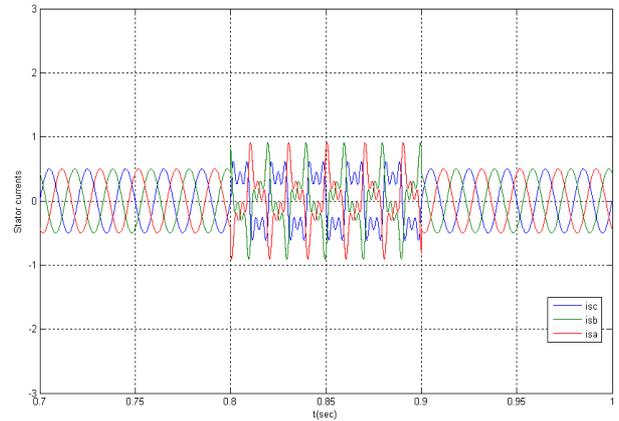


Fig-10(e): Stator Currents

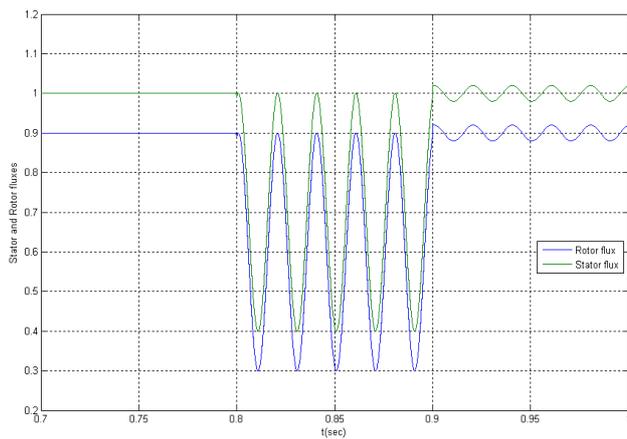


Fig- 10(c): Stator and Rotor Fluxes

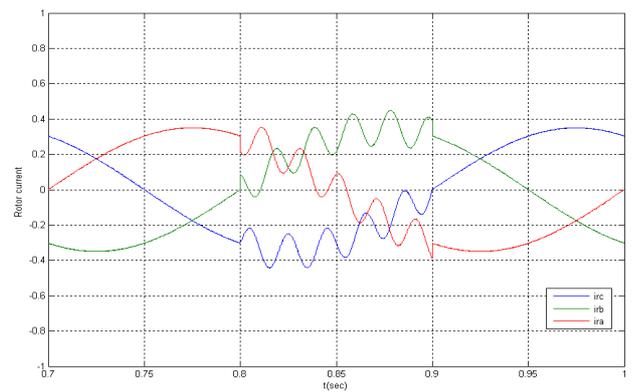


Fig-10(f): Rotor Currents

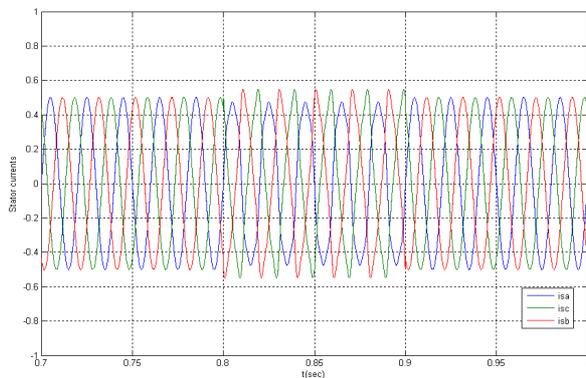


Fig-10(g): Stator Currents

CONCLUSION

Simulation results have shown that the proposed control strategy mitigates the necessity of the crowbar protection during low depth voltage dips. In fact, the dc bus voltage available in the back-to-back converter, determines the voltage dips depth that can be kept under control. For future work, it would be interesting to explore the possibility to generate a modified reference of rotor flux and torque, in order to be able to address deeper voltage dips without crowbar protection.

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BIOGRAPHIES

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