DSP-based doubly fed induction generator test bench using a back-to-back PWM converter

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Abstract:-Present Paper describes the design of a doubly fed induction generator (DFIG) test bench with active crowbar, using a PWM voltage-fed inverters connected between the grid and the rotor. A vector control scheme is proposed in order to control the power-side and the rotor-side of the converter. A control board, based on a digital signal processor (DSP) and a FPGA, has been developed to manage the overall equipment. Real time system supervision is implemented by a monitor program.

INITRODUCTION

Doubly fed induction generator bas become during the last years in one of the most used systems in wind power production. The major advantage of the doubly-fed induction generator is that the power electronic equipment only has to handle a fraction of the total system power. This means that the losses in the power electronic equipment are reduced in comparison to power electronic system which has to handle total power. Cost saving of using a smaller converter is an important reason too. However, control of the doubly-fed induction machine is more complicated than the control of a standard induction machine and bas some important limitations. e.g., starting problem, synchronization and oscillatory transients. A doubly fed induction generator test bench using a back-to-back PWM converter connected between the rotor and the grid (known as Scberbius drive) has long been a standard option for high-power applications. Most Scherbius DFIG

II.EXPERIMENTAL RIG

equipments described employ either a cycloconverter or a current-fed DC-Link converter in the rotor circuit. Using a current-fed DC-link converter has some disadvantages. : The DC-link choke is very expensive. and an extra commutation circuit is required for Operation at synchronous speed, and this has resulted in poor performance at low slip speeds. In addition such a converter draws rectangular current waveforms from the supply. The problem at synchronous speed may be overcome by the use of a cycloconverter.Both schemes have the disadvantages of requiring a transformer to form the neutral; in addition naturally commutated DC-link and cycloconverter schemes may, in many cases ,require a transformer for voltage matching. In this paper, a complete doubly fed induction generator test bench bas been designed; two functional hardware boards have been developed and implemented. The first one. the handling & measuring board, adapts sensors information from the power electronic to the control system, controlling the signal levels and its possible saturation. It also handles the power switches of the system to connect-disconnect the power-side and the stator side to the grid. The PWM pattern and control signal to the IGBT drives are also generated in this board. It is based on a Texas instrument ®DSP and a Xilinx® FPGA. DSP perform the control algorithmic of the system meanwhile FPGA manages encoder signals.

A schematic diagram of the overall system is shown in Fig. 1. The main cbarac1eristics of the DFIG used are the following

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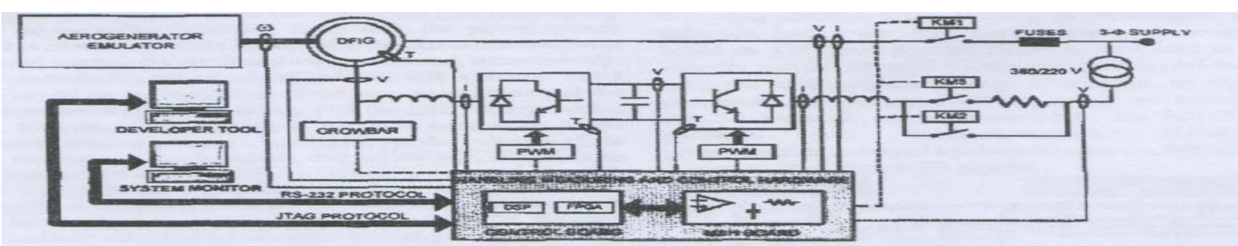

Fig.1 Schematic of the 40 KW doubly fed induction machine test bench

Asynchronous doubly fed generator
General Electrica EspafIola, Asynchronous generator UNELEC, Class B type FNAl22SMx4,
50 Hz, 54 CV, 40 KW 1470 rpm, Δ/Y 220/380170/190 A, Rotor A 200V 120A, Temperature protection

Tab1e:1Asynchronous doubly fed generator characteristics

Squirrel cage motor.
MEB Mot. 3 Ph Type TF 22SM-4,380-420/660-725 V. Δ/Y 50Hz 80.5146.6A 45 KW
1475 min^{-1}, Cos Φ 0.87 IP55 in. Cl. F IEC 34-1

Table 2 Squirrel cage motor characteristic

Back to Back converter:

978-1-4244-2487-0/09/$25.00 ©2009 IEEE

Semikron 4Q inverter 40 K.W,SKF 16 A-23o- 11135 W 1300 U/min,0.6A µF-400V ISO-KIB.TW

As we can see in figure 1, the DFIG system bas been implemented Using a IGBTs based, back-to-back converter between the rotor-side and the power-side, three single-phase chokes of 1.2 mH have been used. The doubly fed induction generator is a 40 K.W, 50Hz, 1470 rpm, 4 pole machine, whose parameters are g1ven in Table-I.A squirrel cage motor is used to emulate the wind turbine. Three power switches conned:-disconnect power and rotor sides to the grid; KM1; KM2 and KM3.The DFIG connection to the grid must be done in five steps. The first step consists on the power side-connection of the converter. The DC-link is charged to 300 volts through tbree220 ohms resistances using the anti-parallel diode rectifier of the IGBT's (working as a no-controller rectifier).After that. the power switch KM2 is closed and KM3 opened and the direct connection is realized starting the commutation process and, consequently, the controlled-rectification of the DC-link voltage. Third step would be the regulation of the statoric voltages and the correspondent synchronization with the grid voltages. After that. following step consists in the stator connection to the network, closing power switch K.M1.As the voltages of.tbe two devices are synchronized, this connection can be done without problem. Once this connection is achieved, the fifth step is the power regulation between the stator and the network. A crowbar protection has also been implemented It can be designed in many ways [7]. For example, the rotor can be short-circuited by two pairs of anti-parallel connected thyristors connected between the phases, Fig.2 (a)

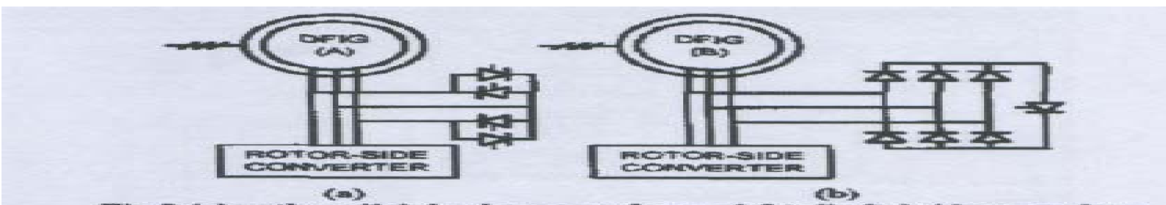

Fig.2 (a) antiparallel thyristor crowbar and (b) diode bridge crowbar.

Another possibility is to employ a diode bridge to rectify the phase currents and use a single thyristor to control the shorting, Fig. 2(b). In the developed system, the second option has been chosen due to it can cut the short-circuit current whenever needed.

A. Hardware control system: The hardware control system is based on two designed boards, figure 3, the handling and measuring board and the control board. First one is the interface of the control board with the power electronic system. All analog signals from sensors, as voltages and currents or temperatures are filtered and their levels adjusted in this board. Hall Effect sensors are used to transducer current measurements wm power-side, rotor-side and stator-side, as we can see in figure I. To measure voltages wm power, stator and rotor-side we have employed transformers, meanwhile a Hall Effect sensor is used to DC.link voltage. Grid-side power switches and rotor-side power switch are also managed. The crowbar protection and digital encoder signals are interfaced too. Temperature protections are been implemented in the asynchronous doubly fed generator and the back-to-back converter. The PWM signals are also managed employing this board, see figure 1. General purpose pins arc accessible to use them in the future. In other way, the control board manages the overall system. The DSP used in the control board is a Texas Instruments@ TMS32DVC33, with the following characteristics: floating point, Harvard memory structure, low power, high performances. A co-processor based on a Xilinx@ Spartan FPGA is also used to process encoder signals. External 12-bits analog to digital converters are used to obtain the sensors information by the digital processor. PC communications, based on asynchronous RS-232 protocol, are implemented by the PC16SS2D, an universal dual receiver/transmitter (UART). A programmable universal I/O interface device, MSM82CSSA, is used to latch digital I/O signals.

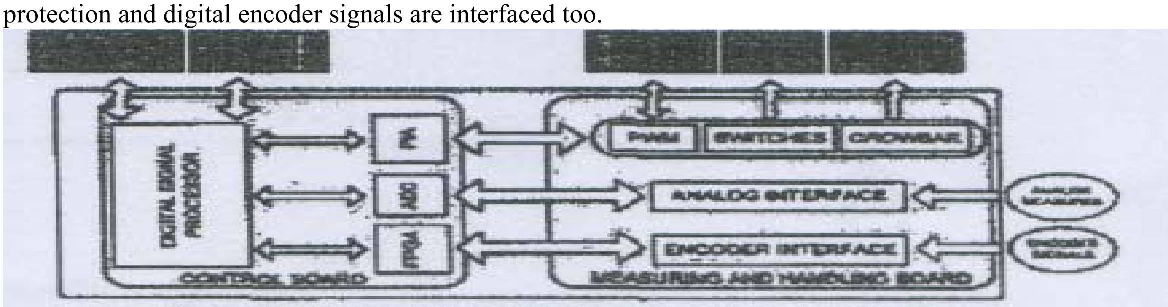

Fig.3 Block diagram of the control electronic boards

B. Software control system

TMS320VC33 control program is the core of the overall system. The main of the DSP

Program consists on the power and the rotor side control strategies and algorithms It manages all the data acquisition and digital signals from the test bench. A digital filtering of the different measures has been implemented too. In order to avoid the induction machine and power electronic damages, analog and digital signals, as driver errors, temperature alarms. and voltage measures. For example, are processed and a system protection has been realized. The connection-disconnection of the different power switches (KM1, KM2 and KM3) is synchronized by the c9ontrol software. Other important task is DSP-PC communication; polling and interruption strategies are used to implement the asynchronous protocol. The core of the program has been structured as a- machine, this implies a huge programming effort; however, this philosophy improves the debugger task. TMS320VC33 DSP has been programmed employing the Code Composer TooI® which enables a deeper visibility for a quick: and precise problem resolution, simplifies tedious guess work and enables a better management for real-time applications.

C. PC monitor program

Real time PC monitor software has been developed. The main characteristics of this program are the following, as shown in figure 4:Real-time sensors information displaying, Digital calibration, PI controllers parameters establishment, System alarm events and system status, Oscilloscope function, Signals plot storage, PC-DSP communication status., FIG test bench local and stand-alone control.

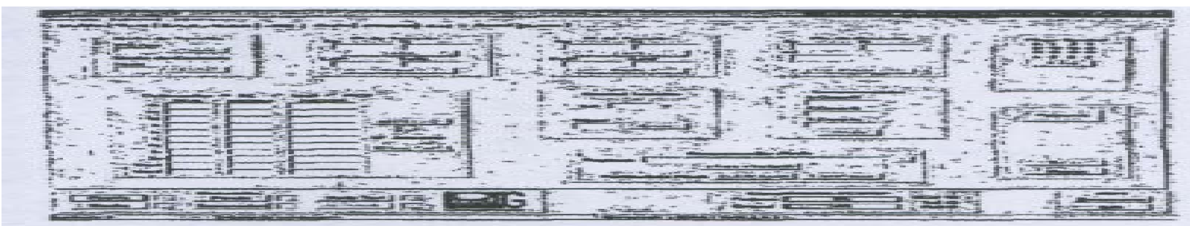

Fig.4 PC Monitor program

III.DOUBLY FED INDUCTION GENERATOR TEST BENCH CONTROL

The control of the DFIM test bench using back-to-back PWM scheme is well known. It has two main parts: the DC-link voltage regulator and the rotor voltage controller.

The DC-link voltage controller is a vector controller that permits keeping constant the DC-link voltage level.D&.rotor-side controller is a vector controller that enables independent control of the induction machine active and reactive powers.

A. Control of supply side three-phase-PWM rectifier

A control scheme for connecting the converter system to the grid bas been proposed in this paper and it is shown In Fig. 5. It consists in an outer loop to control the voltage of the DC-link V_{dc}. A reference of active power P_{cood} is obtained nom a PI controller and it is used to generate the current reference $I_{\alpha d}$ and $l_{\beta d}$ in static axis based on the Self Tunned Vectorial Filter STVF .The objective of the proposed STVF is to extract (filtering) the positive sequence symmetrical component of the fundamental harmonic of the grid voltage. The idea behind the filter was to generate a narrow band pass filter with unitary gain and zero phase at the fundamental harmonic.

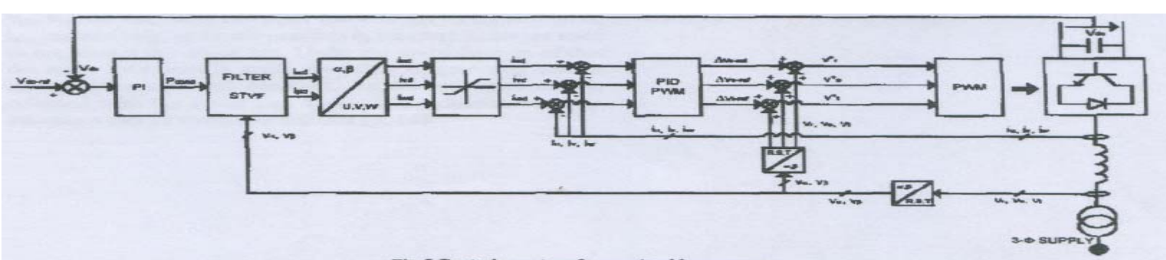

Fig.5 Control structure for supply-side converter

After that. the algorithm calculates the current references i_{ud},i_{vd}, i_{wd} using a 2 to 3 coordinates transformation which are saturated in order to avoid high current peak that could provoke a damage in the equipment. The voltage reference for the PWM block is obtained from the filtered grid voltage, adding a small signal component obtained from the PID PWM controller comparing the actual

current with its reference, In the figure 6 an example of the experimental control of VDC at 600 V is showed. we can observed the charge of the capacitor bus at first via a resistance circuit, as shows figure ,after that, where the capacitor is over 300 V the direct connection is realized and 315 V in DC-bus are reached, at this moment the rectifier begins to control the bus, after a time it is disconnected to connect and disconnect again. We can see the bus discharge at least when the power-side is opened

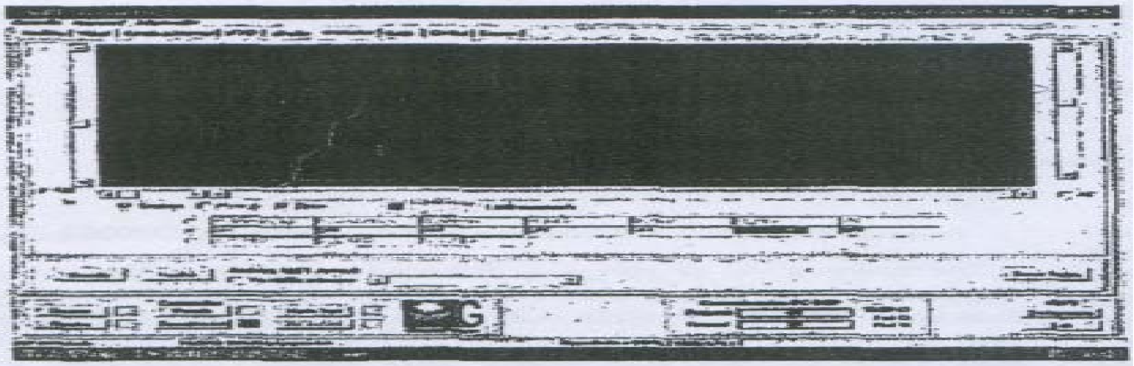

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Fig. 6 DC-link control visualization

B. Induction machine control

The wound-rotor induction machine control scheme is presented in figure 7. It is based on convectional control diagrams. A decoupled control between the active and reactive power is sea.rched.To control the induction machine. a rotating reference axis d-q.oriented along the stator flux, is employed .Stator voltages $v_{us}v_{vs}$ and v_{ws} stator and rotor currents at. i_{ud},i_{vd}, i_{wd}., and i_{ur},i_{vr}, i_{wr} respectively, and rotor position Φr. measurements are used to implement this algorithm. Under the consideration of that the stator resistance is small. the stator magnetizing current i_{ms}. can be considered constant. The active and: reactive power errors are processed by the PI controllers to obtain i_{dr} and i_{qr} current reference which are compared. with the measured currents and using other PI stage we obtain v' dr and v' qr. respectively- After adding a compensation term. the references v' dr and v' qr. are obtained. After that. a $\alpha\beta$ scheme is obtained and a 2 to 3 variable conversion is realized to obtain $v_{us}v_{vs}$ and v_{wr}.These are the voltage references to the PWM converter, as we can see in figure. 7.

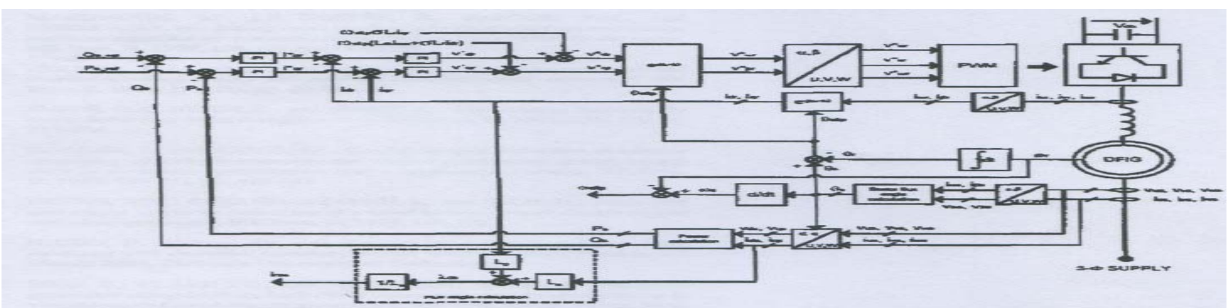

Fig.7 Rotor side schematic control block

IV.Conclusion and Experimental Results

The purpose of this research project is to implement a doubly fed induction generator test bench and implement: the control of the system, to analyse the different techniques and its advantageous. Actually. Power electronic system and con1ro1 electronic boards, DSP based, has been designed and implemented successfully and are well suited to the power electronic control. Photography of tile system can be seen in figure8.

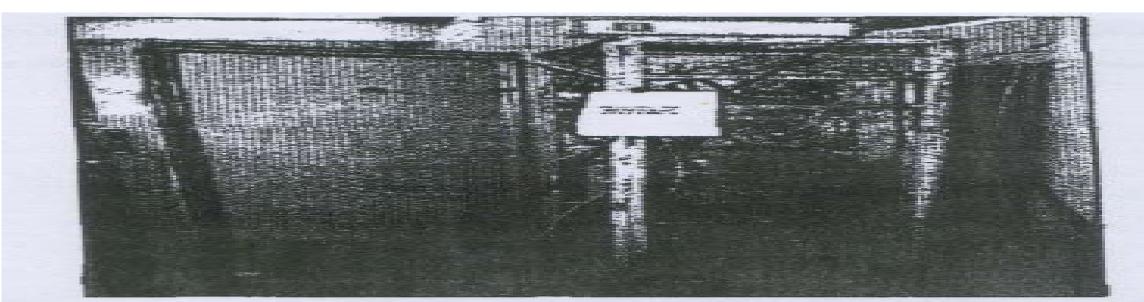

Fig. 8 Doubly fed induction generator converter

Developed monitor program makes easier the system magnitudes visualization, as voltage. current and temperature sensors signal or PWM templates. At the same time, PC program enables remote real-time control of the complete system. Photography of complete system. Where two Pcs are used, one to monitor the system and a second one with the

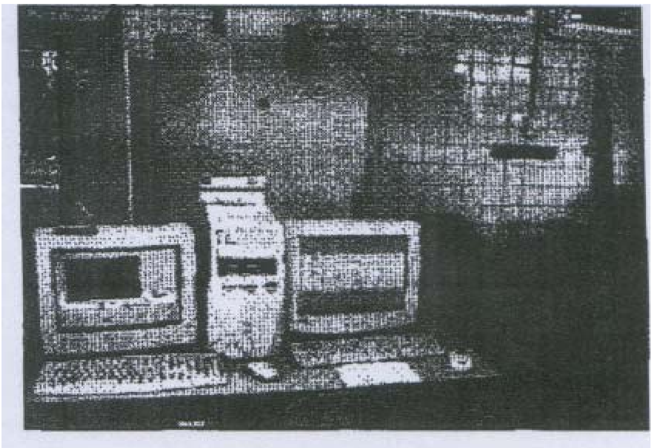

Fig. 9 Photography of the complete system

debugger tool can be Seen figure 9. Control Software of the system is being programming and the power-side of the converter is already correctly working. Rotor-side converter control is being implemented.

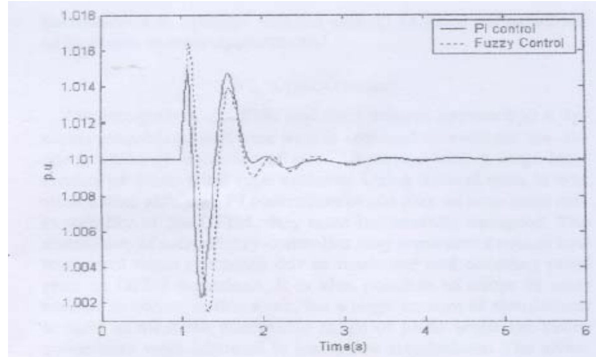

Fig. 11. Rotor speed with PI and Fuzzy controllers during symmetrical impedance fault at bus-bar 6.

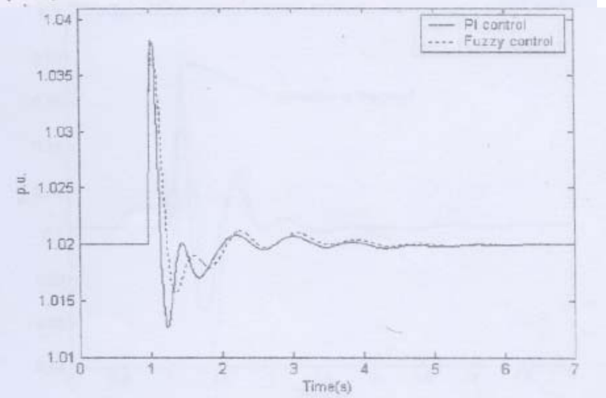

Fig. 9. Terminal voltage behavior with PI and fuzzy controllers for load loss in bus-bar 5.

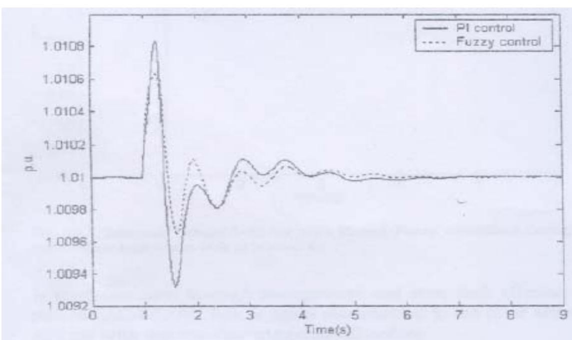

Fig. 8. Rotor speed behavior with PI and fuzzy controllers for loss load in bus-bar 5.

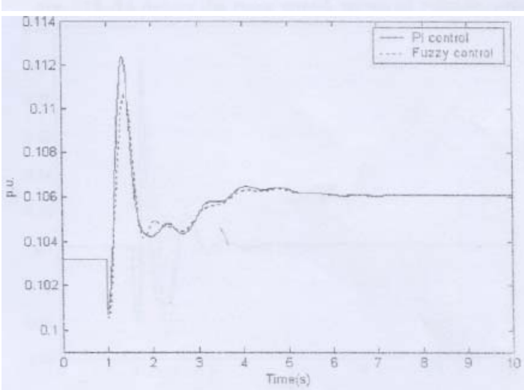

Fig. 10. Rotor current behavior for load loss at bus-bar 5.

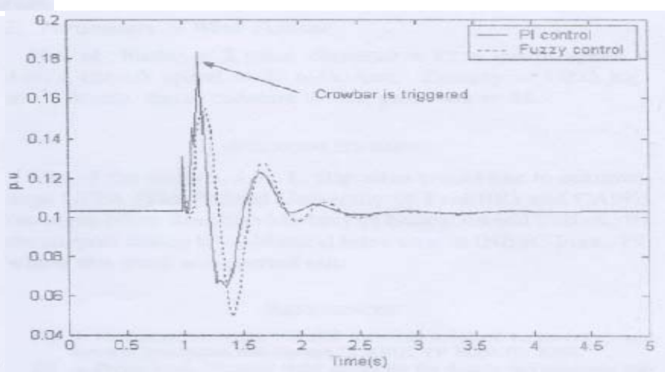

Fig. 13. Rotor current behavior with PI and Fuzzy controllers during symmetrical impedance fault at bus-bar 6.

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