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Performance Evaluation of Doubly Fed Induction Generator Using Neural Network

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Abstract: This Paper presents a new control strategy for the rotor side converter (RSC) of wind turbines (WTs) based on Doubly Fed Induction Generators (DFIG) to improve its low voltage ride through capability. The crowbar-based systems that were initially applied to protect the Rotor Side Converter(RSC),do not fulfill the requirement, i.e., to support the grid voltage, during faults.This project proposes a coordinated control strategy of the DFIG converters during a grid fault, managing to ride-through the fault without the use of any auxiliary hardware. The coordination of the two controllers is achieved through a neural network controller. This technique is to improve the dynamic performance of the DFIG driven by wind energy conversion system.

Key words: Doubly Fed Induction Generator (DFIG) · Fuzzy control · Low voltage ride through (LVRT) · power system faults · Wind power Generation

INTRODUCTION

Wind energy can meet the growing energy needs of mankind due to its clean and inexhaustible nature. The Windpowergeneration has developed fast because of commercial application and large-scale development future [1, 2]. DFIG concept is similar to variable speed controlled wind turbine with a wound rotor induction generator. DFIG consists of a wound rotor IG with its stator windings directly connected to the Grid and its rotor windings connected to the grid via two ac/dc back-to-back converters [3].

Wind turbines based on the DFIG are very sensitiveto grid disturbances, especially to voltage dips.During fault conditions over currents appear on the generator and it creates damage to the semiconductors of the RSC, without tripping it [4, 5]. The introduction of crowbar connection on the rotor windings is temporarily disabled the RSC. Thus, the short-circuit current flows through the crowbar instead of the rotor-side converter. With this solution, the machine is effectively protected, but due to the fact that the blocking of the RSC leads to the partial loss of power control during the crowbar action, large transients are generated after the fault, which may lead to the disconnection of machines from the grid. In addition, during the activation of crowbar, the DFIG is converted to a squirrel-cage induction generator, absorbing a large amount of reactive power from the grid [11, 12]. For that the STATCOM is used for the uninterrupted operation of the wind turbine. In some cases the complexity and additional cost impair their applicability [8, 9]. Other papers propose some methods for FRT without any auxiliary external devices [10-20]. The Neural Network (NN) presents a better performance in presence of variations of parameters and external disturbances than a PI controller [13]. This paper proposes a control strategy of DFIG converters during grid fault managing to ride through the fault. Here no auxiliary hardware is used. NN system for the RSC of the induction generator is made to improve the transient response in relation to dynamic performance.

Throughout this paper, we subjected our new model to a gradual increase of active power consign independently to reactive power. Neural network technique has been used as it has advantage of robustness, easily adaptive fast technology is also used and best results are advised when compared other technique.

Modelling and Control of the DFIG Wt System: The schematic diagram of DFIG WT is shown in Fig. 1. The DFIG consists of a wound rotor induction generator with its stator windings directly connected to the grid and its rotor windings connected to the grid via

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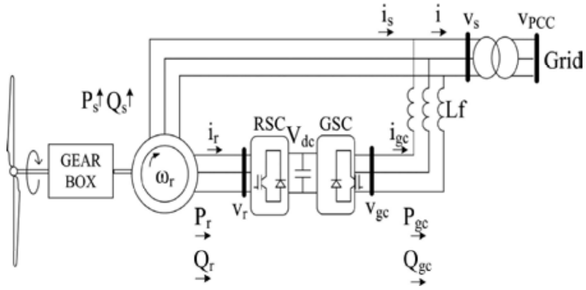


Fig. 1: Configuration of the DFIG WT

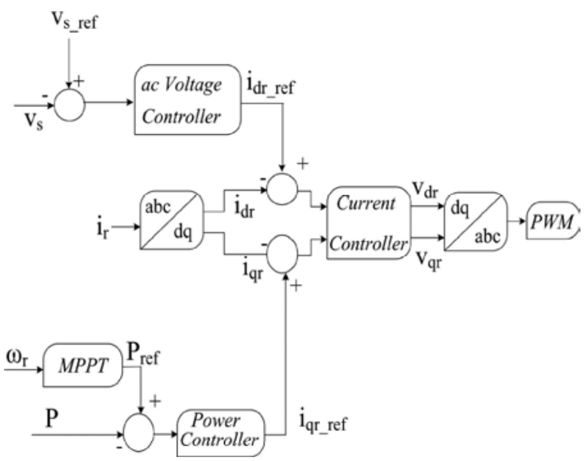


Fig. 2: RSC control system

an arrangement of two ac/dc back-to-back converters. The rotor side converter (RSC) and grid side converter (GSC) are pulse width modulated (PWM), IGBT voltage source converters (VSCs).

Modeling of the DFIG: A synchronously rotating d-q reference frame has been selected to model the dynamic behavior of the DFIG, considering the generator convention, the stator and rotor voltages are given by the following equations

$$v_{ds}= -R_s i_{ds}-\square_s \lambda_{qs}+ \frac{d\lambda_{ds}}{dt} \tag{1}$$

$$v_{qs}= -R_s i_{qs}+ \square_s \lambda_{ds}+ \frac{d\lambda_{qs}}{dt} \tag{2}$$

$$v_{dr}= R_r I_{dr} - (\square_s-\square_r)\, \lambda_{qr}+ \frac{d\lambda_{dr}}{dt} \tag{3}$$

$$v_{qr} =R_r\, i_{qr} +(\square_s-\square_r)\, \lambda_{dr}+ \frac{d\lambda_{qr}}{dt} \tag{4}$$

The indices d and q indicate the direct and quadrature axis components of the reference frame.

The flux linkage in (1) and (4) is defined as

$$\lambda_{ds} = -L_s\, i_{ds} + L_m i_{dr} \tag{5}$$

$$\lambda_{qs}= -L_s i_{qs} +L_m\, i_{qr} \tag{6}$$

$$\lambda_{dr}= L_r i_{dr} +L_m\, i_{ds} \tag{7}$$

$$\lambda_{qr}= L_r\, i_{qr} +L_m i_{qs} \tag{8}$$

In the following paragraph is cited a brief description of a conventional control system, where no special provisions are taken for the FRT of the DFIG.

Description of the Conventional Control System: The control system of RSC is shown in Fig, 2. Its objective is to independently regulate the stator active and reactive power, P_s and Q_s.

To achieve decoupled control of P_s and Q_s,the rotor current i_r is transformed to d-q components, i_{dr} and i_{qr}, using a reference frame oriented to stator flux. The q-axis component i_{qr} is used to control the stator active power P_s. The reference value of active power P_{ref} is using Maximum Power Point Tracking (MPPT) technique [21, 22]. P_s is subtracted from P_{ref} and the error is driven to the power controller.

The output of this controller is the reference value of the q-axis rotor current $i_{qr\text{-}ref}$. This signal is compared to the actual value of i_{qr} and the error is passed through the current controller whose output is the reference voltage for the q-axis component v_{qr}. The reactive power control of RSC can be tuned to keep the stator voltage v_s within desired range, when the DFIG feeds into a strong power system. When the DFIG feeds into a strong power system the command of Q_s can be simply set to zero.

In this paper, the case of the DFIG which feeds a weak ac grid is studied; therefore ac voltage control is used instead of reactive power control. The v_s at generator terminals is compared to its reference value $v_{s\text{-}ref}$ and error is passed through the ac voltage controller to generate the reference signal for the d-axis current$i_{dr\text{-}ref}$. This signal is compared to i_{dr} and theerror is sent to current controller, which determines the reference voltage v_{dr}. The signals v_{dr} and v_{qr} are transformed back to abc quantities which are used by the PWM module to generate the IGBT gate control signals to drive the RSC.

The objective of the GSC control system to keep the dc-link voltage constant. It is designed to be reactive neutral by setting$Q_{gc\text{-}ref}$=0. The setting is chosen considering that the converter is rated for only 30% of the

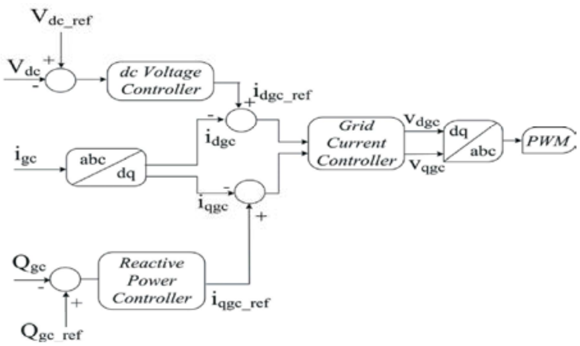


Fig. 3: GSC control system

DFIG rating and it is used to supply active power to the grid. The control system of GSC is shown in Fig. 3. As shown in Fig. 3, the dc voltage v_{dc} is controlled through the signal $i_{dgc\text{-}ref}$ and the reactive power Q_{gc} is controlled the signal $i_{qgc\text{-}ref}$.

Description of the Optimized Control System: In the above-described control system, no provisions are taken for the FRT of the DFIG. In this paragraph, a modification of this system is attempted, in order to ride-through the fault without any additional hardware. The proposed control scheme, achieving an optimal coordination between the two converters, manages to attenuate the system disturbances caused by the fault, even in the case where the wind turbine (WT) feeds a relatively weak ac grid. As the control system has to act efficiently in avery short period of time, it should be insensitive to the measurement noise and to the lack of accurate information concerning the machine parameters. In order to encounter these difficulties and considering the nonlinearity of the system, the controllers designed

As shown in Fig. 4. The optimized control system is a modification of the RSC control system, accomplished by adding the block "Fault Detection and Confrontation System" (FDCS).This block is active only when the ac voltage, v_s, deviates more than 10% from its reference value.The control of GSC is unchanged. The concept of control strategy is analyzed below: in order to successfully protect the DFIG, there are two major issues that should be addressed properly: the rotor over current and dc-link voltage [12].

Neither the dc voltage nor the rotor current should exceed their acceptable limits during the restoring period. The amount of the extra energy that is induced to the rotor during the transient must be properly "pumped" through the converters to the grid, in order to bring the values of the rotor current and the dc voltage back to their normal values. The problem that rises when trying to do this following: if the value of the rotor current is sharply dropped quickly "pumping" the stored energy in the rotor to the grid, the value of the dc voltage will rise suddenly, risking exceeding its limits. Respectively, if the value of the rotor current is slowly reduced in order to avoid the dc over voltage, there is a high risk that it reaches unacceptable values. Therefore, the correction signals of the rotor current should also take into account the respective values of the dc voltage, in order to achieve a successful FRT. As depicted in Fig. 4, output $v_{qr}$of the current controller is corrected by a quantity u_{crf}

$$V_{dc}{*} = \frac{\mathrm{Vdc} - \mathrm{Vdc\_ss}}{Vdc_{mv} - Vdc\_ss} \tag{9}$$

$$I_r{*} = \frac{\mathrm{ir} - \mathrm{ir\_ss}}{ir_{mv} - ir\_ss} \tag{10}$$

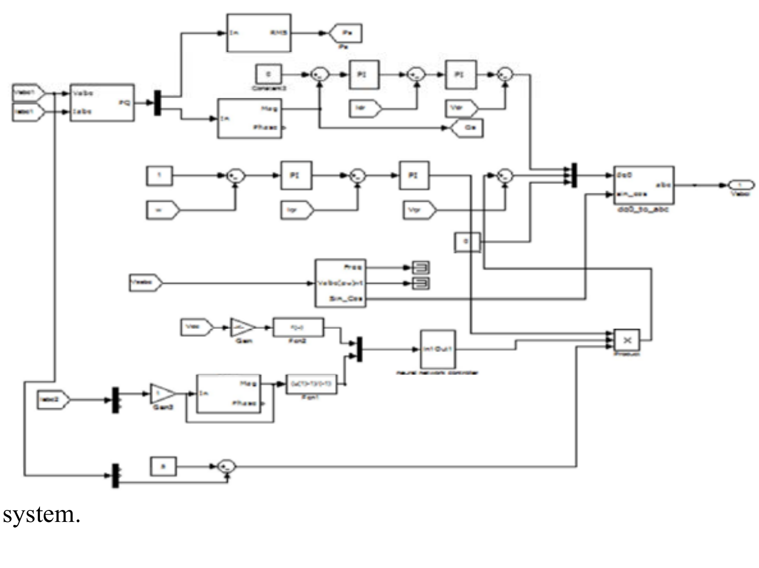


Fig. 4: Optimized control system.

Equations (9), (10), where the indicator *ss* stands for the steady state just before the dip and the indicator *mv* stands for the maximum acceptable value, imposed by the manufacturer. I_r is the rotor *rms* current (the maximum value of the three phases). In order to equally participate to the modulation of u_{crf}, the deviations of the two quantities from their steady state values are divided by their maximum acceptable deviations. It should also be mentioned that only the positive deviations are taken into account to the modulation of u_{crf}. Negative deviations are taken as zeros. This contributes to a smoother transition from the FDCS to the steady state control system. Artificial neural networks are a family of statistical learning algorithms inspired by biological neural networks and are used to estimate or approximate function that can depend on a large number of inputs. The neural network having 13 hidden layers number of inputs two and number of output one.

Simulation Results:

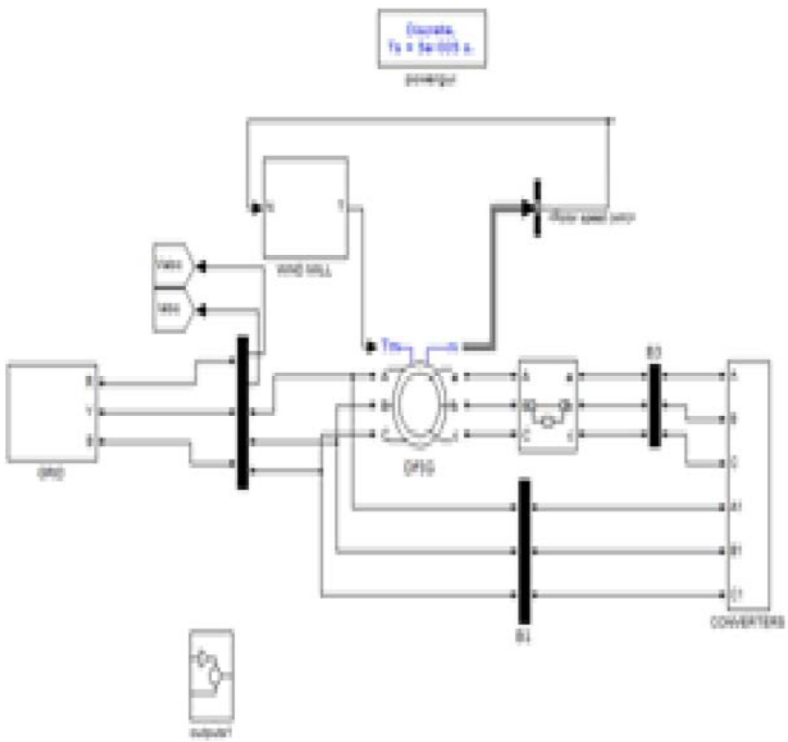
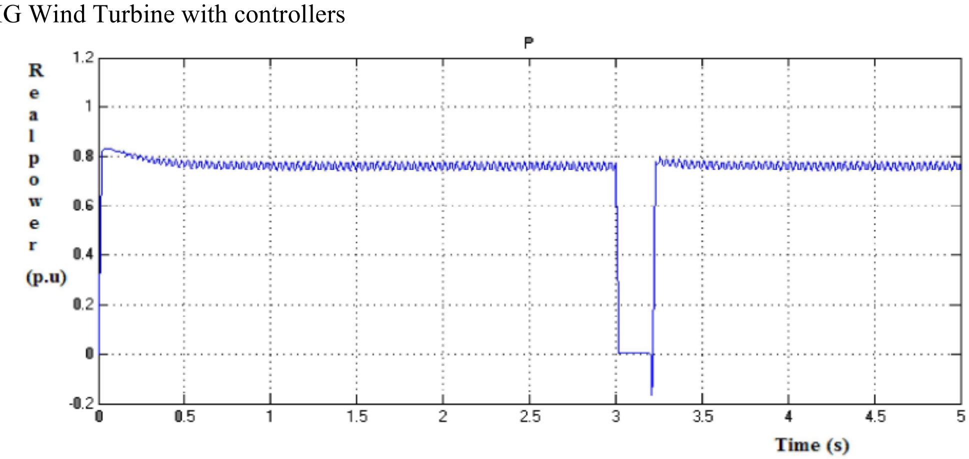
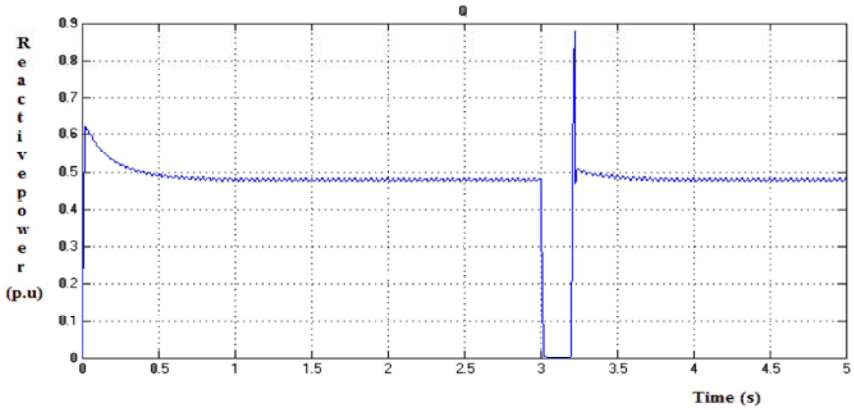


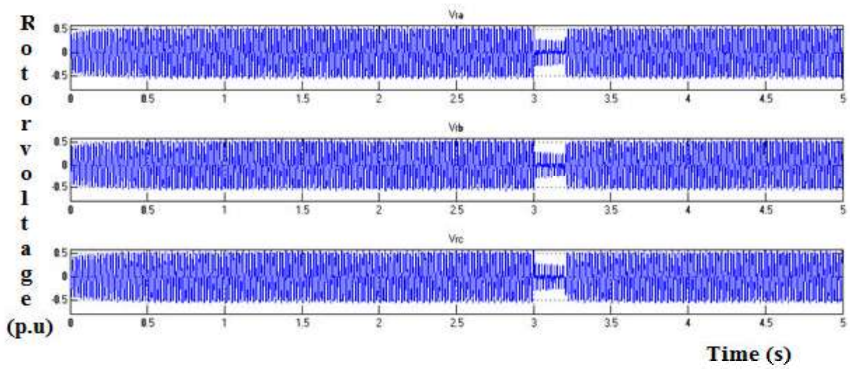
Fig. 5: DFIG Wind Turbine with controllers



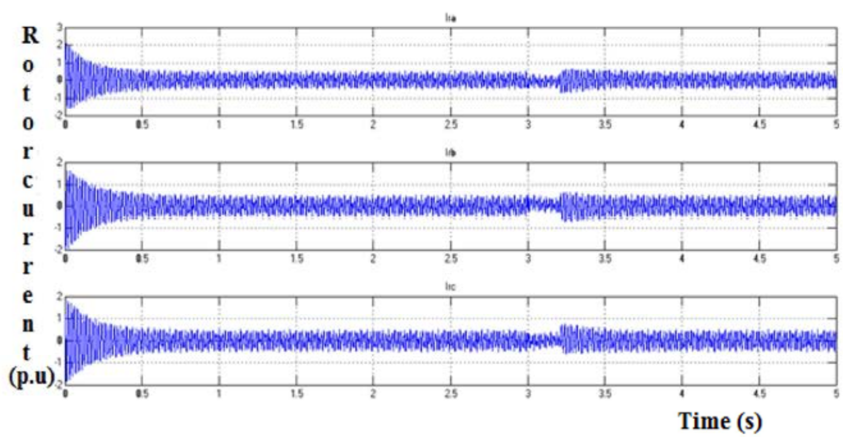
(a)



(b)



(c)



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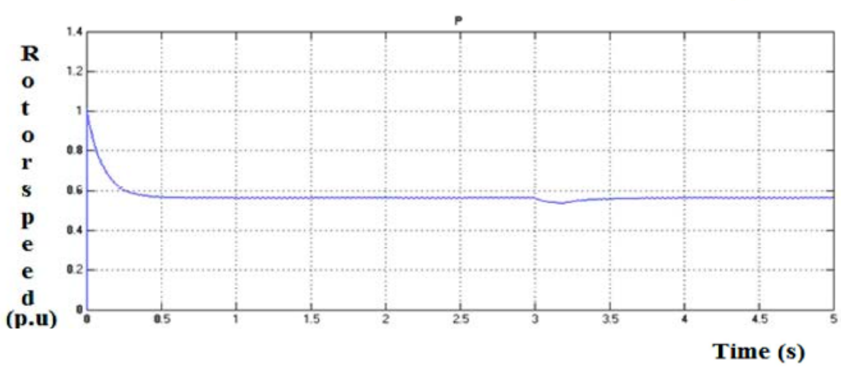
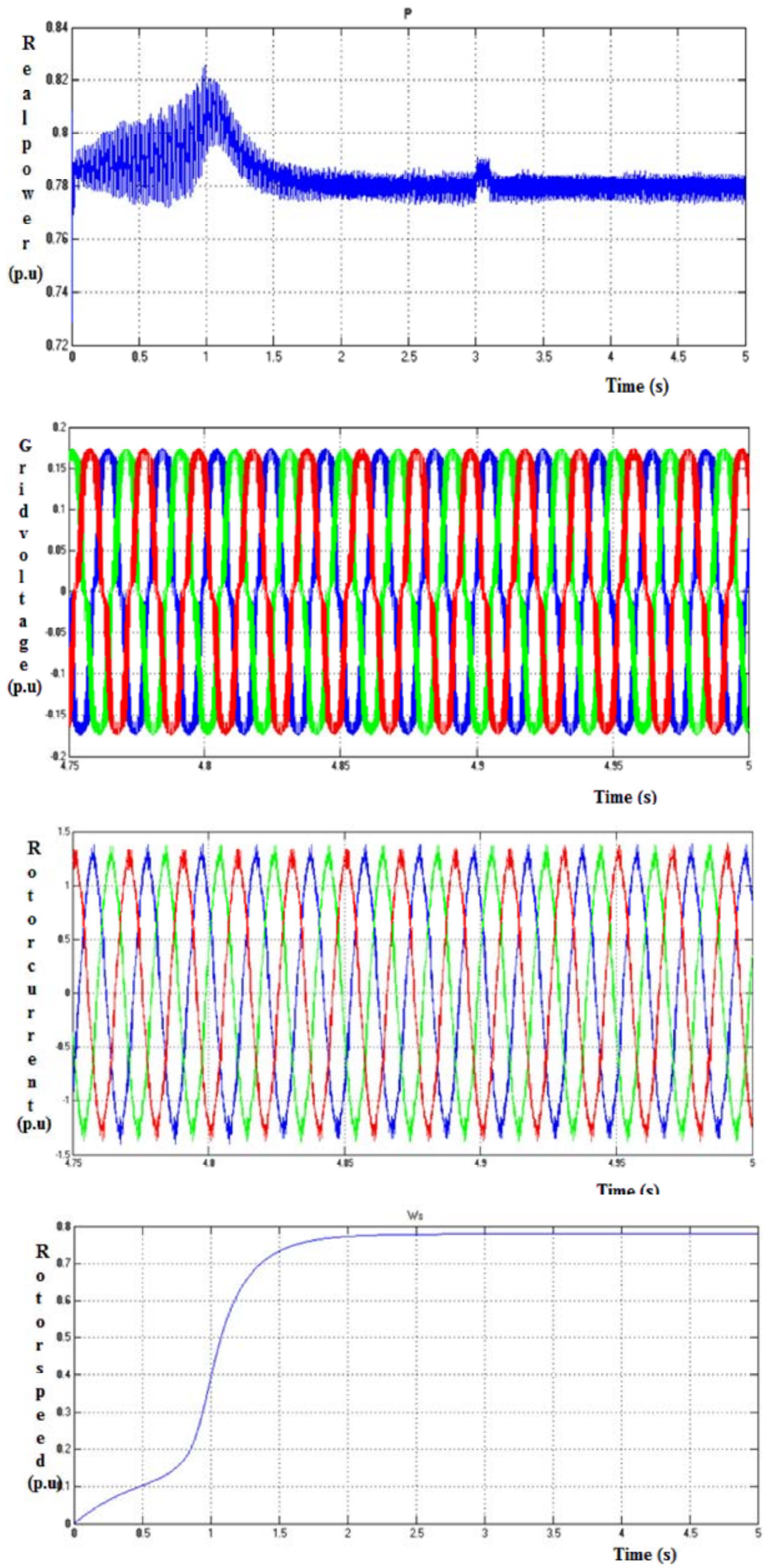


(e)

Fig. 6: Response of the system without controllers (a) WT output active power (b) WT output reactive power (c) Three phase voltage (d) Three phase current (e) Rotor speed



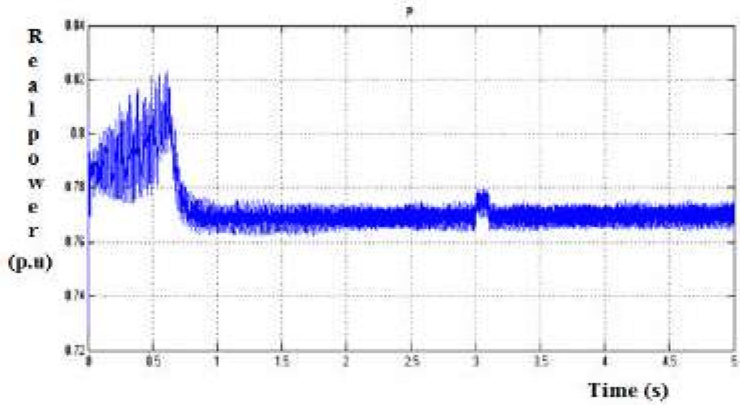
(a)

(b)

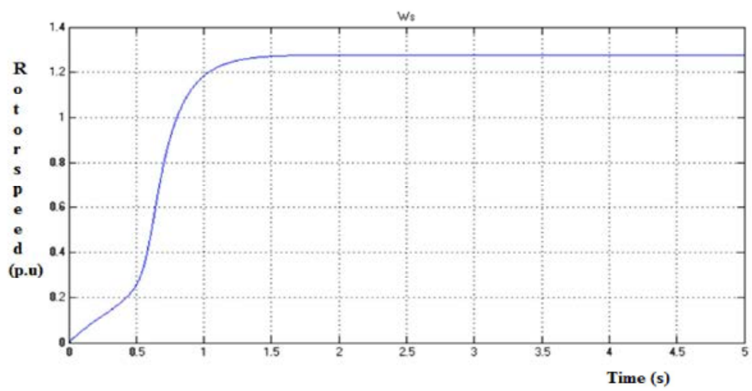
(c)

(d)

Fig. 7: Response of the system with fuzzy controller (a) WT output active power (b) Three phase voltage (c) Three phase current (d) Rotor speed



(a)



(b)

Fig. 8: Response of the system with neural network controller (a) WT output active power (b) Rotor speed

CONCLUSIONS

This paper proposes a coordinated control strategy for the rotor side controllers, oriented to improve its response during severe voltage sags and to enhance the LVRT capability of grid connected DFIG WTs without need of any auxiliary hardware. Its basic idea is the optimal coordination of the DFIG converters through a neural network controller. The results show that using the proposed control system, the DFIG can successfully ride-through the fault, even in the case where the WT feeds a relatively weak ac grid. The overcurrent's at the rotor windings and the dc over voltages are effectively eliminated and the DFIG can continuously supply the electrical system with reactive power during and after the fault, contributing to the support of the ac voltage.

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