

A New Control strategy to Enhance LVRT for Doubly Fed Induction Generator

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Abstract: - Nowadays renewable energy resources had become more important for dropping the green house gases. Since the renewables installed in utility grid gets increasing, stabilizing the power systems becomes a major issue. For renewables integration into the utility grid, the specific requirement should be placed by the grid operators. Among grid codes issues Low-voltage ride-through (LVRT) is a most important one. In wind power system, for certain period of time the power converters are demanded by grid codes to remain coupled with grid in the event of voltage drop. In this paper a new modified computational intelligence based control strategy is proposed to enhance the LVRT capability of grid connected doubly fed induction generators (DFIG). To support grid voltage during and after the fault, wind turbine (WT) should supply reactive power to the grid which is the world-wide requirement of grid codes. To protect the rotor side converter from grid faults a conventional crowbar-based systems were used, but this method fail to fulfill the requirement since DFIG acts as squirrel cage machine during the connection of crowbar and it absorbs reactive power from the grid. This makes to design a control system without using crowbar. In order to overcome the drawbacks mentioned above, this paper proposed the new coordinated control strategy of DFIG converters which can manage to ride-through the fault without any secondary hardware. This is achieved by using fuzzy logic controller which is tuned properly by genetic algorithms. The result will prove that our proposed method is much effective.

Key-Words:- Fuzzy logic control, low voltage ride through (LVRT), Doubly fed induction generator (DFIG), RSC and GSC, power systems faults.

1 Introduction

For past few years, doubly fed induction generators have played a significant role in the world market share of wind turbine, for conventional variable speed generators it is an alternative model. The DFIG has wound rotor induction generator, with its rotor windings via collection of two ac/dc converters back to back, it is connected to grid, where its stator winding is directly connected to grid [1][2]. These converters are sorted for only one third of the turbine rated power, this topology achieves an decoupled control of reactive and active power, and proven to be cost effective[3][4]. During grid fault the DFIGs produce a major drawback. Due to grid fault there is a voltage drop at stator windings, it results in an abrupt change of the DFIG stator flux, and due to magnetic coupling it leads an over current to the rotor winding. Then to the large fluctuations of dc-link voltages and to the semiconductors of rotor side converters, this overcurrent may cause an severe damages [5][6]. After being used DFIGs in wind turbine, the WTs penetration to power system was fairly low, and no special steps were taken to present the DFIGs with the ability of contributing to network support. With

crowbar circuit its rotor windings were protected, in order to protect the generator [7][8][9]. To the crowbar resistors the rotor windings are connected, the rotor-side converter will be disabled temporarily when fault occurs, which makes SC current to flows through the crowbar section. This concept effectively protects the machine, but due to the rotor-side converter blocking, power control loss occurs which generate large transient after the fault and leads the machine to disconnect from the grid. And during crowbar action, reactive power absorbed from the grid in large amount, which makes DFIG to acts as a conventional squirrel-cage induction generator[10][11].

Nowadays, in electrical systems the WTs characterize a significant part of the total generation; this makes the grid codes (GCs) to be revised worldwide. The WTs should afford LVRT capability for grid faults resulting in voltage drop of 85% or even more, which is a major requirement of GCs. To contribute to the stability of system, they should stay connected to the grid. Moreover, to support voltage recovery they should supply reactive power [12]-[15]. The DFIGs protected with a crowbar circuit cannot accomplish this

requirement, since during the activation of crowbar they can't generate reactive power. For this reason, the FRT issue of the DFIG turned the attentions of many researchers from different point of view. In [16] new method is proposed with improved crowbar circuit, which eliminate the period of crowbar action. The STATCOM application is investigated to attain the continuous operation of wind turbine during grid faults [17]. The series grid side converter with new control strategy is proposed in [18]. Although these methods have advantages in some cases, the additional cost and the complexity impair their applicability.

From the knowledge gained from the above studies, this paper extends the concept of DFIG protection without any additional hardware. In more challenging situation such as connection of weak electrical system with the DFIGs, which results in large voltage dip, as it required from grid codes. The proposed control method tends to satisfy the system disturbance caused by faults and ensures the stability of the system. The controllers were arranged based on fuzzy logic and genetic algorithms, which is more efficient to overcome the

difficulties of the uncertain system modelling and the system nonlinearity .By using this method, over-voltages on the dc side and overcurrent at the rotor winding is effectively eliminated. This paper proposed the new coordinated control strategy of DFIG converters which can manage to ride-through the fault without any secondary hardware. This is achieved by using fuzzy logic controller which is tuned properly by genetic algorithms. The result will prove that our proposed method is much effective.

2 Modeling and Controlling of DFIG WT System

The grid connected DFIG wind turbine schematic is shown in Fig. 1. The system includes the wind turbine, the back to back PWM converters, the induction generator, the shaft system and the control system. To protect the converters and capacitors from over voltages, a dc-chopper is installed inside the DC-link. The stator of the grid side converter and the induction generator are connected directly to the grid synchronously.

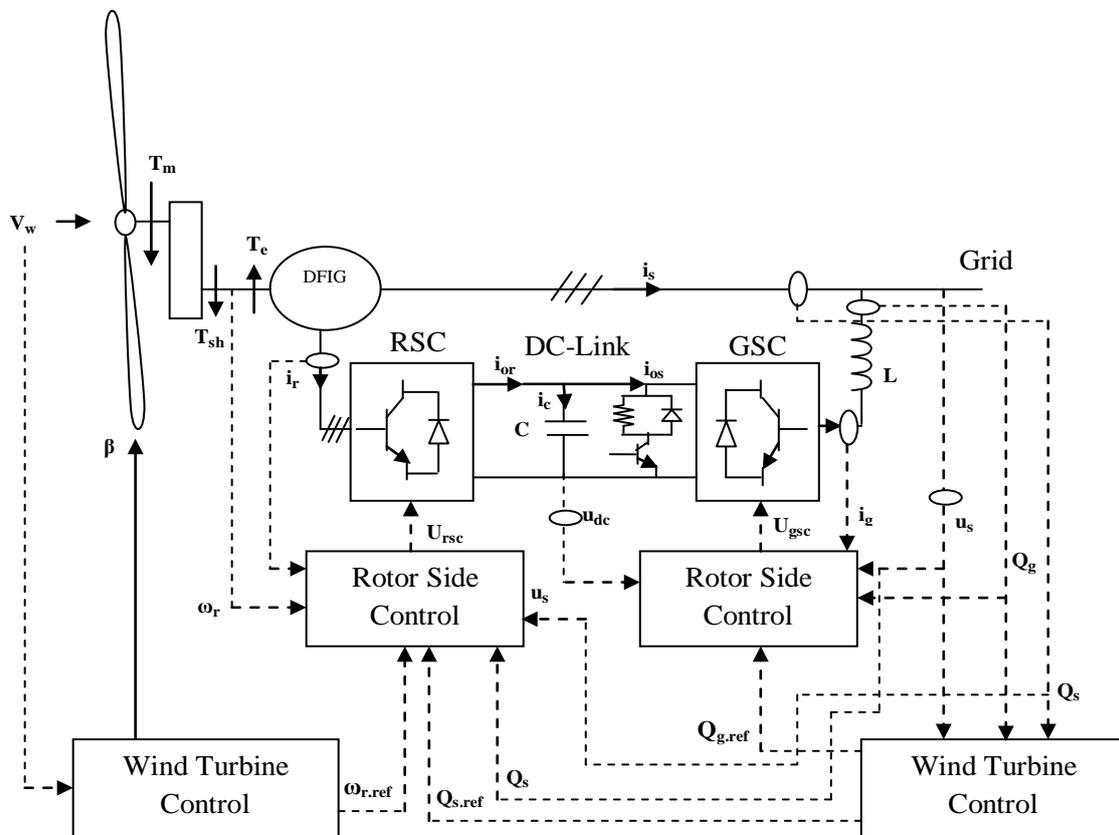


Fig. 1. Modelling and controlling of DFIG WT system

For DFIG and WT the control system consist of two sussystems respectively. Based on the most

optimum power-speed characteristic curve, the rotor's reference is generated by WT, in order to get

maximum wind power which is called as a maximum power point tracking (MPPT) control. Until stopping at the cut-off wind speed, the WT will work at the rated speed which is ensured by pitch control during high winds. The DFIG

controller operates grid side and rotor side converter based on vector control techniques to regulate reactive and active power output of DFIG independently, according to the grid code power factor requirement and the rotor's reference speed.

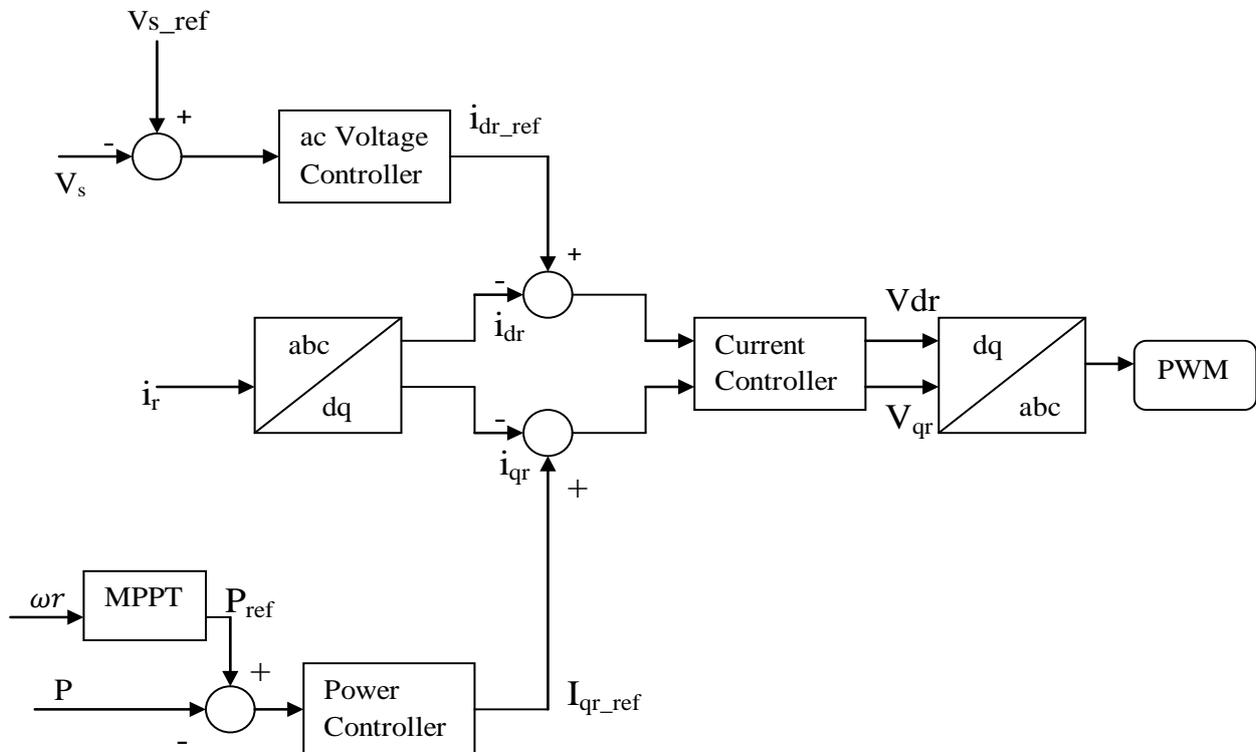


Fig. 2. Control System of RSC

3 Description of the Conventional Control System

The conventional control systems of DFIG were presented in various papers, which is divided into GSC and RSC control [19]-[21]. The RSC control system is shown in Fig.2. Its main objective is to independently control the stator reactive and active power, Q_s and P_s respectively. To attain decoupled control of Q_s and P_s , the rotor current i_r is transformed to i_{qr} and i_{dr} of d – q components, using frame reference oriented to stator flux. The i_{qr} is a q-axis current component used to regulate the active power of stator p_s . Using a technique maximum power point tracking (MPPT), the active power P_{ref} reference value is obtained [22][23]. From P_{ref} the measured value P_s is subtracted and to the power controller the error is driven.

To keep the stator voltage v_s inside required range, the RSC reactive power control can be tuned, when weak power system is provided by DFIG without local reactive compensation. The Q_s command can set to zero when strong power system

is supplied by DFIG. In this paper, the weak ac grid which fed from DFIG is analysed. Therefore, instead of reactive power control ac voltage control is used. At the generator terminals the reference value v_{s_ref} is compared with the actual voltage v_s and through the ac voltage controller the error is passed to create reference signal for d-axis current i_{dr_ref} . And to the d-axis current value i_{dr} , this signal is compared and to the current controller the error is sent, which determines the d- axis component v_{dr} of reference voltage. To drive the RSC, the IGBT gate control signals are generated which are used by PWM module to transform the signals v_{qr} and v_{dr} back to abc quantities. Keeping dc-link voltage constant is the main objective of GSC control system. The GSC control system is shown in Fig 3. The frame reference oriented to stator voltage is used for the transformation of signals to d-q quantities. Through the signal i_{dgc_ref} the dc voltage V_{dc} is controlled and through the signal i_{qgc_ref} the reactive power Q_{gc} is controlled.

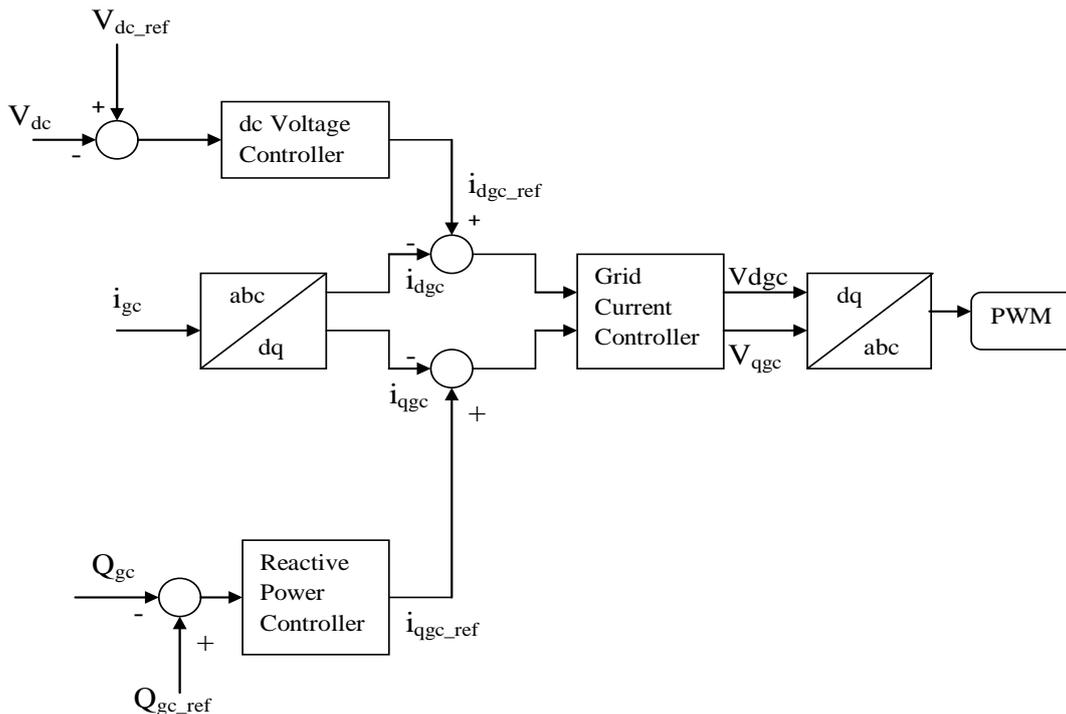


Fig. 3. Control System of GSC

4 Description of Optimized Proposed Control System

In the existing control systems no steps were taken to reduce FRT of the DFIG. In this paper the modified control system is proposed without any additional hardware to ride through the fault. By achieving a best coordination between the two converters, even in the case when WT feed weak AC grid, the proposed control scheme manages to satisfy the disturbances of system caused by the fault. In order to act efficiently in short amount of time, the control system should be insensitive to the lack of information and to the measured noise concerning machine parameters. Considering the system nonlinearity and to overcome these difficulties, the efficient computational intelligence (CI) was used to design the controllers. The FCs was used for all controllers, while tuning FC it achieves FRT, FCFRT which is realized using GAs. FCFRT is tuned using GA-based approach; the reason behind that is it can't come from simple fuzzy equations and it is quite complicated..

The modified control system with fault detection and confrontation system is shown in Fig 4. Only when ac voltage v_s , deviates from its reference value by more than 10% the block gets activated. The GSC control remains unchanged. The control strategy is analysed in order to protect the DFIG successfully. The dc-link overvoltage and rotor

current are the two major issues that should be properly addressed, during restoring points these two issues should not exceed their limits. In order to bring the dc voltage and rotor current values back to normal, the extra amount of energy induced to the rotor must be pumped properly through the grid converter during the transient. And also to achieve the successful FRT, the rotor current correction signal is also considered. The current controller output v_{qr} is corrected by a u_{crf} quantity derived by FC, FC_{FRT} . The FC_{FRT} , i_r^* and V_{dc}^* inputs are given by

$$V_{dc}^* = \frac{V_{dc} - V_{dc_ss}}{V_{dc_mv} - V_{dc_ss}} \tag{1}$$

$$i_r^* = \frac{i_r - i_{r_ss}}{i_{r_mv} - i_{r_ss}} \tag{2}$$

In the above equations, ss, mv and i_r stands for steady state value, maximum acceptable value and rotor rms current. By their maximum adequate deviations, the deviations of two quantities are divided in order to contribute to the u_{crf} modulation equally, it is also mentioned that only positive deviations are considered. This makes the smoother transition to the control system of steady state from the FLDS. The FC_{FRT} rules is given in table 1 which is mentioned that to tune the membership function of FC_{FRT} , GA based approach is used. The fitness function which is to be minimized is mentioned below

$$Fitness = \left(\frac{V_{dc_max} - V_{dc_ss}}{V_{dc_mv} - V_{dc_ss}} \right)^2 + \left(\frac{i_{r_max} - V_{dc_ss}}{i_{r_mv} - i_{r_ss}} \right)^2 \tag{3}$$

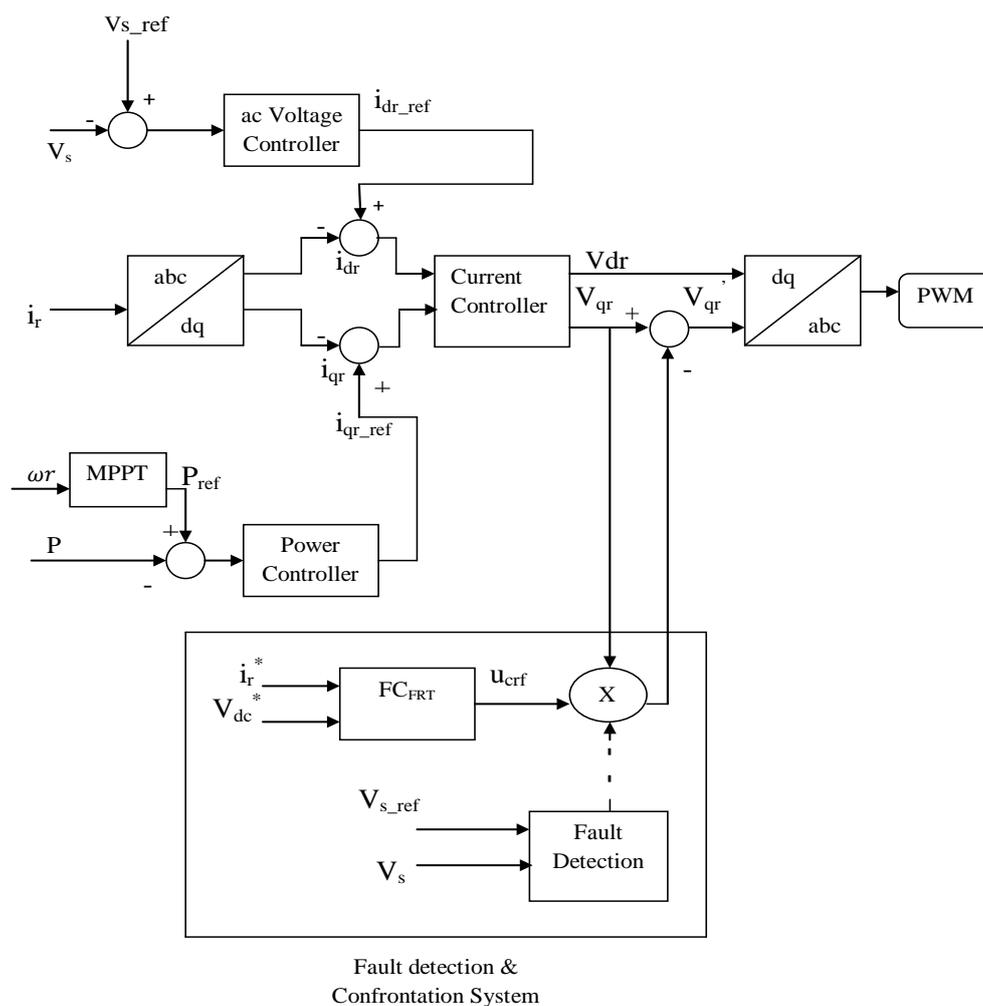


Fig. 4. Optimized Proposed Control System

The above fitness function is chosen for the FRT problem.

Reasons for chosen this fitness function

1. Generally, to solve the wide range of problems integral function is chosen as fitness problem. When using integral, the target in time interval is an overall behaviour of the system. In this case, in order to avoid the DFIG tripping, the instantaneous values i_r and V_{dc} to be limited in the target. Therefore, the function selected does not consist of any integral and the squared value sum to be minimized.
2. In order to maintain the quantities below the acceptable values, the target is not just minimizing the two quantities, it should maintain the specific balance between them.
3. In order to use the fitness function normalized quantities the maximum

deviation of i_r and V_{dc} are divided by maximum acceptable limits during the restoring points from their steady state values.

5 Result

The proposed control scheme effectiveness is validated by using DFIG which supplying comparatively weak electrical system. The result of the proposed control system is compared with the conventional method. The result is compared to show that the conventional system needs an auxiliary system to ride through the faults and also to prove that in the proposed control system, the DFIG improves its overall response during and after the fault period. Overall the proposed control system without any secondary hardware successfully rides through the fault.

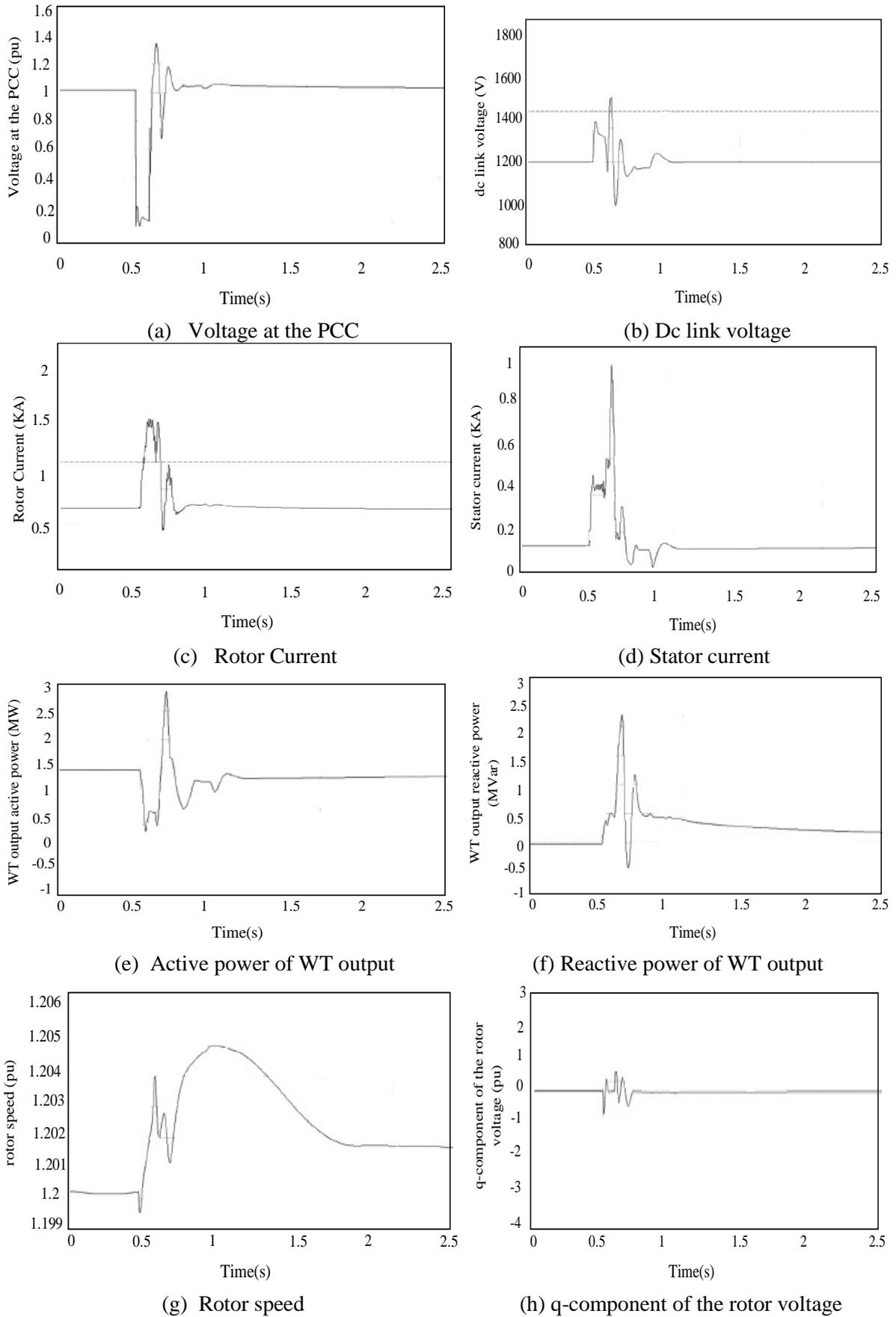
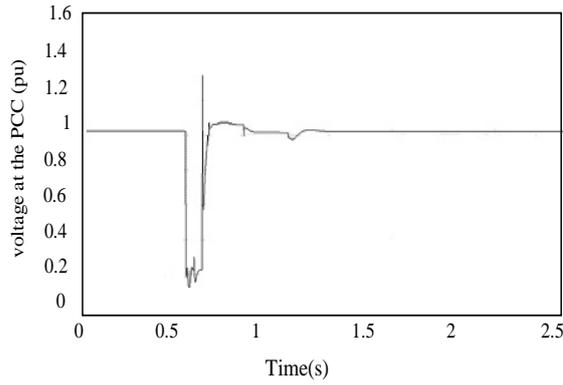
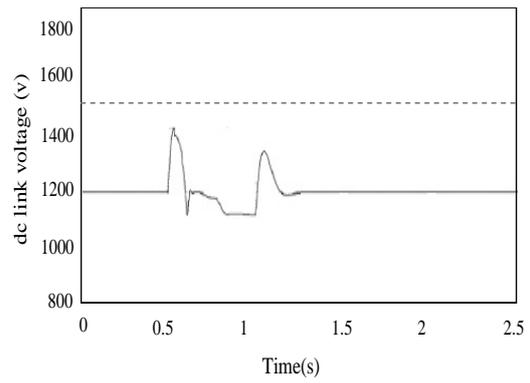


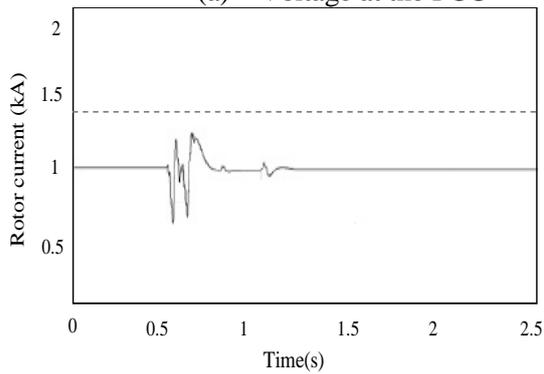
Fig. 5. System Response without confrontation system and fault detection -wind speed 12 m/s.



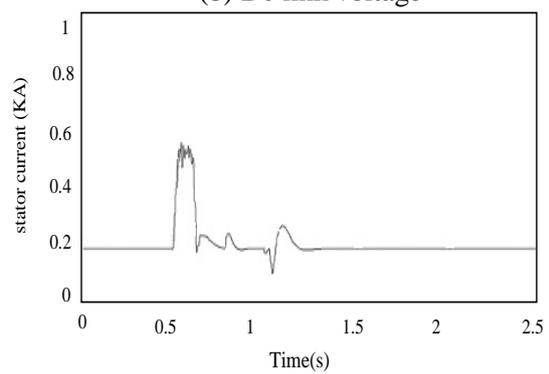
(a) Voltage at the PCC



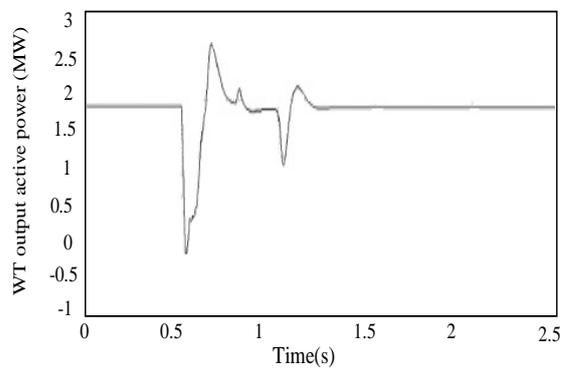
(b) Dc link voltage



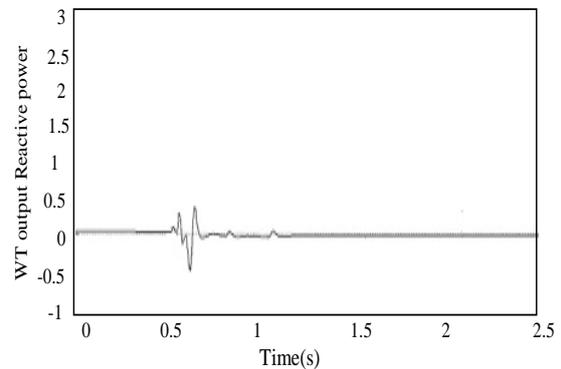
(c) Rotor current



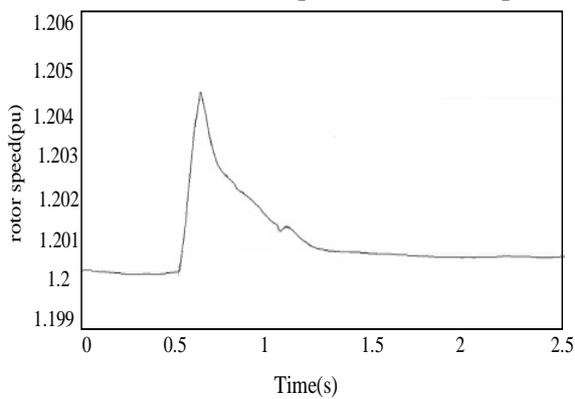
(d) Stator current



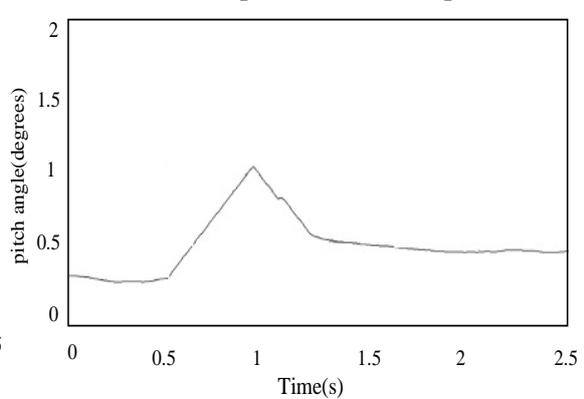
(e) Active power of WT output



(f) Reactive power of WT output



(g) Rotor speed



(h) Pitch Angle

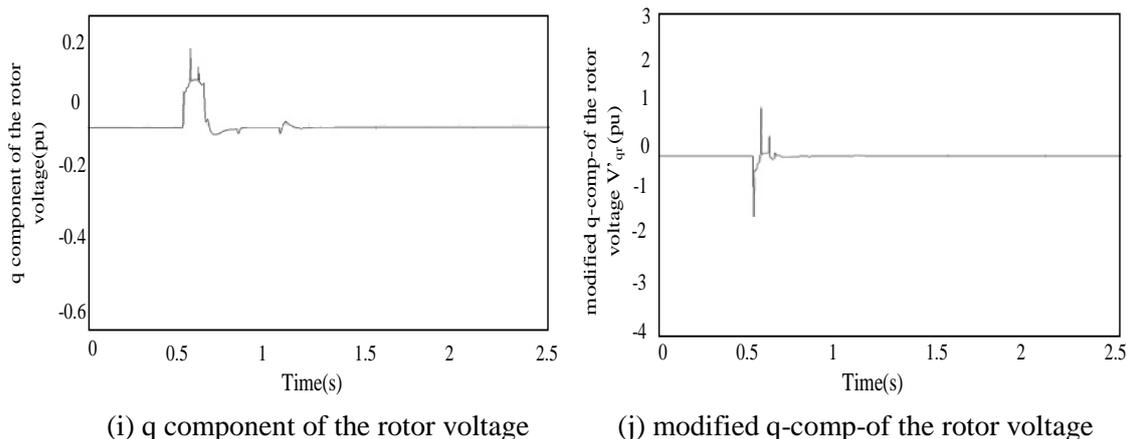


Fig. 6. System response with confrontation system and fault detection- wind speed 12 m/s.

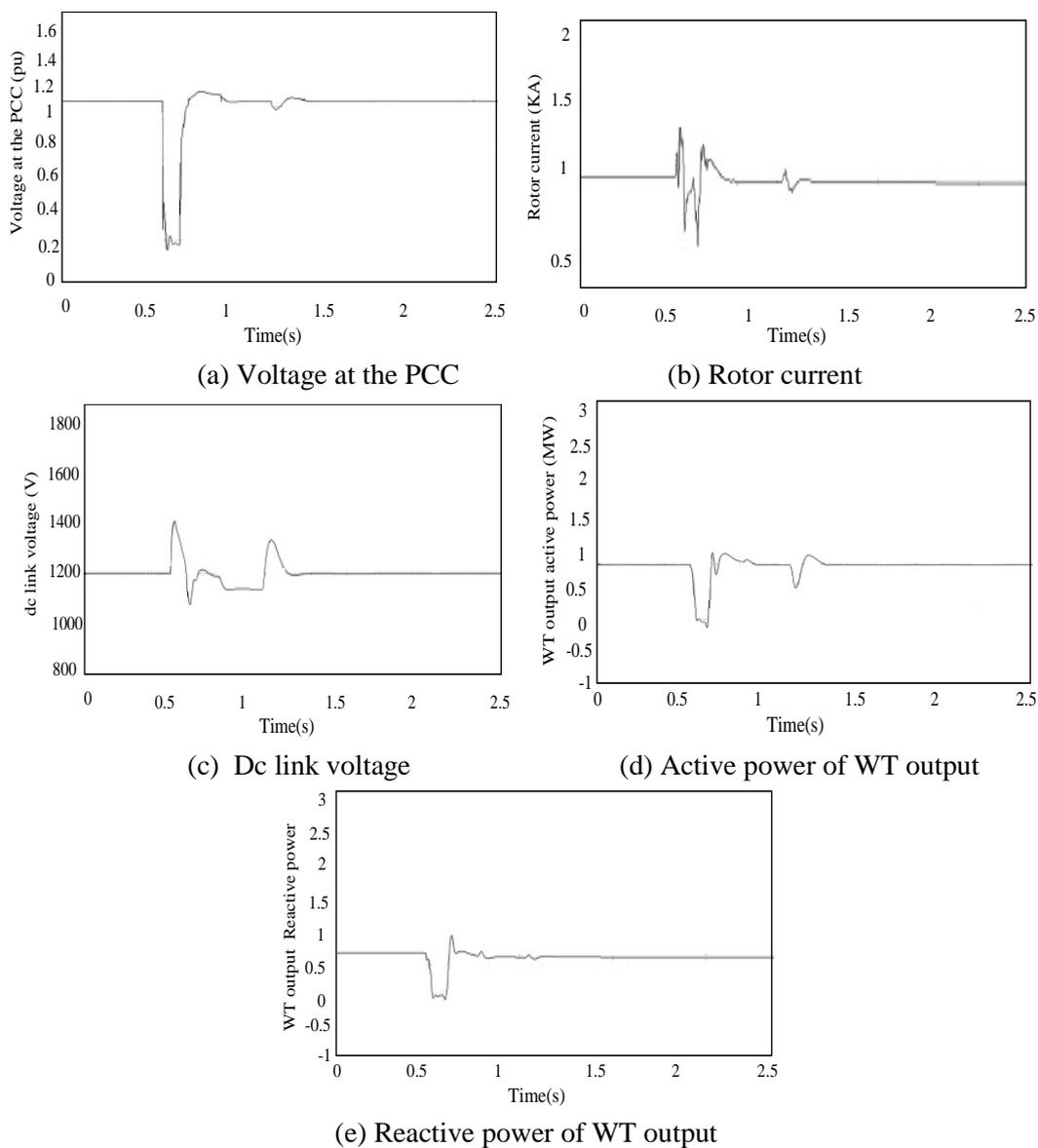


Fig. 7. System response with confrontation system and fault detection- wind speed 10 m/s..

The conventional control system response is shown in Fig. 5(a-h) and the proposed control system response is shown in Fig. 6(a-j). As shown in Fig. 5(a-h), in the conventional control systems there is a fluctuation in the dc voltage of 125%, which is above its adequate limit of its rated value. Moreover, the rotor current surpasses its maximum rating which is forced by IGBTs of RSC.

Overall the system response is quite fluctuating which creates great stress to the drive train. Consequently, a proper modification is needed for this system to ride through the faults and increase its performance during and after the faults.

As shown in Fig. 6(a-j), when using the proposed control schemes, the fluctuations are alleviated and the system reaches its steady state. Through the most favourable coordination of converters, the DFIGs FRT is achieved, as the over voltages at the dc-link and the rotor windings over-currents are effectively controlled below their maximum values. The dc capacitor stressing and the destruction are avoided when the fluctuations of dc-link are effectively attenuated

The reactive power of WT is shown in Fig. 6 (f) as mentioned, during the fault the rotor side converter of the proposed method is not disabled. As forced by several grid codes, for supporting voltage recovery it is possible to supply reactive power. The proposed control system quickly recovers, which reduces the amount of DFIG reactive power after fault. The pitch angle response and rotor speed is illustrated in Fig. 6(h) and Fig. 6(g).

The rotor voltage q-component v_{qr} is shown in Fig. 6(i) and Fig. 5(h) and by the proposed system the modified signal v'_{qr} is achieved as shown in Fig. 6(j). The described fitness function is optimized not just for the case as shown in Fig. 6., it is used also for variety of cases leading to voltage dip of 85%. Finally as shown in Fig. 7, the proposed method proves that it can effectively ride through the fault.

6. Conclusion

Without the need of any secondary hardware, this paper proposes a new coordinated control strategy to improve the low voltage ride through (LVRT) capabilities of grid connected DFIG WTs. Using genetic algorithm the optimal synchronization of the DFIG converter is designed through a fuzzy controller. The result shows that, even in case where weak ac grid is provided by WT, the DFIG can effectively ride through the fault. The overvoltages at the dc side and the rotor windings overcurrents

are successfully eliminated and with reactive power the DFIG can constantly supply electrical system during and after the fault, which contributes the ac voltage support.

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