Performance Improvement of Grid-Connected DFIG-Based Wind Turbine with a Fuzzy-Based LVRT Controller

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Abstract: This paper provides a complete justification of fuzzy-based low-voltage ride-through (LVRT) of grid-connected doubly fed induction generator (DFIG)-based wind turbines,providing a comprehensive study of the transient characteristics and also the dynamic behavior of DFIGs during asymmetrical and symmetrical grid voltage sags. A new control scheme is proposed for the rotor-side wind turbine to enhance its LVRT capacity during critical voltage sags; finally, the results are compared with and without fuzzy controllers. DFIG-based wind turbines showed improved performance using the proposed fuzzy-based controllers.

Keywords: DFIG – doubly fed induction generator; LVRT – low-voltage ride through.

1. Introduction

In modern years, there has been a large expansion in the global market for power as a consequence of not only technical advancement but also community. Consequently, the rise in expenditure of conventional fossil fuels has led to several dangerous effects such as power deficiencies, pollution, global warming, shortfall of conventional fossil power sources, and energy uncertainty. These circumstances necessitate the development of renewable energy technologies, which are a prerequisite of a well-balanced power scenario. Wind energy is considered to be the most likely near-term alternative source of energy. As renewable power leads to market development and growth, wind power is currently one of the fastest-growing renewable sources of electrical energy. More than 54 GW of wind power was established in 2016 [1].

With the increasing size of a wind energy mill, it is expected to stay operational detach from the grid, and maintaining the grid with reactive power as voltage sags. Such conditions are known as fault ride-through (FRT) or low-voltage ride-through (LVRT) capability [2].

In paper [3] discussed the distinct requirements and the real-time situation, which is very important for entrepreneurs and academicians studying the problems of renewable power integration to find solutions. Although there are many advantages to using retrofitting-based resolutions for LVRT capacity in wind turbines like an active crowbar, fault current limiter, changing voltage restorer, static compensator, etc., they have become infeasible for lighting owing to industrial and policy restrictions. This study discusses the difficulties as well as potentials in learning the likely systems appropriate for the Indian scenario.Difficulties in implementing the LVRT capacity, which is based on the conditions specific to various turbine types, the extra costs, the trouble faced by companies, and the policy issues and real-time challenges in implementing additional conditions and ways to overcome this drawback [3].

The above situation has motivated sustainable energy experts, especially toward wind energy. It is considered as the most encouraging renewable energy source in terms of development. Along with the development of wind-power capacity, wind power plants now need increased active shareholders to manage the operability and power quality of grids. Consequently, wind power plants are expected to run similar to traditional power plants. Power usage builders need to meet specialized standards, known as grid regulations, which wind turbines must meet, related to grids. The grid code technical specifications can be divided into static conditions, which discuss the steady-state behavior and power flow at the connection point to the transportation grid, and the dynamic conditions, which involve the wind turbine generator production required during faults and trouble periods. Usually, these circumstances involve various factors such as voltage-producing rate, power factor control, frequency acting range, the grid maintenance capacity, and low FRT conditions. The LVRT capacity is considered the biggest challenge when planning and designing wind turbines. LVRT requires wind turbines to remain connected to the grid even during grid voltage sags [4].

2. SIMULINK MODEL AND FUZZY LOGIC-BASED LVRT CONTROLLERS

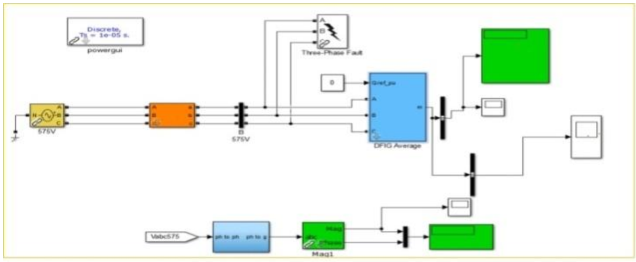


Fig. 1. SIMULINK model of a simplified DFIG crowbar

Fig 1.shows the simplified DFIG crowbarSIMULINK model and the basic configuration of FLC is shown in Figure 2; it consists of four main steps: (i) fuzzification, (ii) knowledge base, (iii) inference engine, and (iv) defuzzification.

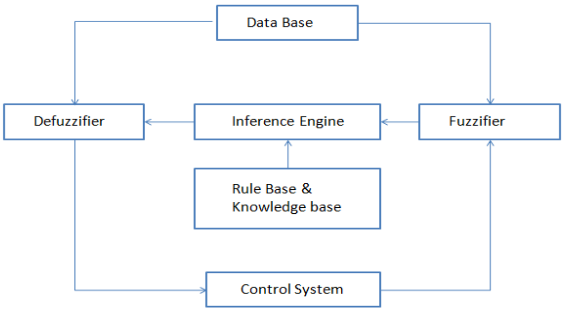


Fig 2basic configuration of FLC

For simplicity, it is assumed that MFs are symmetrical and each one overlaps the adjacent functions by 50%, i.e., it is a triangle-shaped function, with the other types of functions used being trapezoidal-shaped and bell-shaped. Figure 3 shows the seven linguistic variables and the triangular MF with 50% overlap and the universe of discourse from –a to a.

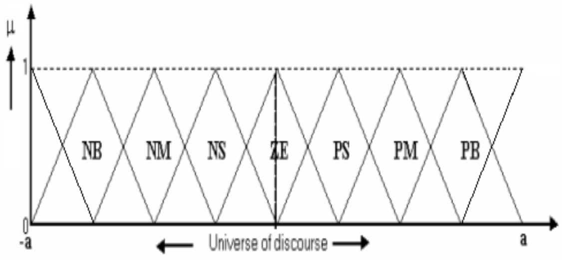
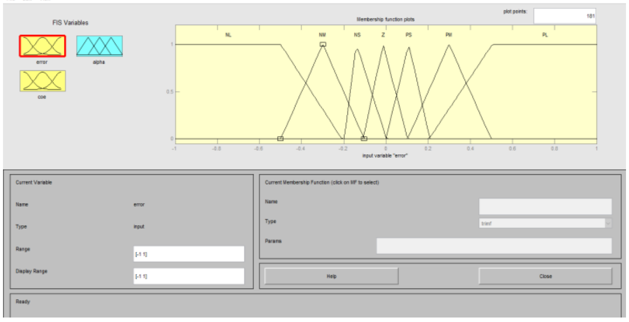


Fig. 3. Triangular MFs

To validate the proposed low-voltage ride-through control approach, we used MATLAB/Simulink-based simulations.



Current Variable

Name error

Type input

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

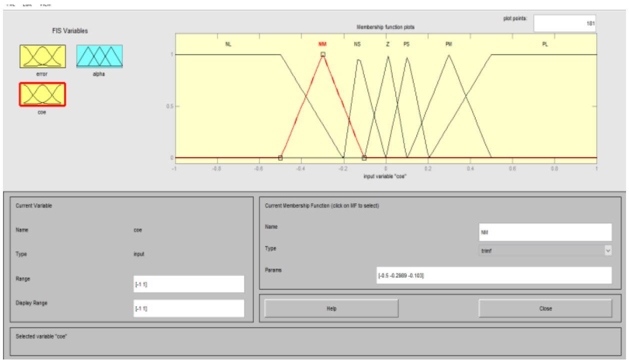
Name

Type trimf

Params

Ready

Fig. 4. Fuzzy logic-based LVRT controller error MFs



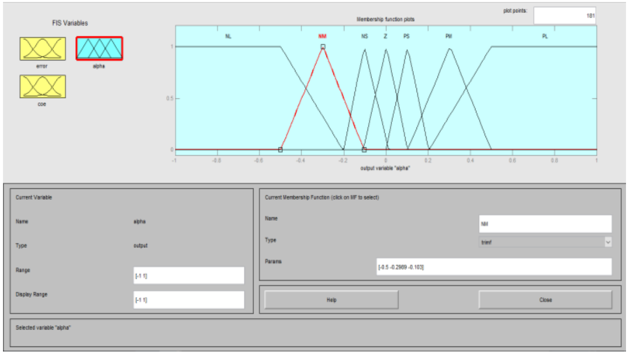
plot points: 181

Name coe
Type input
Range [-1 1]
Display Range [-1 1]

Name NM
Type trimf
Params [-0.5 -0.2989 -0.103]

Selected variable "coe"

Fig. 5. Fuzzy logic-based LVRT controller change in error MFs



plot points: 181

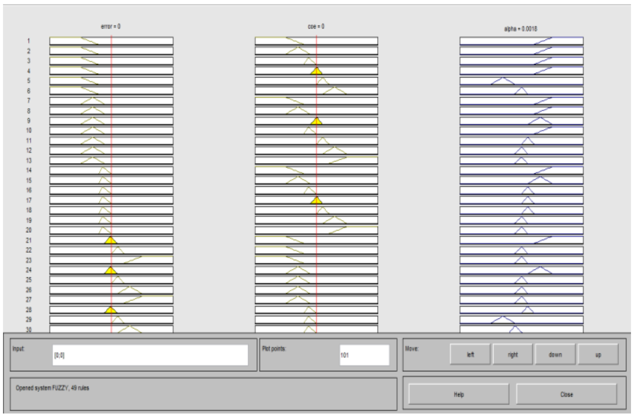
Name alpha
Type output
Range [-1 1]
Display Range [-1 1]

Name NM
Type trimf
Params [-0.5 -0.2989 -0.103]

Selected variable "alpha"

Fig. 6. Fuzzy logic-based LVRT controller output MFs

Figs. 4 and 5 show the fuzzy logic-based LVRT controller error and change in error MFs, respectively. Fig. 6 shows the fuzzy logic-based LVRT controller output MFs. Figs. 7 and 8 show the fuzzy logic-based LVRT controller rule viewer and the rule viewer, respectively.

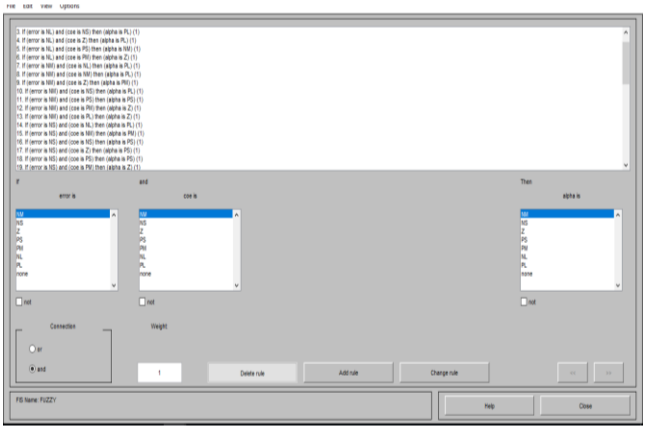


Input: [0;0]

Plot points: 101

Opened system FUZZY, 49 rules

Fig. 7. Fuzzy logic-based LVRT controller rule viewer



3. If (error is NL) and (coe is NS) then (alpha is PL) (1)
4. If (error is NL) and (coe is Z) then (alpha is PL) (1)
5. If (error is NL) and (coe is PS) then (alpha is NM) (1)
6. If (error is NL) and (coe is PM) then (alpha is Z) (1)
7. If (error is NM) and (coe is NL) then (alpha is PL) (1)
8. If (error is NM) and (coe is NM) then (alpha is PL) (1)
9. If (error is NM) and (coe is Z) then (alpha is PM) (1)
10. If (error is NM) and (coe is NS) then (alpha is PL) (1)
11. If (error is NM) and (coe is PS) then (alpha is PS) (1)
12. If (error is NM) and (coe is PM) then (alpha is Z) (1)
13. If (error is NM) and (coe is PL) then (alpha is Z) (1)
14. If (error is NS) and (coe is NL) then (alpha is PL) (1)
15. If (error is NS) and (coe is NM) then (alpha is PM) (1)
16. If (error is NS) and (coe is NS) then (alpha is PS) (1)
17. If (error is NS) and (coe is Z) then (alpha is PS) (1)
18. If (error is NS) and (coe is PS) then (alpha is PS) (1)
19. If (error is NS) and (coe is PM) then (alpha is Z) (1)

○ or
● and

Weight: 1

FIS Name: FUZZY

Fig. 8. Fuzzy logic-based LVRT controller rule viewer

3. SIMULATION RESULTS

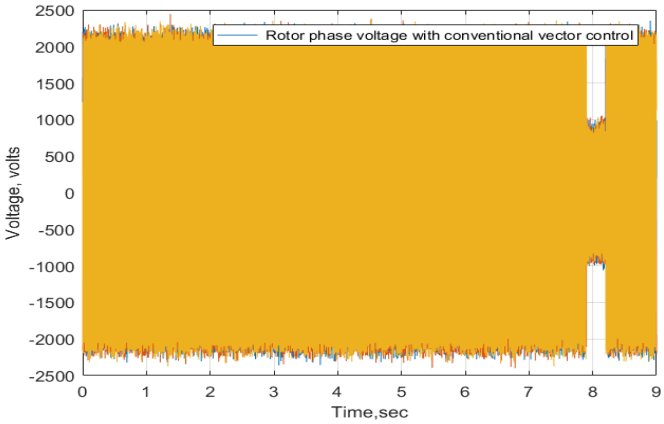


Fig. 9.Rotor phase voltage with a conventional vector control

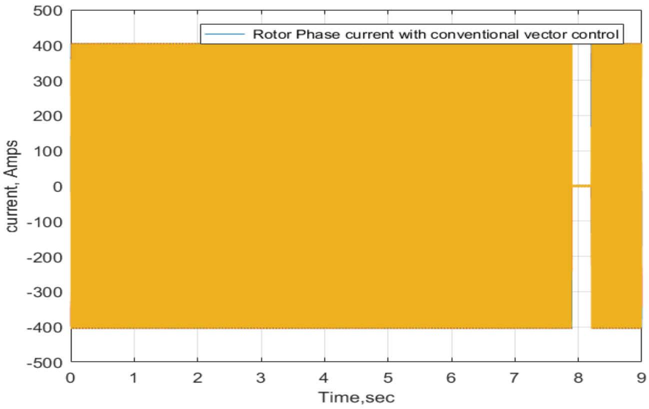


Fig. 10.Rotor current with a conventional vector control

Fig. 9 shows the rotor phase voltage (with respect to time) with the conventional vector control method over a fault period of 7.9–8.1 s, during which the voltage changes from 2200V to 1000V, i.e., a decrease of 1200V is achieved using this control method.

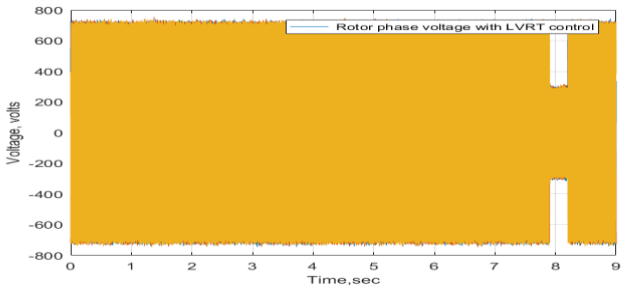


Fig. 11.Rotor phase voltage with respect to time by LVRT Control

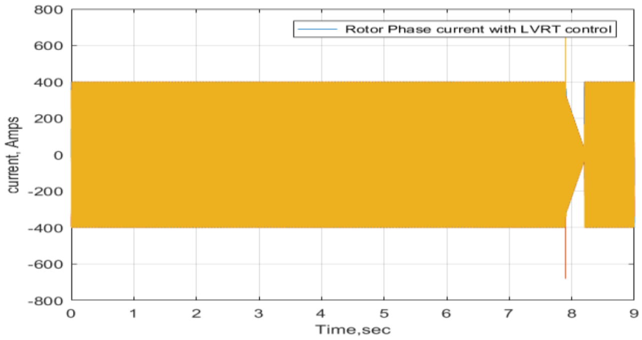


Fig. 12.Rotor phase current with respect to time by LVRTControl

Fig. 10 shows the rotor current with the conventional vector control method over a fault period of 7.9–8.1 s, during which the current changes from 400A to 20A, i.e., a huge current decrease is attained with this controller.

Fig. 11 shows the rotor phase voltage with respect to time using the LVRT control method over a fault period of 7.9–8.1 s, during which the voltage changes from 740V to 380V, i.e., a decrease of 3340 V is achieved with this controller.

Fig. 12 shows the rotor phase current with respect to time by the LVRT control method during a fault period, during which the current changes from 400A to 100A, i.e., a decrease of 300A is achieved using this controller.

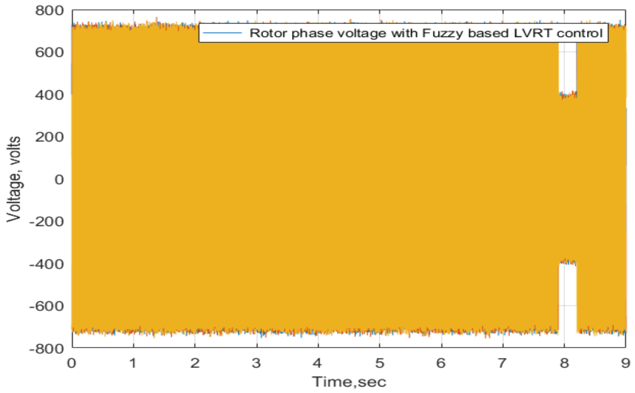


Fig. 13.Rotor phase voltage with the fuzzy-based LVRT Controller

Fig. 13 shows the rotor phase voltage with the fuzzy-based LVRT controller fault over a fault period of 7.9–8.1 s, during which the voltage changes from 700V to 420V, i.e., using this controller, the maximum voltage change is 280V, which is far better than when using the vector control method and the LVRT control method.

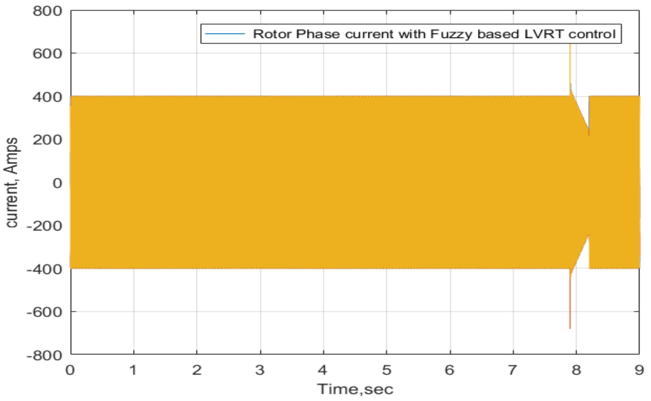


Fig. 14. Rotor phase current with respect to time using the fuzzy logic-based LVRT

Fig. 14 shows the rotor phase current with respect to time using the fuzzy logic-based LVRT controller over a fault period of 7.9–8.1 s, during which the current changes from 400A to 250A, i.e., using this controller , the current drops by 150A, which is a far better value than achieved using conventional and LVRT controllers.

Fig. 15 shows the stator voltage with a conventional controller with respect to time over a fault period of 0.5–0.7 s, during which the voltage changes from 2200V to 900V, i.e., a decrease of 1300V is achieved.

Fig. 16 shows the stator voltage with the LVRT controller with respect to time over a fault period of 0.5–0.7 s, during which the voltage changes from 550V to 220V, i.e., a decrease of 380V is achieved using this controller, which is better than what is achieved using a conventional controller.

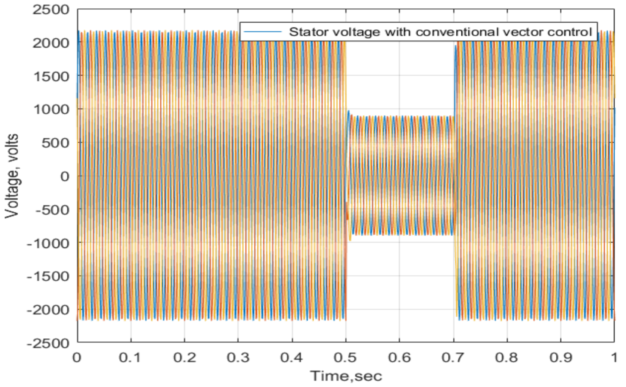


Fig. 15. DFIG stator voltage during fault with the conventional vector control strategy.

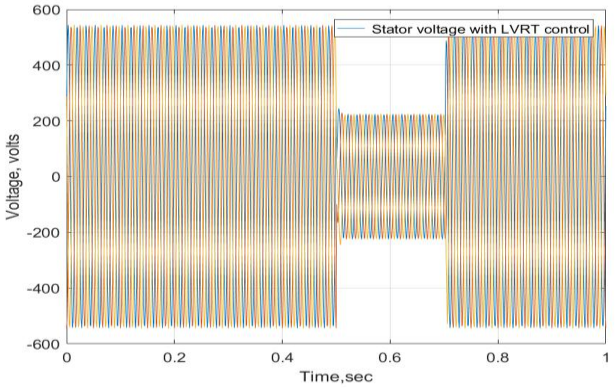


Fig. 16.DFIG stator voltage during fault with the LVRT control strategy.

4.CONCLUSIONS

This paper presents a detailed investigation of the LVRT of grid-connected DFIGs, along with the dynamic behavior of DFIG-based wind turbines during different types of grid voltage sags. It is seen that LVRT plays a significant role in maintaining the voltage stability of the grid-connected wind power system. The control fuzzy strategy tries to mitigate the rotor-side voltage and current shock during abnormal grid conditions. The results of this study clearly show that the proposed method is effective compared with the LVRT and the conventional method.

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