Fuzzy control strategy for Harmonics compensation in Stand-Alone Doubly-Fed Induction Generators with Nonlinear Loads

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Abstract: This paper presents a stand-alone doubly-fed induction generator (DFIG) supplying a balanced three-phase diode rectifier. These harmonics are rejected by using the rotor current controller in the fundamental synchronous reference frame. The proposed control algorithm is based on a fuzzy logic controller and a bank of resonant filters. In this frame, each resonant filter in the rotor current controller has the possibility of rejecting one pair of the positive and the negative stator harmonic voltages at the PCC. The proposed method describes a stand-alone doubly-fed induction generator (DFIG) supplying a balanced three-phase diode rectifier. These harmonics are rejected by using the rotor current controller in the fundamental synchronous reference frame. The proposed control algorithm is based on a fuzzy controller and a bank of resonant filters.

1. INTRODUCTION

Wind power generation based on the doubly-fed induction generator (DFIG) has gained increasing popularity due to several advantages, including smaller converters rating around 30% of the generator rating, variable speed and four quadrants active and reactive power operation capabilities, lower converter cost, and power losses compared with the fixed-speed induction generators or synchronous generators with full-sized converters [1], [2]. Several novel control strategies have been investigated in order to improve the DFIG operation performance,

i.e., the vector oriented control (VOC) [3], direct power control [4], and predictive current control [5]. Up to now, the steady and transient response of DFIG-based wind power generation system under balanced [6] and unbalanced [7]–[11] grid voltage conditions have been discussed widely. There are mainly two control methods adopted, VOC, and direct power control (DPC). The authors in [7]–[9] introduced the unbalanced control strategy with the VOC technique, in which the detrimental influence on the DFIG system caused by negative component of the grid voltage was also analyzed. Several alternative control targets focusing on the elimination of negative component of stator/rotor current, as well as stator active/reactive power and electromagnetic torque pulsation were proposed. Zhou et al. [10], [11] explicitly illustrated the unbalanced control strategy using the DPC technique with different stator power compensation item, in which the five different control targets were proposed to improve the DFIG operation ability under transient unbalanced grid voltage. However, there are always voltage harmonic distorted components in the transmission system of the power grid. It has been pointed out that the highly distorted stator/rotor current, significant electromagnetic torque and power oscillations would occur if grid voltage harmonics are not taken into account by DFIG's control strategy [12]. The authors in [13]–[16] have presented a theoretical analysis and an improved VOC strategy for DFIG, in which alternative control targets were proposed to keep the three-phase sinusoidal stator/rotor current, or remove pulsations in both stator active and reactive powers, or remove pulsations in the electromagnetic torque and stator reactive power. Furthermore, in addition to the conventional rotor current control loop, a distinctive and independent stator current resonant control loop was also given out in [17] to successfully eliminate the stator current harmonic components. Nevertheless, all the aforementioned investigation on the DFIG system under the harmonic voltage is based on the VOC technique, which requires the decomposition of grid voltage fundamental and harmonic components; thus, the closed-loop operation stability and dynamic response of the entire control system will be deteriorated [10], [11]. The DPC technique has been proved to be preponderant for DFIG control, such as simple implementation, fast dynamic response, robustness against parameter variations, and grid disturbance [18], [19]. In order to overcome the traditional DPC drawback of variable switching frequency, the DPC integrated with space vector modulation (DPC-SVM) has been adopted to decrease the broadband harmonics injecting into the grid and simplify the filter design [20].

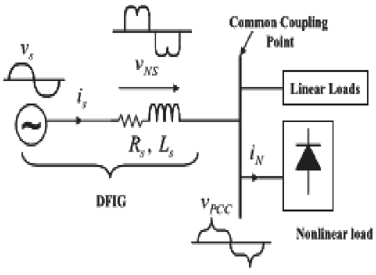


Fig 1.Connection interface between the DFIG and loads.

II DOUBLY FED INDUCTION GENERATOR

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator.

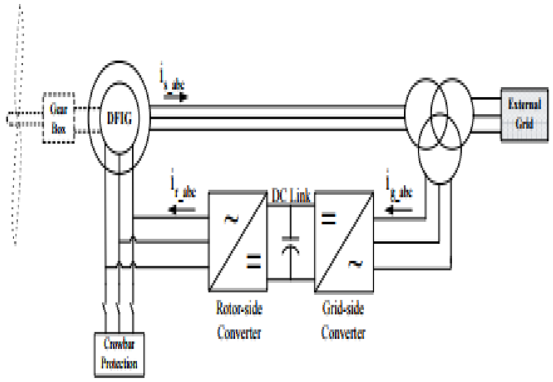


Fig 2Typical DFIG-based wind turbine system

2.1. Operating Principle of DFIG:

The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator for further generation. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltageThe slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine.The mechanical power and the stator electric power output are computed as follows $Pr=Tm*\omega r$ (1) $Ps=Tem*\omega s$ (2) For a loss less generator the mechanical equation is $J\ (d\omega r/dt)=Tm-Tem$ (3) In steady-state at fixed speed for a loss less generator $Tm=Tem$ and $Pm=Ps+Pr$ (4) And it follows that: $Pr=Pm-Ps=Tm\ \omega r-Tem*\omega s=-S\ Ps$ Where $S=(\omega s-\omega r)/\omega s$ is defines as the slip of the generator.

2.2. Back-to-Back AC/DC/AC Converter Modeling: Mathematical modeling of converter system is realized by using various types of models, which can be broadly divided into two groups: mathematical functional models and Mathematical physical models (either equation-oriented or graphic-oriented, where graphic-oriented approach is actually based on the same differential equations)

III.PROPOSED CONTROL SCHEME

Each resonant filter tuned at 6nωs resonant frequency in rotor current controller is capable of rejecting one pair of the positive and negative 6n ± 1 stator harmonic voltages. The proposed rotor current controller is described in Fig. 2 where Rr ,Lr ,σ,ωc ,E1 rdq ,v1∗ rdq are rotor resistance, rotor inductance, total leakage factor, cutoff frequency, disturbance of rotor back-electromagnetic force, and reference rotor voltage vector in the fundamental reference frame, calculated by

$$v_{rdq}^{1*} = \left(K_p + \frac{K_i}{s} + \sum_{n=1}^{\infty} \frac{K_r \omega_c s}{s^2 + 2\omega_c s + (6n\omega_s)^2}\right) \times \left(i_{rdq}^{1*} - i_{rdq}^{1}\right) + E_{rdq}^{1}.$$

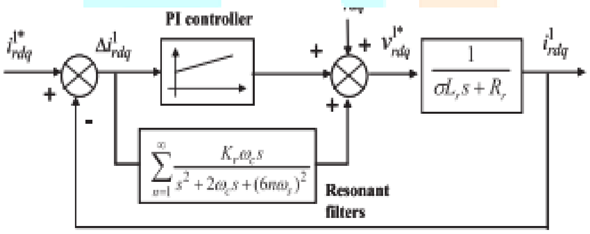


Fig 3 Proposed closed loop PI-R controller

By adopting the PI-R controller in the fundamental reference frame, it is possible to regulate both of current components in which the dc quantity is controlled by the PI controller whereas the ac harmonic quantities are controlled by an array of resonant filters. The controller gains are designed using Naslin polynomial technique. Once these rotor currents are precisely regulated, a proper stator output voltage of the DFIG (vs) is induced. This voltage will cancel the voltage drop due to nonlinear loads in order to produce a pure sinusoidal stator voltage at the PCC (vPCC).To improve response of pcc voltage further implemented with fuzzy controller with is we are reducing total harmonic distortion.

IV.FUZZY LOGIC

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection. To understand why use of fuzzy logic has grown, you must first understand what is meant by fuzzy logic.

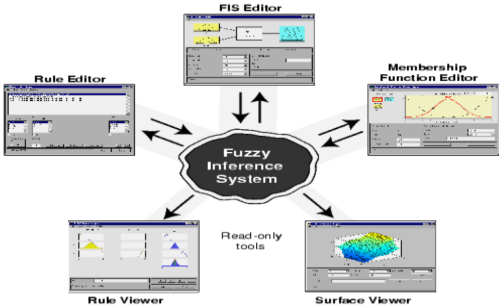
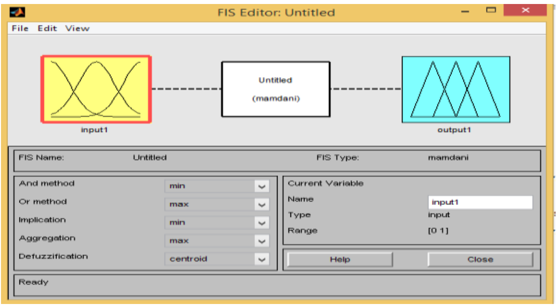


Fig.4 The Primary GUI Tools Of The Fuzzy Logic Toolbox

The FIS Editor handles the high level issues for the system How much input and output variables? What are their names? The Fuzzy Logic Toolbox doesn't limit the number of inputs. However, the number of inputs may be limited by the available memory of our machine. If the number of inputs is too large, or the number of membership functions is too big, then it may also be difficult to analyse the FIS using the other GUI tools. The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. The Rule Editor is for editing the list of rules that defines the behaviour of the system.

4.1The FIS Editor

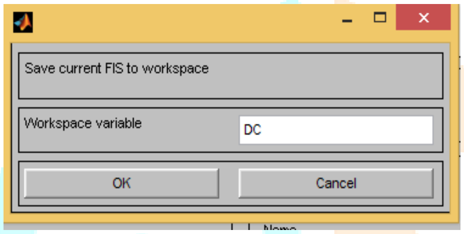
The following discussion walks we through building a new fuzzy inference system from scratch. If we want to save time and follow along quickly, we can load the already built system by typing fuzzy tipper This will load the FIS associated with the file tipper. Is (the .fis is implied) and launch the FIS Editor. However, if we load the pre-built system, we will not be building rules and constructing membership functions.



FIS Name: Untitled
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: input1
Type: input
Range: [0 1]
Ready

Fig.5 The FIS Editor

We will see the diagram updated to reflect the new names of the input and output variables. There is now a new variable in the workspace called tipper that contains all the information about this system.



Save current FIS to workspace
Workspace variable: DC

Fig.6 'Save to workspace as...' window

By saving to the workspace with a new name, we also rename the entire system. Our window will look like as shown in Fig.8.

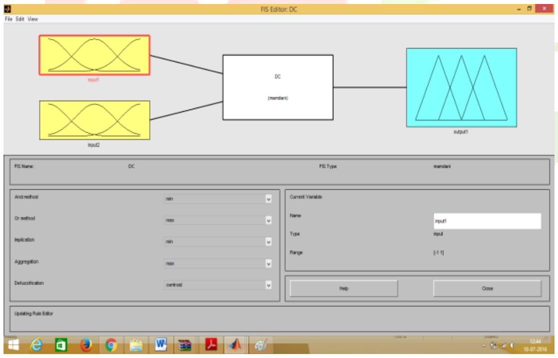


Fig.7 The Updated FIS Editor

4.2 The Membership Function Editor

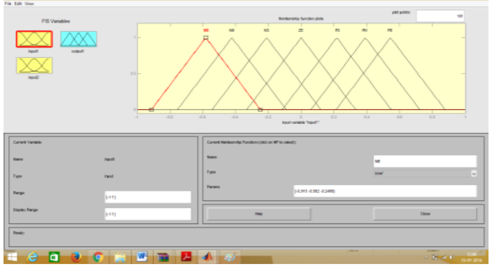
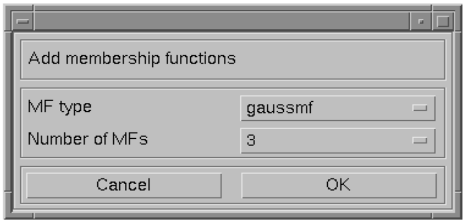


Fig. 8 The Membership Function Editor



Add membership functions
MF type: gaussmf
Number of MFs: 3

Fig.9 Add MFs… Window

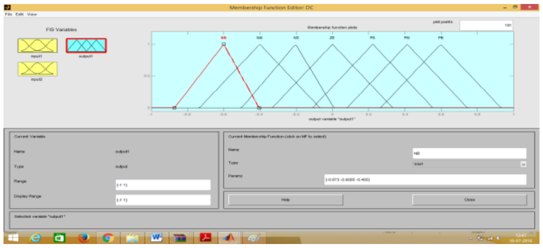


Fig.10 The Updated Membership Function Editor

4.3 The Rule Editor

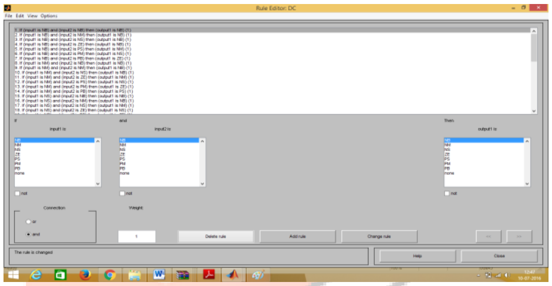


Fig.11 The Rule Editor

	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Fig.12 Fuzzy rules

V.SIMULATION RESSULTS

For the sake of simplication, in Simulation tests, only the fifth and seventh harmonics ,which are the most severe case, are studied. In this case, the integer value n is equal to one. Fig.3(a) shows the performance of three phase stator voltage at the PCC and the nonlinear load current. As seen, without any rejection method, this stator voltage becomes distorted with fifth and seventh harmonics due to the nonlinear load current. With the proposed rejection method based on the PI-R controller, these harmonics are fully rejected as shown in Fig. 3(b). The pure sinusoidal stator voltage waveforms vPCC can be obtained effectively. Fig. 3(c) shows the rotor current tracking performance of the PI-R controller. It can be observed that the reference current i1∗ rdIs composed of both ac and dc components. The frequency of the ac component is 360 Hz where synchronousfrequencyofstatorvoltageis60Hz.Theme asured rotor current i1rd

is well regulated, and hence the zero steady state current error Δi1rd can be achieved. The pure sinusoidal voltage vPCC after compensation and then on linear load current also are also shown in this figure.

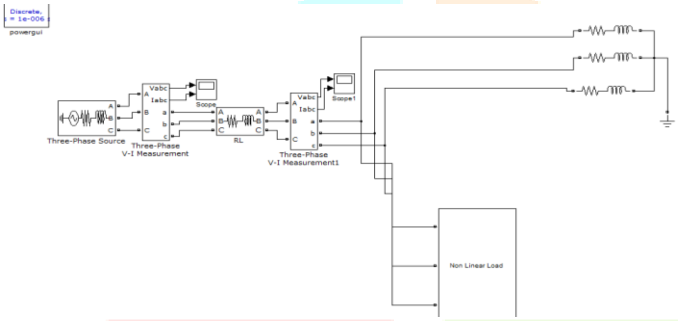


Fig.13 un compensated system

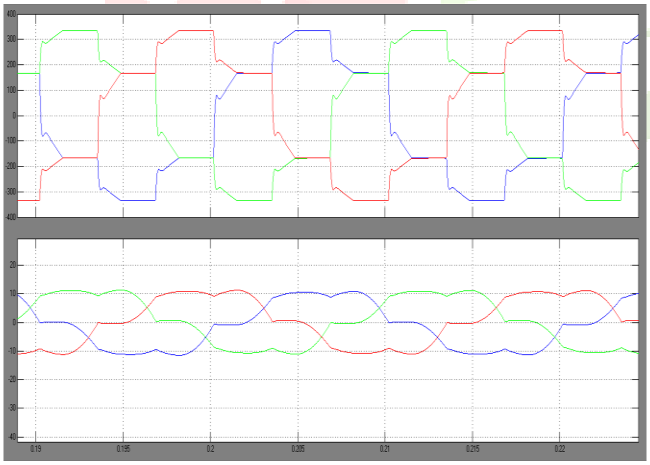


Fig.14 uncompensated voltage &current

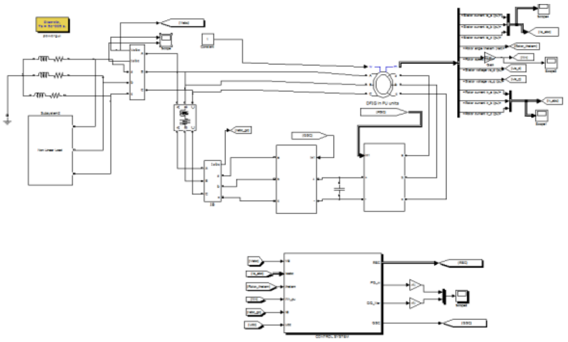
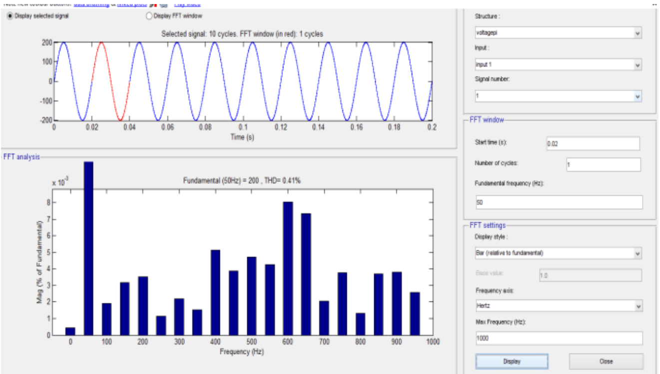


Fig .15 compensated voltage &current using PI controller



Selected signal: 10 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 200 , THD= 0.41%

Structure : voltagepi

Input : input 1

Signal number: 1

Start time (s): 0.02

Number of cycles: 1

Fundamental frequency (Hz): 50

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

Fig.16 THD

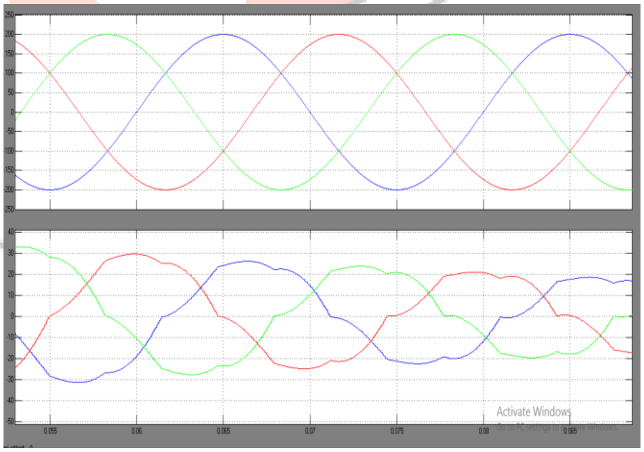
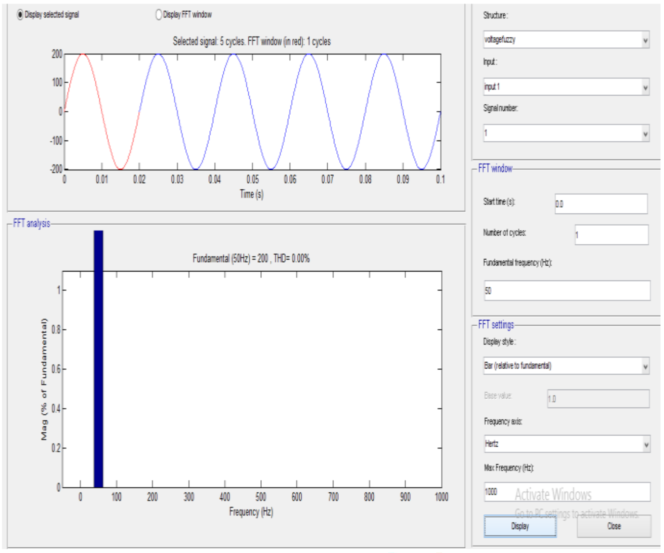


Fig .17 compensated with fuzzy controller



Structure: voltagefuzzy
Input: input 1
Signal number: 1
Start time (s): 0.0
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig .18 THD with FUZZY

VI.CONCLUSION

A novel 6n ± 1 harmonics rejection method for the standalone DFIG with nonlinear loads has been proposed. The proposed rejection method is developed based on the Fuzzy controller in the fundamental frame. In this frame, each resonant filter adopted in the rotor current controller is capable of rejecting one pair of the positive and negative stator voltage harmonics. The algorithm is totally applicable to the DFIG in term of harmonics rejection, which is clarified by experimental verifications for fifth and seventh harmonic components

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