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A NOVEL DESIGN AND IMPLEMENTATION OF THREE-PHASE RECTIFIER-INVERTER FOR DFIG IN WIND POWER APPLICATIONS

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Abstract- *The three-phase grid connected converter is most widely used in renewable and wind power applications. A study of the literature shows that there are some limitations in the conventional standard vector control method. The other researchers have found out some of these limitations. It is found in many research papers that still there exist a limitation in the conventional vector control technique. This paper proposes a new enhanced fuzzy control method for rectifier –inverter model. The merits of both the conventional and the proposed control methods are compared and evaluated in a laboratory hardware experiment environments. The results shows that fuzzy control approach is effective for grid connected power converter control in a wide range of system conditions.*

Keywords: Power converter; fuzzy logic; rectifier –inverter; Direct current vector control.

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1. Introduction

Wind energy is one of the most important fast growing nonpolluting promising, cost effective and safe renewable energy source in the world. Therefore wind electrical power generation system has recently become more attractive compared to other sources such as fossil fuels and nuclear power generation [1]-[2]. Compared to traditional variable-pitch fixed speed wind turbines, variable speed wind turbine systems with power converter control have been developed more in recent time.

In renewable and electric power system application, a three-phase grid-connected voltage source PWM converter is usually employed for interface between dc and ac systems. The converter configuration containing the grid connected converter includes

(i) a dc/dc/ac converter for solar application
(ii) a dc/ac converter for STATCOM applications
(iii) an ac/dc/ac converter for wind power application.

In the conventional method, the grid connected dc/ac converter is controlled through a standard decoupled d-q vector control approach using PI technology. In [3], it is reported that, the controller behavior is normally evaluated within the converter linear modulation mode through either transient simulation or transient measurement approaches. Recent studies show that the conventional vector control approach has a limitation in nature [4-5].Some limitation of the conventional GCC vector control method has also been found and reported by other researchers in different application. In [6], it is found through both theoretical and experimental studies that the conventional vector control approach is very sensitive to model uncertainties. In [7], the shortcoming of the conventional vector control technique, an adaptive control method was proposed lately by eliminating current-control loops. But it was found later that the elimination of the current control loop has deteriorated power quality in terms of harmonics and unbalance. Due to this reason, a direct-current control strategy was developed for dc/ac converter under a constant dc-voltage source condition to

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improve power quality of vector controlled GCC systems [8]-[9].

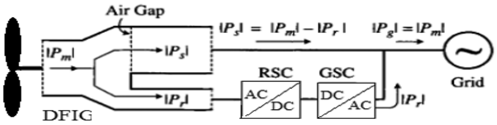
An alternative approach, using a wound-rotor induction generator fed with variable frequency rotor voltage, is receiving increasing attention for wind power generation. With changing wind speed, one can adjust the frequency of the injected rotor voltage of the DFIG to obtain a constant-frequency at the stator [10].There are several reasons for using DFIG in WECS as listed below: converters of about 25-30% of the generator rating are increasingly popular, four quadrant active and reactive power capabilities, lower converter cost and reduced power loss compared to wind turbines using fixed speed generators, increased wind turbine energy capture capability, reduced stress on the mechanical structure, make better control and integration of the active and reactive power and reduced power loss compared to wind turbines using fixed speed induction generators.

Section 2 presents DFIG mechanical system and power flow operation. Section 3 describes the DFIG modeling unit of GCC. Section 4 presents hardware implementation section 5 presents results and discussion and comparison of study of the experimental results. Final section gives the conclusion.

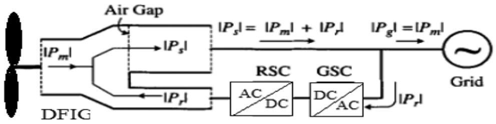
2. Dfig Mechanical System And Power Flow Operation

A DFIG wind turbine primarily consists of three parts: a wind turbine drive train, an induction generator, and a power electronic converter Fig. 1. [11-12]. In the wind turbine drive train, the rotor blades of the turbine catch wind energy that is then transferred to the induction generator through a gearbox. The induction generator is a standard, wound rotor induction machine with its stator windings directly connected to the grid and its rotor windings connected to the grid through a frequency converter. The frequency converter is built by two self- commutated voltage source converters, viz. the rotor side converter (RSC) and the Grid side converter (GSC), with an intermediate DC-link voltage.

The DFIG can be operated in two modes of operation namely sub-synchronous and super-synchronous modes depending on the rotor speed, below and above the synchronous speed.



(a) Supersynchronous mode



(b) Subsynchronous mode

Fig.1. Power flow in DFIG wind energy conversion system

Figure.2 shows the basic scheme adopted in the majority of systems. 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[13].

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 has to be maintained at a constant value. The 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. As a result, the machine can be controlled as a generator in super synchronous speeds or as a motor in sub-synchronous speeds; thus realizing four operating modes[14-15]. Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter, where slip power is returned to the stator. Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and stator-side converter as a rectifier, where slip power is supplied to the rotor [16-17]. 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 stator converter and rotor converter has been modeled and implemented in the hardware. The fuzzy logic controller has been used in the implementation of rectifier-inverter.

3. Modeling Of GCC In D-Q Reference Frame

The schematic of the GSC is shown in fig.2, in which a DC-link capacitor is on the left and a three-phase voltage source, representing the voltage at the point of common coupling (PCC) of the ac system, is on the right.

In the d-q reference frame, the voltage balance across the grid filter is given by equ.(1).

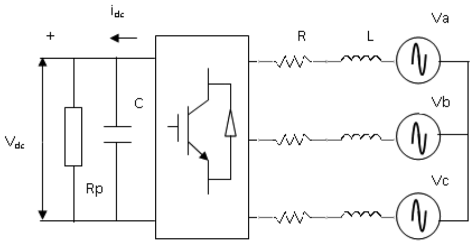


Fig. 2 Schematic diagram of grid-connected converter.

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = R_f \begin{bmatrix} i_d \\ i_q \end{bmatrix} + L_f \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega_s L_f \begin{bmatrix} -i_q \\ i_d \end{bmatrix} + \begin{bmatrix} v_{d1} \\ v_{q1} \end{bmatrix} \quad (1)$$

where ω_s is the angular frequency of the PCC voltage and L_f and R_f are the inductance and resistance of the grid filter. Using space vectors, (1) is expressed by a complex (2) in which $v_{dq,}$ i_{dq} and v_{dq1} are instantaneous space vectors of the PCC voltage, line current, and converter output voltage. In the steady-state condition, (1) becomes (2), where $V_{dq,}$ I_{dq} and V_{dq1} stand for the steady-state space vectors of PCC voltage, grid current, and converter output voltage.

$$v_d = R_f i_d + L_f \frac{di_d}{dt} - \omega_s L_f i_q + v_{d1} \quad (2)$$

$$v_q = R_f i_q + L_f \frac{di_q}{dt} + \omega_s L_f i_d + v_{q1} \quad (3)$$

The voltages in (2) and (3) are d-axis and q-axis voltages and can be expressed from the d-q reference frame (1)

$$v_{dq} = R_f i_{dq} + L_f \frac{di_{dq}}{dt} + j\omega_s L_f i_{dq} + v_{dq1} \quad (4)$$

$$V_{dq} = R_f I_{dq} + j\omega_s L_f I_{dq} + V_{dq1} \quad (5)$$

In the PCC voltage oriented frame [16-17], the instant active and reactive powers absorbed by the GSC from the grid are proportional to grid d-axis and q-axis currents, respectively, as shown by (6) and (7)

$$p(t) = v_d i_d + v_q i_q = v_d i_d \quad (6)$$

$$p(t) = v_q i_d - v_d i_q = -v_d i_q \quad (7)$$

This paper describes an implementation of rectifier–inverter for DFIG variable speed wind-turbine to enhance the performance of a DFIG wind turbine. The conventional, DFIG system controller normally uses the PI controller [18-19] but in this paper PI controller can be replaced with fuzzy logic control technique used for triggering the back-to-back connected MOSFET decoupled circuits. The stator and rotor side controllers were developed separately to regulate the voltage of the DC bus capacitor and also used to partly control the flow of real and reactive power from the turbine system to the grid [20-21]. This paper deals with the control of grid side controller for wind power application. The experimental study has been made for the verification of simulated value.

4. Hardware Implementation

A experimental setup is built using rectifier-inverter laboratory prototype model. A power electronic back-to-back voltage source converter system was developed which is connected between the rotor circuit and the grid, a microcontroller is programmed to perform the controller tasks. A microchip PIC16F872A microcontroller was chosen for its high computational performance at an economical price with addition of high endurance enhanced flash program memory and a high-speed 14 bit A/D converter. On top of these features, PIC16F872A introduces design enhancements that make this microcontroller a logical choice for many high performance motor control applications. The working voltage is 400V and the current is a maximum of 3A with switching frequency of 5 kHz. The best choice is MOSFET.The chosen MOSFET is from international rectifier (IRF) with a part number IRF450.It is an n-channel power MOSFET having a rated voltage of 400V and rated current of 400mA. In case of IRF450, the total gate charge is 63nC with turn on time of 40ns which gives a gate current of 1.54A. The gate drive selected is SG3525 from IRF. It is capable of providing 4A for the MOSFET gate. After selecting the component, the next stage is to build the circuit and fabricates the printed circuit board (PCB). All the waveforms are recorded using a scientific make SM040ME two channel digital storage oscilloscope.

5. Result And Discussion On Hardware Prototype Model

The proposed rectifier-inverter prototype model was developed in laboratory as shown in Fig. 3. It contains the AC voltage controller, uncontrolled rectifier, dc-link capacitor, three-phase controlled inverter, MOSFET driver circuit, current transformer, potential transformer, potential divider and PIC16F872A. The output of AC SSR (0-400V) is given to the three-phase rectifier to get a desired voltage and it is given to the capacitor to maintain the voltage as constant and constant link voltage is given to the three-phase inverter to get a three-phase AC output voltage. The three-phase inverter output voltage is given to the current transformer and potential transformer which are connected to three-phase loads. Potential divider is used to divide the voltage and given to the pulse generating IC SG3525 to produce the pulse given to the three phase ac voltage controller to control the output voltage. The fuzzy logic coding is downloaded from the PIC16F872A microcontroller. It is used to generate a pulse given to the MOSFET driver circuit. It is given to the three-phase inverter to get a desired output voltage.The proposed rectifier-inverter prototype model has to maintain a dc-link voltage about 300V. The dc-link voltage waveform is shown in Fig. 4.

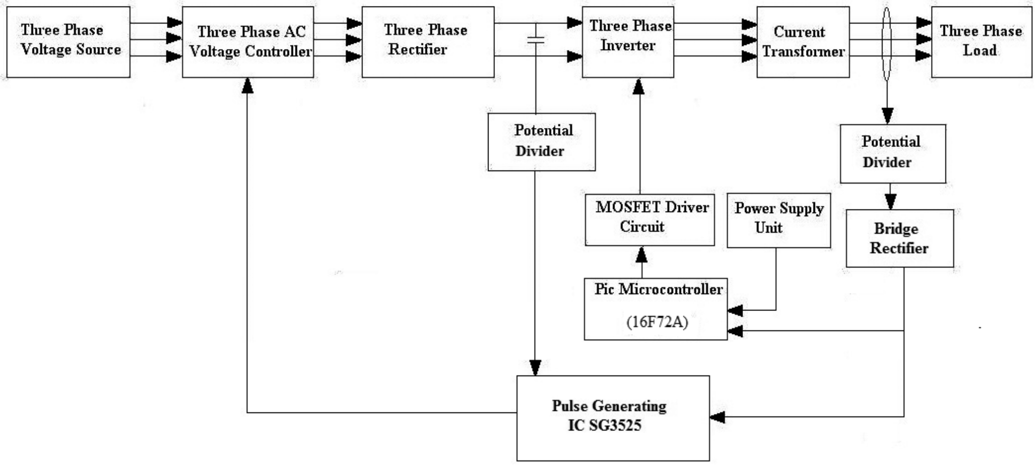


Fig.3 Hardware block diagram for proto type rectifier- inverter circuit

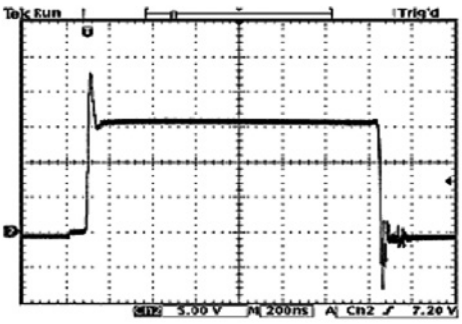


Fig. 4. DC-link voltage waveform

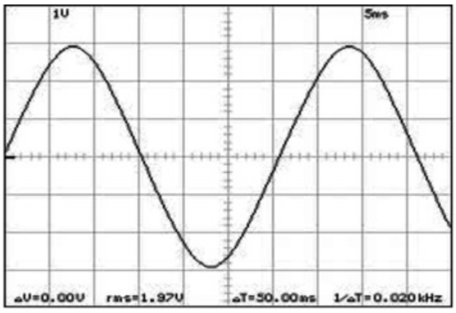


Fig. 5. R phase current waveform

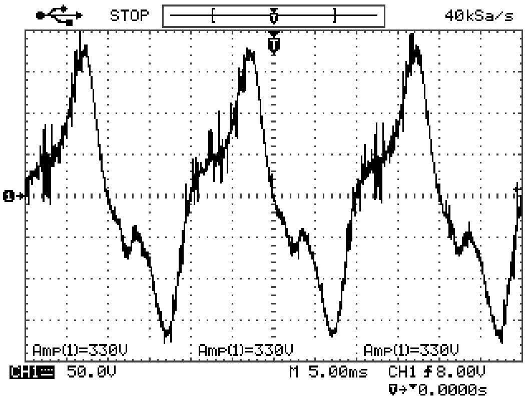


Fig. 6. Single-phase voltage waveform with sag.

The above hardware results show the proposed method of control of DFIG under voltage sag condition. The fig. 4 shows that dc- link output voltage and the q-axis current reference of the GSC controller are set zero so that the reactive power demand is met by the RSC control. The net reactive power is maintained at the reactive power references. The desired dc-link voltage reference value is 300V. It is observed from Fig.4 that the fuzzy logic controlled approach of the GSC and RSC stabilized the dc-link voltage much faster.

Table: 1. Output values of the rectifier-inverter proto type model.

S.No	Input Voltage in V	DC- Link Voltage in V		Output Voltage in V	
		Simulated value	Experi mental value	Simul ated value	Experi mental value
1	80	120	100	100	60
2	160	200	180	150	127
3	240	280	260	270	230
4	300	300	300	280	250

The fig.6 shows the three-phase voltage sag under overload condition, with controller, the real and reactive power of both RSC and GSC to maintain the grid voltage and frequency under low voltage condition. It is inferred from the table.1 that in the proposed fuzzy logic controller based approach; the dc-link voltage and the output voltage have close agreement with simulated and experimental values. The simulated results are in close agreement with the hardware results; hence the rectifier-inverter, used for

DFIG wind power application, has superior performance when compared to the conventional approach.

6. Conclusion

This paper has presented the fuzzy logic based control of rectifier-inverter for wind turbine-driven doubly fed induction generator, which feds the power to the utility grid. GSC and RSC model has been described based on the direct current vector control approach. The equations derived are to be used in the matlab / simulink environment. The proposed method can be compared with hardware implementation. This paper shows that under fuzzy logic based configuration, GSC and RSC control can be implemented for stabilization of dc-link voltage and output voltage. A comprehensive simulation and hardware studies show that the rectifier-inverter system, maintains constant output voltage when the dc-link voltage value is constant. Beyond physical constraints of a GSC system, the proposed control approach operates the system by regulating the RSC by controlling the GSC to stabilize the dc-link voltage as the main concern. In the proposed enhanced controller method, it is very simple to implement the fuzzy logic controller in hardware. Compared to conventional method the proposed method is more stable and quickly attains its steady state and has better dynamic performance. In the above said task the rectifier-inverter circuit, can be utilized for DFIG wind power application. The proposed rectifier-inverter control structure can effectively control the real and reactive power flow of DFIG system, dc- link voltage and rotor speed, under both steady and variable wind conditions.

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