

A Novel Fuzzy System for Wind Turbines Reactive Power Control

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Abstract— The paper proposes a new fuzzy controller for variable speed wind turbines (WTs) in order to compensate the variations at the point of common coupling (PCC) by controlling the reactive power generated by WTs. A protection system is used to disconnect the WTs from the grid when the controller is unable to compensate the voltage variations. Simulations carried out on a real 37-bus Italian weak distribution network demonstrated that the controller allows compensating voltage variations during voltage sags.

Keywords- Variable speed wind turbines, weak distribution network, voltage sag, fuzzy controller

I. INTRODUCTION

Nowadays, the penetration of the wind turbines (WTs) into electric grids has been increased. With the growing penetration of WTs into electric grids, voltage control, stability and security of the system have been influenced. In many countries, the new established grid codes demand that variable speed WTs should participate in improving voltage control in the distribution networks [1,2]. WTs are usually located in remote and rural areas with a weak network infrastructure. Weak networks are characterized by low X/R ratio and unbalanced voltage conditions. Connection of WTs to a weak distribution system has effects on voltage waveform, voltage variations and steady state voltage level [3]. The main constraints are related to the effect that WTs has on voltage quality.

According to the previous described problems, the Italian standard CEI 11-32, dealing with production systems connected to the grid has been updated with new indications related to WTs such as: disconnection from the grid, power production curtailment during voltage variations and contribution to active and reactive power control.

With regards to the reactive and voltage control, the Italian standard provides that the WTs should be able to control the reactive power at the terminals so that the power factor can be adjustable between 0.95 lagging and 0.95 leading [4].

Recent grid codes prescribed that WTs must withstand voltage variations to a certain percentage of the nominal

voltage and for a specified duration. Such requirements are known as Fault Ride- Through (FRT) capability [5,6].

The variable-speed WTs have the ability to control the active and reactive power independently [7,8]. A DFIG based WT can be used as a reactive power source to voltage control with a fewer costs rather than the reactive power compensation devices.

Many previous works has been carried out on the WT reactive power control methods. A control strategy to increase the reactive power output by DFIG based WTs after the fault for improving the voltage variation had been proposed in [9]. Moreover, a mathematical model based on dynamics of DFIG has been defined. In [10], a proportional-integral (PI)-based control algorithm to control the reactive power generated by WTs has been proposed. In [11], the authors have presented a control method for regulating the reactive power generated by DFIGs in a wind farm in order to control voltage variations in the network. The relation between reactive and active power to maintain DFIG operating inside the maximum rotor and stator currents and the steady state stability limit have been described in [12]. In [13], the authors have proposed active network management to exploit maximum wind energy extraction from WTs.

In this paper, a new fuzzy controller for reactive power control of variable speed WTs is presented. The controller is designed in order to compensate the voltage sags at the PCC by controlling reactive power generated by WTs.

This paper is organized as follow: the considered wind turbine model is presented in Section II. The proposed fuzzy controller is described in Section III. Case studies and simulation results are presented and discussed in Section IV, while conclusions are given in Section V.

II. Wind Turbine Generator System

A. WT Modeling

A DFIG is a wound rotor induction generator with the stator connected to the grid directly and with the rotor connected to

The control of the DFIG is obtained by controlling both converters. The aim of the RSC is to control the active and reactive power injected to or absorbed from the grid autonomously, while the GSC has to maintain the DC-link voltage at a set value. A crowbar is also used to short-circuit the RSC in order to protect it from over current in the rotor circuit during disturbances.

Fig.1. Configuration of DFIG based WT connected to a grid

The control system for the DFIG, operating under maximum power extraction, is based on a flux oriented control of the induction machine, in which the d - q current and voltage values are referred to the reference frame aligned with air-gap flux. The control system is composed by two distinct parts: in the first one, the WT output power and the voltage at the grid terminal are controlled by means of RSC; in the second, the voltage at DC bus capacitor is controlled by means of GSC.

Fig.2. (a) Rotor side converter, (b) Grid side converter

III. DESCRIPTION OF THE FUZZY CONTROLLER

Due to nonlinearity of power system and linearization problems the control of variable wind speed WTs could be difficult with conventional control methods. For example, Proportional- Integral (PI) controller design requires identifying the WT transfer function, the linear model of the network and defining an accurate tuning process. Because of these reasons, designing a PI controller is not an easy process.

The use of a fuzzy controller can overcome these problems and presents some advantages if compared to a PI controller: it is easy to obtain variable gains depending on the error and to solve problems affected by uncertain models [15-18].

The proposed controller is designed in order to compensate the voltage at the PCC by injecting the reactive power generated by both of the GSC and RSC.

Moreover, it is used in combination with a protection system for disconnecting the WT from the grid when the controller is unable to compensate the voltage variations and respect voltage limits.

The fuzzy controller, as shown in Fig. 3, presents two inputs: the error, the integral of error and one output that is the reference value for the reactive power reference signal (Q_{ref}) sent by the fuzzy controller to the WT local controller.

The error is defined as the difference between the reference voltage (V_{ref}) and the measured voltage at the PCC.

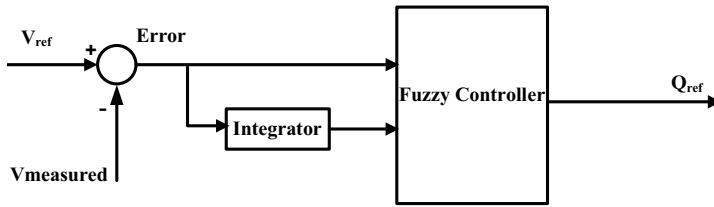


Fig.3. Fuzzy controller

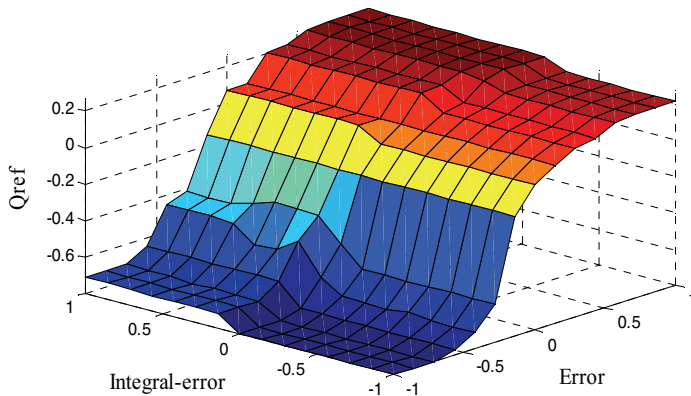


Fig.4. Fuzzy surface of controller

The fuzzy sets of the inputs and outputs assume the following names: “NVB”= Negative-Very-Big, “NB”= Negative-Big, “NM” = Negative-Medium, “NS” = Negative-

Small, “ZE” = Zero, and so forth. Nine triangular membership functions have been selected for the inputs and outputs.

A Mamdani-based system architecture is realized; Max-Min and Centroid methods are used in the inference engine and defuzzification process, respectively.

The control surface of the fuzzy controller is provided in Fig.4.

IV. CASE STUDY AND SIMULATION RESULTS

A. Network and WTs data

In order to test the proposed controller, two 1.5-MW WTs connected to a real 20 kV weak distribution system at buses 16, 35 are considered.

The network is characterized by lines with high resistances and low X/R ratios. The WTs and network parameters are provided in the Appendix. The single line diagram of the network is shown in Fig. 5. The base for power and voltage are 1.5/0.9 MVA and 575 V, respectively.

Real wind data sets acquired by the Wind Engineering Research Field Laboratory [19] are considered. The wind speed time history consists of 17500 observations within 50 seconds interval with sampling rate 25 Hz. The wind profile and generated active power profile are shown in Fig.6.

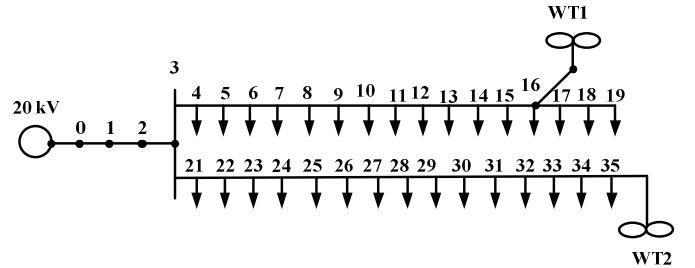


Fig.5. 20kV weak distribution system

The performance of proposed control method is verified considering a 5% voltage sag with a duration of 10 seconds initiated at $t=25$.

When the voltage at the PCC drops, reactive power is injected by the WTs during the voltage sag in order to help to increase the voltage to about 0.93 and 0.94 p.u., for WT1 and WT2, respectively as shown in Fig. 7.

The injected reactive power varies between about 0.40 MVAR for WT2 to about 0.43 MVAR for WT1, according to the voltages at the connection buses.

It can be also evidenced that the reactive power measured at the PCC follows its reference value as shown in Fig.8.

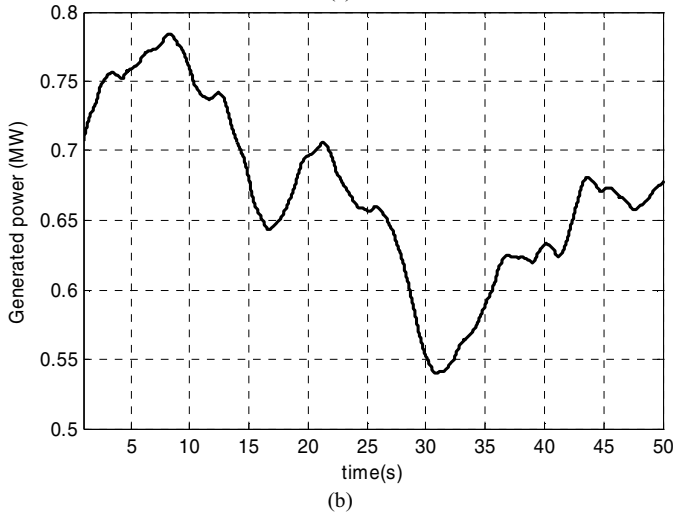
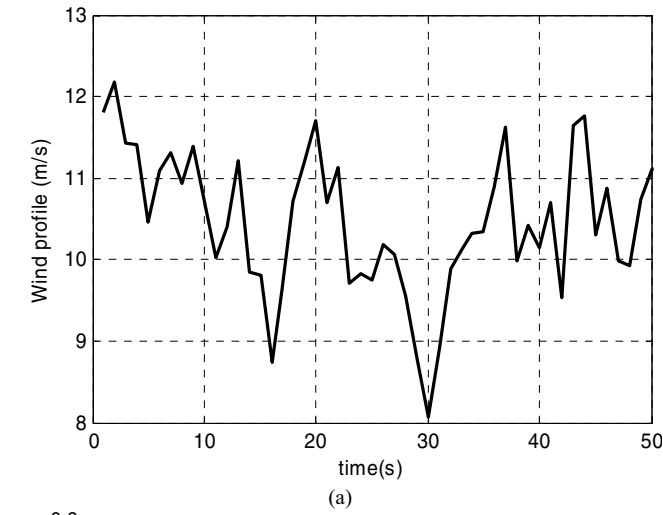


Fig.6. (a) Wind profile (m/s), (b) Generated active power (MW)

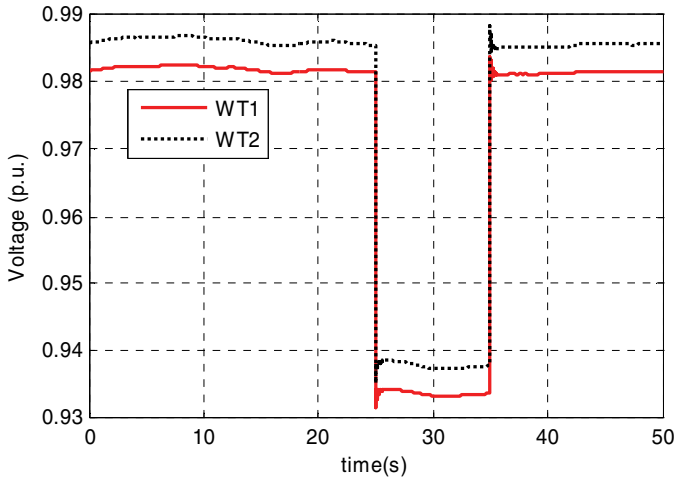


Fig.7. Voltage at the PCC

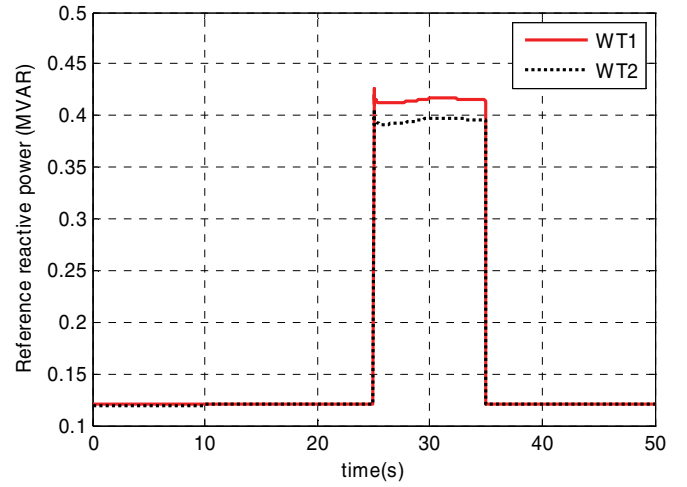


Fig.8. Reference reactive power (MVAR)

In order to evaluate the effectiveness of the proposed controller, its performances are compared with those of a classical PI controller [20] as is shown in Fig. 9.

It can be evidenced that the proposed fuzzy controller exhibits a better voltage compensation compared to the PI controller.

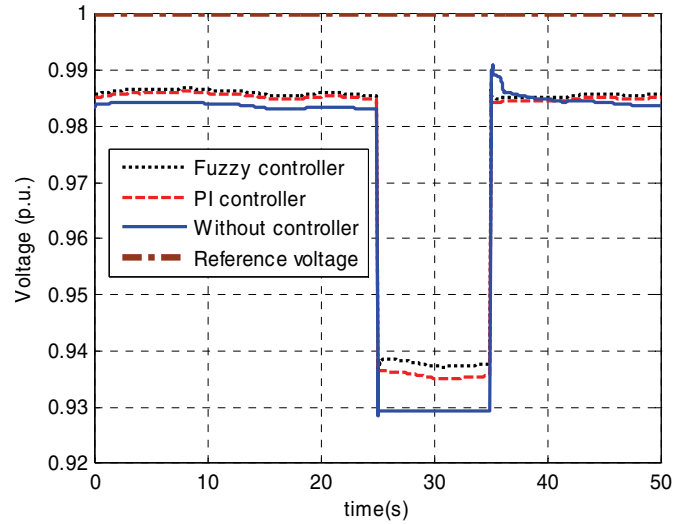


Fig.9. Voltage at bus 35

V. CONCLUSION

This paper proposes a new fuzzy controller for variable speed WTs to compensate voltage variations. at the PCC by controlling the generated reactive power. Simulations carried out on a real 37-bus Italian weak distribution network showed that the proposed controller exhibits good performances and allows compensating voltage variations.

APPENDIX

TABLE I. LOAD DATA

Load No.	P(kW)	Q (kVAR)	Load No.	P(kW)	Q (kVAR)
1	500	200	17	100	50
2	300	100	18	100	50
3	100	50	19	100	50
5	100	50	20	100	100
6	100	50	21	100	100
7	200	100	22	100	100
8	300	100	23	100	100
9	300	100	24	150	100
10	500	200	25	150	100
11	200	100	26	150	200
12	100	50	27	150	200
13	400	200	28	150	200
14	300	100	29	150	200
15	100	100	30	100	50
16	100	150	31	100	50

TABLE II. LINE DATA

Line No.	R (p.u.)	X (p.u.)	X/R	Line No.	R (p.u.)	X (p.u.)	X/R
1	0.0063	0.0031	0.50	19	0.3187	0.15	0.50
2	0.5437	0.3187	0.48	20	0.6375	0.3125	0.51
3	0.8688	0.45	0.49	21	0.0063	0.0031	0.50
5	0.25	0.0938	0.45	22	0.3812	0.15	0.48
6	0.0687	0.0338	0.50	23	0.1125	0.049	0.49
7	0.2375	0.162	0.52	24	0.275	0.1	0.50
8	0.45	0.2287	0.50	25	0.0938	0.045	0.50
9	0.0562	0.0313	0.55	26	0.2437	0.1225	0.50
10	0.1063	0.0625	0.45	27	0.5250	0.25	0.49
11	0.0438	0.0213	0.48	28	0.2575	0.125	0.49
12	0.0750	0.035	0.50	29	0.2575	0.125	0.49
13	0.1375	0.05	0.51	30	0.3125	0.1587	0.50
14	0.3063	0.1563	0.50	31	0.3637	0.1750	0.48
15	0.0125	0.0063	0.50	32	0.1213	0.687	0.49
16	0.3563	0.1437	0.55	33	0.2	0.0813	0.48
17	0.3125	0.1550	0.49	34	0.1375	0.05	0.51
18	0.3562	0.1875	0.50	35	0.2	0.1	0.50

WIND TURBINE PARAMETERS

$$\begin{aligned}
 V_{\text{base}} &= 575 \text{ V} & S_{\text{base}} &= 1.5 \text{ MVA} & f_{\text{base}} &= 60 \text{ Hz} & \omega_s &= 1 \text{ pu} \\
 \omega_b &= 2\pi f_b = 377 \text{ rad/s} & R_s &= 0.00706 \text{ p.u.} & R_r &= 0.005 \text{ p.u.} \\
 L_s &= 3.07 \text{ p.u.} & L_r &= 3.056 \text{ p.u.} & L_m &= 2.9 \text{ p.u.}
 \end{aligned}$$

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