Fuzzy Logic Based P/Q Control Design for Grid-Connected Wind conversion System

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***Abstract*— In grid-connected wind conversion systems, traditionally control characterizes by fixed gain Proportional Integral Derivative (PID) regulators. Conventional PID control laws provide good results in case of linear systems with constant parameters. In heather land, these control laws are limited in robustness and effectiveness especially in cases of non linear systems. However, in electrical system control, robustness is of particular very importance. This paper investigates the performance of fuzzy logic controllers (FLCs) applied in grid-connected wind generator to improve performances of control. This purpose needed to achieve good performances of reactive power (Q) compensation. This work at first presents a simple control algorithm for active (P) and reactive power based on PI controllers in which an inverter designed can synchronize a sinusoidal current output with a voltage grid. The controller feeds maximum active power into grid at unity power factor, whereas it also allows the adjustment of reactive power injected into the grid. In the second phase of the study, FLCs changes PIs regulators for improve performance of power control. Simulation results confirm that the intelligent control system has good performances.**

Keywords— Power grid control, PI controller, Fuzzy logic, Wind conversion system, Power factor

I. INTRODUCTION

In recent years, many researchers have contributed to the development of a firm foundation for analysis and design of control applications in grid-connected renewable energy sources. Wind generator is one of the most widely fastest-growing and used renewable energy for produce electricity in industrial applications in the world , that is essentially due to their high reliability, Wind power is cost-effective, non-polluting and It's sustainable Wind is actually a form of solar energy. Winds are caused by the heating of the atmosphere by the sun, the rotation of the Earth, and the Earth's surface irregularities. For as long as the sun shines and the wind blows, the energy produced can be harnessed to send power across the grid. [1,2].

The integration of significant amounts of wind power generation to the electric grid poses a unique set of challenges to utilities and system operators. Grid interconnection of wind power generation system has the advantage of more effective utilization of generated power. However, the technical requirements from both the utility power system grid side and the wind system side need to be satisfied to ensure the safety of the wind installer and the reliability of the utility grid.

Generally, grid connected wind power systems is based on two cascade convertors AC/DC and DC/DC allow bay DC/AC convertor which must provide a target active and/or reactive power to the line, and for this an appropriate power control strategy is required. With proper controls of DC/AC inverter, wind generators are capable of producing necessary amount of reactive power so as to provide required voltage support. Similarly, the amount of active and reactive power can be controlled to match the local load profile. Several methods of controlling the active and reactive power injection from the interconnection power system using power electronics interface have been proposed in literature [3-7].

Vector-type control is commonly employed. It has become a very popular control technique [8]. Vector control of electrical systems is implemented by the PID controllers. Generally, performances of electric system control are influenced by the controller capabilities. Classical control techniques influenced by fixed gain PIDs and require exact mathematical model of the system and are very sensitive to parameter variations. Intelligent control techniques are more efficient and robust than classical techniques, since they do not require an exact model of the system.

In this paper independent control of P and Q based on PI controllers is proposed for controlling power injections from wind generator connected to a three-phase distribution system. Also, the specialty of both the control method is that they are entirely developed in the three-phase (*abc*) reference frame with the measurement of the control variables based on instantaneous power and establish the phase angle using phase locked-loop (PLL). This greatly simplifies the controls in avoiding the hassles of conversions between reference frames *abc* and *dq*. Second, FLCs changes PIDs for reason improvement more performances of power grid control. Obtain results using MatLab/Simulink prove the efficiency of the proposed controls with a comparative study of both the control methods confirms that the intelligent purpose batter performance the conventional method.

978-1-5386-6933-4/18/$31.00

II. SYSTEM DESCREPTION

Fig. 1 shows the circuit configuration of the proposed grid-connected wind generator via power converter with a line-frequency transformer. The transformer placed between the DC/AC inverter and the utility grid. The power converter comprises a decoupling circuit and a filter inductor set. The filter inductor is employed to filter out the switching harmonics of the power converter. A de-coupling circuit is used to insure power converter control.

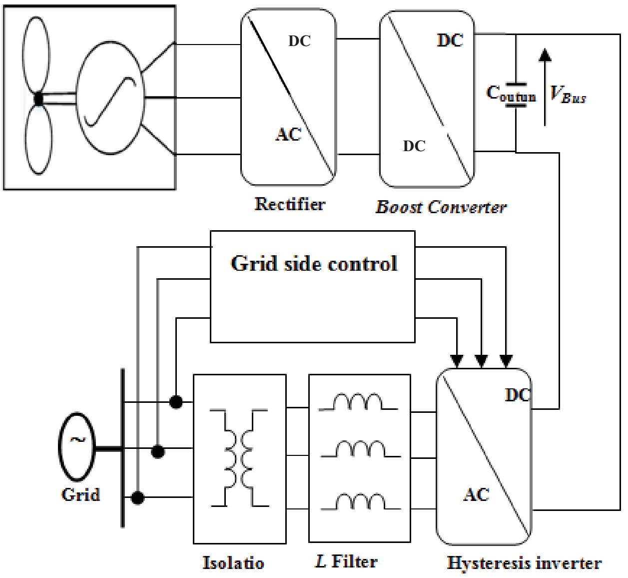


Fig. 1. Circuit configuration of the proposed three-phase grid-connected wind generation system.

A. *Wind convertion system*

Wind conversion system consist a wind turbine with a ac/dc and dc/dc power inverter in which wind power handles both maximum power point tracker (MPPT) algorithm.

- Wind turbine WT: is a power generating device that is driven by the kinetic energy of the wind. In a WT, blades surround the drive shaft of the turbine.
- Boost converter: The Boost converter is the most widely used in wind conversion systems, it has step-up conversion ratio [9]. Therefore the output voltage is always higher than the input voltage. Boost converter is specially used in this work.
- Maximum power point tracker: The power delivered by a wind system of one or more wind systems is dependent on the kinetic energy of the wind strongly depends on wind speed and rotor rotational speed,. In general, there is a unique point on the I-V and P-V curve, called the maximum power point (MPP). The location of the MPP is not known, but can be located. Incremental MPPT algorithms are the most commonly used MPPT technique for wind system conversion [10]. Output power can be maximized without any information of turbine parameters by iteratively changing the control variable which results in generator rotational speed adjustment. INC method is used in this particular work.

B. *Hesterisis Current Controller*

The three phase instantaneous active and reactive power from the WT generator can be calculated directly from the measurement of the terminal voltage and the inverter current. P and Q, in the case of rotating dq frame of references are obtained as follows:

$$\begin{cases} P = \frac{3}{2}\left(v_d i_q + v_q i_d\right) \\ Q = \frac{3}{2}\left(v_d i_q - v_q i_d\right) \end{cases} \tag{1}$$

The principal of the proposed P/Q control based hysteresis inverter is illustrating by Fig.2. A hysteresis current controller is implemented with a closed loop control system. An error signal is used to control the switches in an inverter. This error is the difference between the desired current, i_{ref}, and the current being injected by the inverter, i_{act}. When the error reaches an upper limit, the transistors are switched to force the current down. When the error reaches a lower limit the current is forced to increase. The range of the error signal directly controls the amount of ripple in the output current from the inverter and this is called the Hysteresis Band (HB). The current is forced to stay within these limits even while the reference current is changing. The turn-on and turn-off condition for the inverter switches is:

- Upper switch Off: $(i_{act} - i_{ref}) > \text{HB}$.
- Lower switch Off: $(i_{act} - i_{ref}) < \text{-HB}$.

As the band - width narrows the switching frequency increases. A suitable bandwidth should be selected in accordance with the switching capability of the inverter [6].

The fixed hysteresis band is very simple and easy to put into operation.

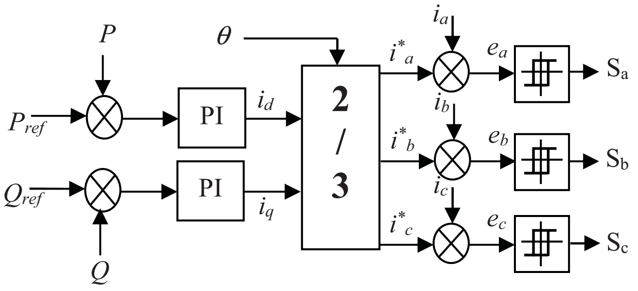


Fig. 2. Principal of proposed P/Q control based Hysteresis PWM Current Control.

C. *Fuzzy Logic Controller*

Under the circumstance of nonlinear and parameter time-varying object controlled, accurate model cannot be given. Although traditional PID control is simple, controlling result better, it cannot solve the circumstance that model parameter occur variety, moreover, in practical spot, because of being subjected to parameter setting, traditional PID parameter stetted is not good, its performance is not quite good, be badly to the adaptability. So, according to complex circumstance applied and the control request of high-performance, having an urgent request to PID parameter self-settled, fuzzy control to PID stetted is a good solution. Fuzzy control is computer intelligent control based on fuzzy set theory, fuzzy language, fuzzy logical-inference, and its basic idea is presented by L. Zadeh, who achieved the great success in fuzzy control theory and application study through development of many years. Fuzzy self adapting controller has many kind of structural style at the present time, but their operating principle is same to each other. Fuzzy self adapting controller take error *e* and error alteration *ec* as an input, amend parameter at a real time using fuzzy control regulation, these constitute fuzzy self adapting controller that using a bloc consist two fuzzy controllers for P/Q are shown in Fig 3. The input variables are:

$$\begin{cases} e_P = P_{ref} - P \\ e_Q = Q_{ref} - Q \end{cases} \qquad (2)$$

The output control variables are:

$$\begin{cases} \Delta P = s.i_d \\ \Delta Q = s.i_q \end{cases} \qquad (3)$$

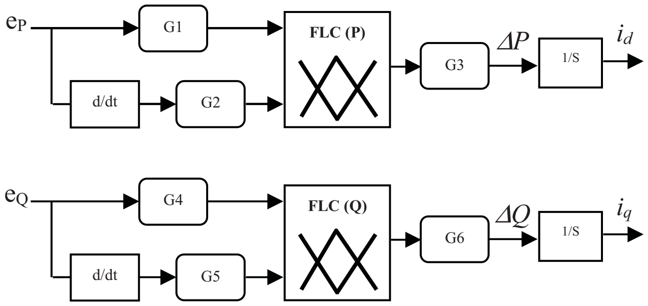


Fig. 3. Principal of proposed P/Q control based FLC.

The fuzzy logic membership functions for both inputs and the output are partitioned using five Membership function (MF) for inputs and five MF for output fuzzy are shown in Fig 4. Triangular fuzzy sets are used for both inputs and outputs, with a restriction that the output fuzzy sets must be isosceles to simplify defuzzification. Input and output values are represented linguistically: NB=negative big; NM=negative medium; ZE=zero; PM=positive medium. PB=positive big.

As it is shown in Fig 4, both inputs and output are normalized between -1 and 1. So it is necessary to define proper gains (scaling factor: G1, ……. , G6) for all parameters in order to change parameters in per unit (see Fig. 3). We note that the P and the Q fuzzy controller are similar and the same difference is in scaling factor. Selecting these gains is one of challenging part of fuzzy logic controller and if it is selected improper, it may be we don't get optimum result or even it leads to instability.

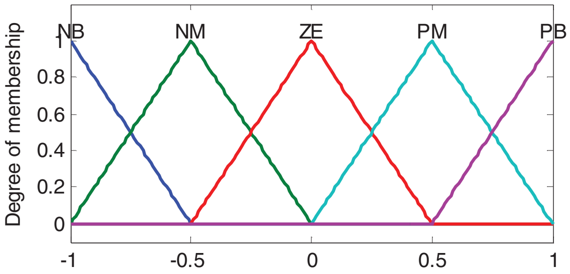


Fig. 4. Membership function of: e_P, e_Q, de_P, de_Q, P and Q.

Rules bases table of such rule is brought in Table 1. The rule base table can be read according to the following example: IF error (e) is zero (ZE) AND change in error (ce) is negative big (NB) THEN output (du) is negative big (NB).

Table 1: P and Q Fuzzy rules bases

e / **ce**	**NB**	**NM**	**ZE**	**PM**	**PB**
NB	**NB**	**NB**	**NB**	**NM**	**ZE**
NM	**NB**	**NB**	**NM**	**ZE**	**PM**
ZE	**NB**	**NM**	**ZE**	**PM**	**PB**
PM	**NM**	**ZE**	**PM**	**PB**	**PB**
PB	**ZE**	**PM**	**PB**	**PB**	**PB**

P/Q correction control is needed because the perturbation approach alters output demands. The active and reactive grid should be maintained with their references spatially Q as constant and equal to zero as possible. The input/output mapping of the FLC is shown in figure 5.

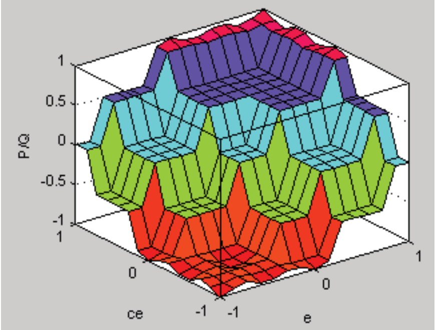


Fig. 5. Crisp input/output mapping of FLC.

III. RESULTS AND DUSCUTION

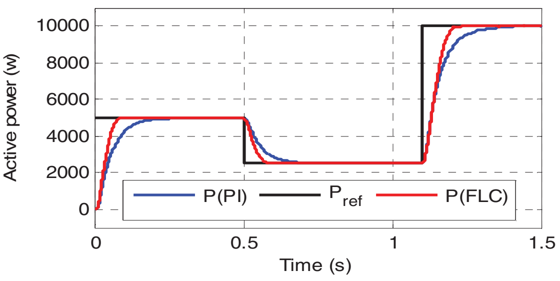
Table 2 summarizes the important required parameters of the wind generator and the utility grid with different accessories of the simulation model. The generated power is converted to the grid using two-level DC/AC hysteresis inverter after filtrate using inductor filter. The switching frequency of the hysteresis inverter is 2 kHz.

Table 2: Parameters for simulation model

	Parameter	Index	Value	Unite
WT	Rated power	P	10	KW
	Rated voltage	V_{mp}	220	V
	Rated frequency	f	50	Hz
	Pole-pairs	p	2	
	Stator resistance	R_S	2.9	Ω
	Rotor resistance	R_R	1.52	Ω
Grid	Grid inductor	L_g	10^{-5}	H
	Grid resistor	R_g	0.01	Ω
	Max of active power grid	P_{Max}	10	KW
	Max of reactive power grid	Q_{Max}	1	KVAR
	RMS phase	V_g	380	V
Filter	Filter Inductor	L_f	0.002	H

A digital simulation was carried out using MatLab Simulink interface for the proposed system which show the results obtained for active and reactive powers on the AC side supplied to the grid, phase angle and power factor. Testing model for tough the control abilities based on PI controllers and for improvement proposed P/Q control using FLCs. It is seen that in Fig. 6 active and reactive power follows their references that indicate the success of the proposed P/Q control in grid connected WT system where the fuzzy control is the best. The major advantage of the proposed control is the capability of compensation of the reactive power under changing the active power. So, the total converted wind power is exploited on active power. Phase angle (Fig. 7) and the power factor (Fig. 8) shows that the superiority of FLC control design compared to PI regulators employing on terms of: dynamic response, rejection capabilities and synchronisms. Fig. 9 confirm that current and voltage grid are in phase.

a.



b

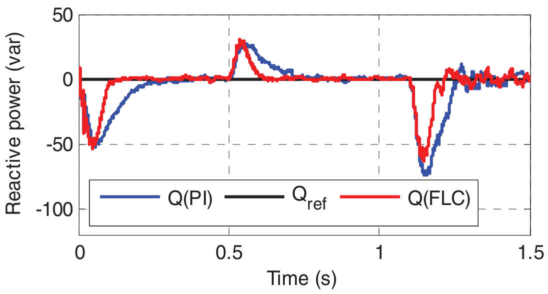


Fig. 6. a: Active power; b:Reactive power.

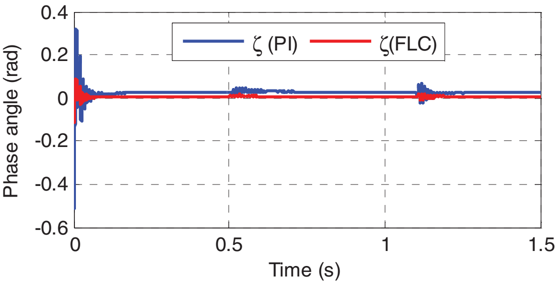


Fig. 7. Phase angle.

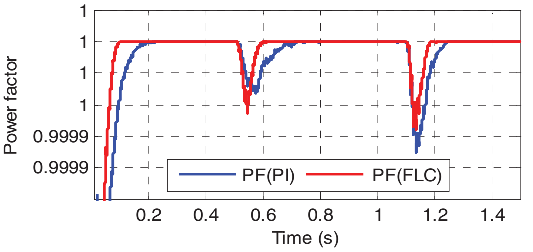
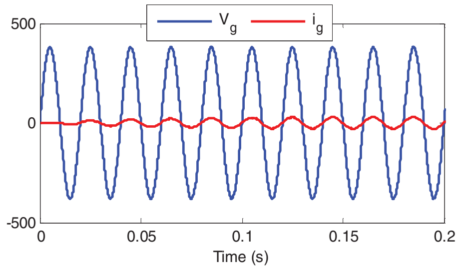


Fig. 8. Power factor.

a



b.

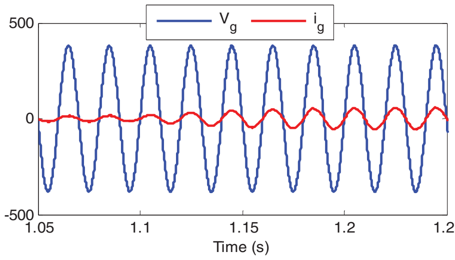


Fig. 9. Grid voltage with current.

IV. CONCLUSION

A simple P/Q control algorithm for three-phase grid-connected wind system via hysteresis inverter was presented. At first, based on PI controllers, the model was simulated where obtain rustles using Matlab/Simulink verify the proposed control behaviors. A sinusoidal form for current and voltage, the proposed control can maintain the inverter current almost in phase with utility grid with unity power factor, the active and the reactive power follows their references and the wind system enable to convert the total generated power to the grid. Simulation results indicate that the using of FLCs often more dynamic and good rejection capabilities of P/Q control recitals.

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