Application of Active Disturbance Rejection Controller in PWM Voltage Source Rectifier

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Abstract –The DC output voltage will deviate as disturbances in the PWM voltage source rectifier based on voltage oriented direct power control. A new strategy was proposed in this paper to solve this problem. The voltage controller is active disturbance rejection controller (ADRC). The load disturbance and other disturbances are contributed to the total disturbances, and then the total disturbances is estimated and compensated by extended state observer (ESO). Simulation results show that this new method has high power factor, low harmonic, fine dynamic performance. Further more it has better robust property to load disturbance.

Keywords - PWM rectifier; active disturbance rejection controller; voltage oriented direct power control

I. INTRODUCTION

Three phase PWM voltage source rectifier is widely used in reactive compensation, active filter, superconducting energy storage, high voltage direct current transmission and renewable energy, since it has some good properties such as sinusoidal AC line current, bidirectional power flow function and unity power factor control [1]. In most voltage source rectifier (VSR) control strategies, the direct power control based on the voltage oriented (VO-DPC) is a more interesting solution for industrial application because of its high power factor and low THD [2]. And the scheme of the system and the algorithm are simple [3]. However, when the load is changed or has a disturbance, the output DC voltage will deviate. Traditional PI controller can't achieve a good performance on the above conditions.

Active disturbance rejection controller (ADRC) is a nonlinear controller. It has got many good performances in many fields. ADRC can estimate and compensate the total system disturbances in real time, combining with special scheme of nonlinear feedback to achieve good character. And the algorithm of ADRC is simple and easy to implement with digital control.

This paper proposes a new control method that ADRC is used in the PWM rectifier based on VO-DPC. In this novel control scheme, the ADRC is used to control the voltage loop. The extended state observer (ESO) is used to estimate the total disturbances including the change of the load. The principle is that ESO can estimate accurately and compensate the change of the load. Simulation results show that this new method has not only the better dynamic and static performance than fuzzy PID control, but also restrain the output voltage fluctuation caused by the change restrain the output voltage fluctuation caused by the change of the load availably.

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II. DIRECT POWER CONTROL BASED ON THE VOLTAGE ORIENTED IN PWM RECTIFIER

Fig.1 shows the block diagram of the direct power control based on the voltage oriented (VO-DPC). The whole system consists of active power control portion and reactive power control portion. When the voltage vector is oriented to the d-axis in rotating d-q coordinates, the relations of output DC voltage v_{dc} and current i_d are linear. So the output DC voltage can be controlled by controlling the current. The instantaneous active power and reactive power can also be calculated from the voltage and the current on d-axis and q-axis. The converter switching states are appropriately selected by a switching table based on the instantaneous errors between the reference values and estimated values of active and reactive power. In order to get the unity power factor, the reactive current is usually set to zero.

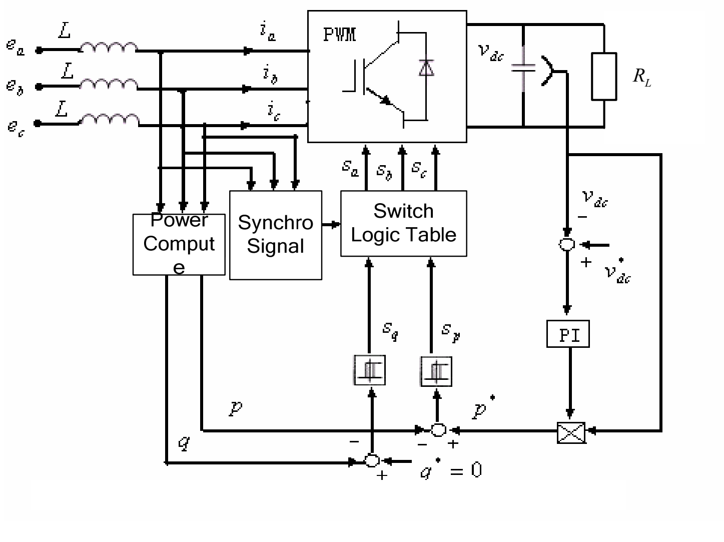

Fig. 1: Block diagram of VO-DPC

VO-DPC has no coordinate transformation. The estimated values of the instantaneous power include not only fundamental component but also harmonic component, leading to the high power factor. The errors are determined by the width of the hysteresis loop controller. The scheme of the system is simple. The disadvantages of VO-DPC are high sampling frequency and variable switching frequency which leads to the random AC current and makes it is hard to design the input filer. Also when the load R_L on DC side is changed, the output DC voltage V_{dc} will fluctuate.

III. Active Disturbance Rejection Controller

ADRC mainly includes tracking-differentiator (TD), extended state observer (ESO) and nonlinear combination on (NLC). It is widely used because of its simple control algorithm, easily be achieved, high precision, rapidly and good disturbance rejection [5].

Many real objects can be expressed as follows

$$\begin{cases} x^{(n)} = f(x,\dot{x},...,x^{(n-1)},w(t),t) + bu \\ y = x(t) \end{cases} \tag{1}$$

where $w(t)$ is the total disturbances of the system' which include the outer disturbances of the system and the inner disturbances caused by the model changed. x is the state value. y is the output value. u is the control value and b is the coefficient value. The main principle of the ADRC is to utilize ESO to observe and compensate the total disturbances, thus makes the system to be integral and serial system.

$$\begin{cases} x^{(n)} = bu_0 \\ y = x(t) \end{cases} \tag{2}$$

Through the feedback of the state errors, the control goal is obtained. Here, it is not important whether $f(x,\dot{x},...,x^{(n-1)},w(t),t)$ is known or unknown, linear or nonlinear, as long as it is limitary.

IV. The ADRC Design in PWM Rectifier

A. Mathematical model of the PWM rectifier

The mathematical model of VSR in rotating d-q coordinates is

$$\begin{cases} C\dfrac{dv_{dc}}{dt} = \dfrac{3}{2}(i_q s_q + i_d s_d) - i_L \\ L\dfrac{di_q}{dt} + \omega L i_d + Ri_q = e_q - v_{dc}s_q \\ L\dfrac{di_d}{dt} - \omega L i_q + Ri_d = e_d - v_{dc}s_d \end{cases} \tag{3}$$

where, v_{dc} is the output DC voltage. i_d and i_q are the AC current on d-axis and q-axis. i_L is the load current. C is the DC-link capacitor. L is the filter inductance of reactor. R is the resistance of reactor. ω is the voltage frequency. S_d and S_q are the on/off values in rotating d-q coordinates.

If ADRC be used in PWM rectifier, the controlled model needs to be transformed as (1).

When the wastage of three phase PWM rectifier is ignored, the AC-link active power p_{ac} is equal to the DC-link power p_{dc}, that is

$$p_{ac} = p_{dc} \tag{4}$$

Taking equation (4) into d-q synchronous mode, the power equations are

$$p_{ac} = \frac{3}{2}e_d i_d + \frac{3}{2}e_q i_q \tag{5}$$

$$p_{dc} = v_{dc}i_{dc} = v_{dc}C\frac{dv_{dc}}{dt} + \frac{v_{dc}^2}{R_L} \tag{6}$$

Equation (7) is derived from (4)-(6) is given by

$$\frac{d}{dt}v_{dc}^2 = -\frac{2}{R_L C}v_{dc}^2 + \frac{3}{C}e_d i_d + \frac{3}{C}e_q i_q \tag{7}$$

Letting $u = v_{dc}^2$, then the equation (7) can be expressed as

$$\frac{du}{dt} = -\frac{2}{R_L C}u + \frac{3}{C}e_d i_d + \frac{3}{C}e_q i_q \tag{8}$$

In the VO-DPC, the voltage is oriented on the d-axis and the voltage on the q-axis is equal to zero.

$$\begin{cases} e_d = \sqrt{3}e_a \\ e_q = 0 \end{cases} \tag{9}$$

where, e_a is a phase effect value of the AC-link voltage. Equation（8）can be expressed as

$$\frac{du}{dt} = -\frac{2}{R_L C}u + \frac{3\sqrt{3}}{C}e_a i_d \tag{10}$$

Using

$$a(t) = -\frac{2}{R_L C}u \tag{11}$$

$$b = \frac{3\sqrt{3}}{C}e_a \tag{12}$$

Then from equation（10）, that becomes

$$\frac{du}{dt} = a(t) + bi_d \tag{13}$$

From equation (13), it is known that the output DC voltage and the current on d-axis are satisfied with equation (1). So the first order ADRC can be utilized in the voltage loop. The equation (11) shows that total disturbances of the system $a(t)$ include R_L. ESO can estimate and compensate $a(t)$ in time. If R_L is changed in the application, the effect of DC voltage fluctuation can be restrained.

B. Design of voltage ADRC in VO-DPC

Design of the ADRC usually uses nonlinear function to get the better result. It will increases the complex of the computation and nonlinear ADRC is difficult to implement. The linear function ADRC, linear ADRC, is used instead of nonlinear function sometimes. The performance of the linear ADRC is appropriately as same as the nonlinear ADRC. But it is much simple in computation and easy to be implemented. The linear ADRC is used in the scheme.

1) Design of tracking-differentiator(TD)

Design linear TD for the reference output DC voltage V_{dc}^{*} is

$$\begin{cases} \dot{v}_{dc1} = v_{dc2} \\ \dot{v}_{dc2} = -1.73 r v_{dc2} - r^2 (v_{dc1} - v_{dc}^{*}) \end{cases} \quad (14)$$

Where, V_{dc1} is tracking signal of V_{dc}^{*}. r is an adjustable parameter.

2) Design of extended state observer(ESO)

Design of the second order liner ESO for the actual output DC voltage in PWM rectifier can be written as the equation (15). ESO can get the estimation of the DC voltage states and the total disturbances of the system.

$$\begin{cases} e = z_1 - v_{dc} \\ \dot{z}_1 = z_2 - \beta_{01} e + b i_d \\ \dot{z}_2 = -\beta_{02} e \end{cases} \quad (15)$$

Where, v_{dc} is DC-link voltage. Z_1 is the state estimation of the voltage v_{dc}. Z_2 is the estimation of the total disturbances $a(t)$. β_{01} and β_{02} are two adjustable parameters.

If $a(t)$ is not estimated by ESO exactly，there has steady state error in the system, even to be unsteady. So tuning the parameters of the ESO is very important. Z_2 shows the estimation of the total disturbances $a(t)$. It affects the dynamic performance and accuracy. The value of Z_1 has a significant influence to the output of the system. There are disturbances in the output voltage of the PWM rectifier, so Z_1 plays a important role in estimating the state accurately for the real voltage.

3) Design of the linear combination

Then control law is given

$$\begin{cases} i_{d0} = k(v_{dc1} - z_1) \\ i_d^{*} = i_{d0} - z_2/b \end{cases} \quad (16)$$

Where k is an adjustable coefficient, i_d^{*} is the d-axis current.

Fig.2 shows the block diagram of ADRC.

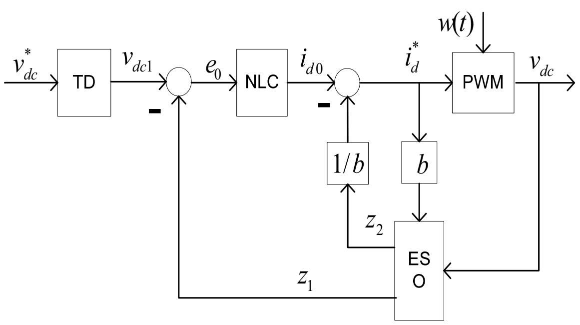

Fig. 2: Block diagram of ADRC

V. SIMULATION RESULTS

The PWM rectifier with the whole control scheme has been simulated. The main electrical parameters of the power circuit are given as tab 1.

Table. 1 Parameters of the PWM Converter

AC-link voltage	Frequency	Inductance	Resistance
380V	50Hz	15mH	0.1Ω
DC-link capacitor	Load resistance	Reference voltage	
660μF	100Ω	600V	

Fig.3 shows the waveform of the output DC voltage. The output DC voltage is rapidly rising without overshoot and the static error is small.

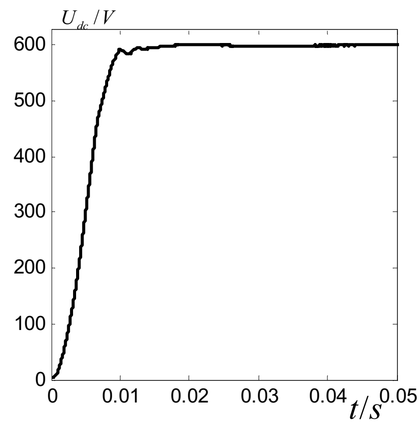

Fig. 3: Output of DC voltage

Fig.4 shows the waveform of the AC-link voltage and current. The phase current vector is aligned with the phase voltage vector, so it achieves the unity power factor. And the harmonic spectrum of the line current is 2.73%.

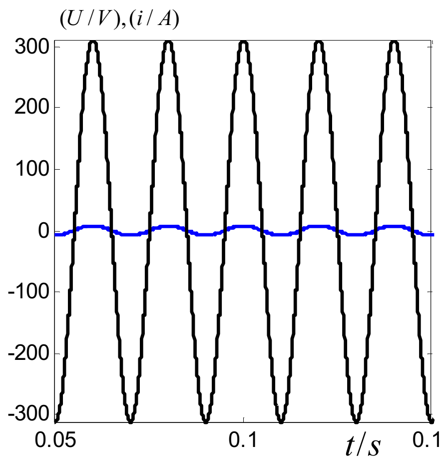

Fig. 4: Voltage and current of phase

The new strategy with ADRC is compared with the fuzzy PID controller. Fig.5 shows the waveform of the output DC voltage when the reference voltage is changed. The reference voltage is changed to 625V at the time 0.2s, From Fig.5, it is known the system with ADRC is more rapidly achieve to the steady than fuzzy PID.

Fig.6 shows the waveform of the output voltage when load resistance is changed from 50Ω to 100Ω at the time 0.5s. Comparing with the fuzzy PID, the new method has smaller voltage-fall and rapidly renew-time.

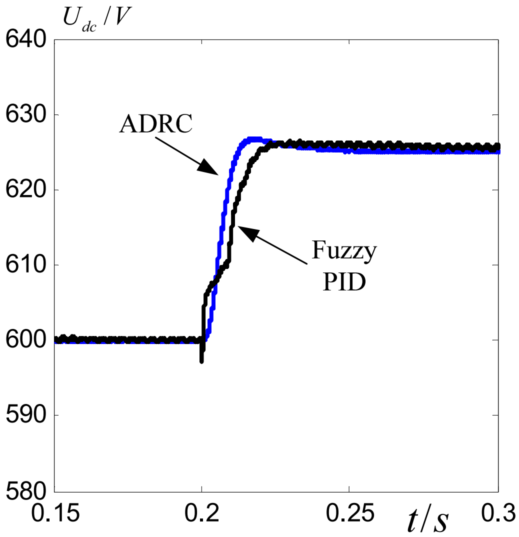

Fig. 5 Control results when reference voltage changed

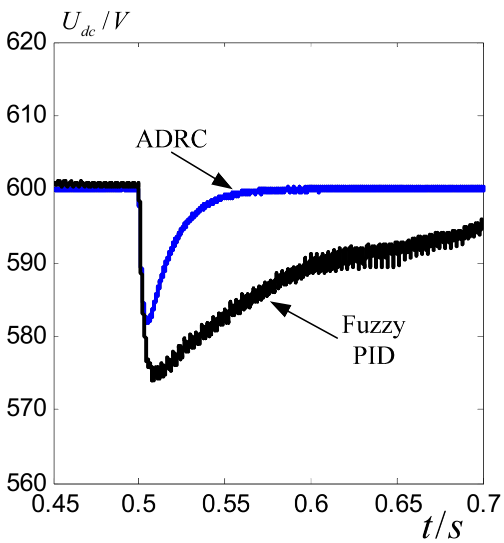

Fig. 6 Output of DC voltage when load changed

VI. Conclusion

The present ADRC voltage control scheme is proposed in PWM rectifier based on VO-DPC. ESO is used to observe the total disturbances. Then controlled and compensated them with ADRC, the effect caused by load change can be restrained availably. Simulation results show that this new method can control the output voltage rapidly without overshoot. It achieves the unity power factor, furthermore, the effect caused by load change is restrained.

References

[1] N. Silva, A. Martins, "Design and Evaluation of a PWM Rectifier Control System for Testing Renewable DC Sources Connected to the Grid," IEEE Transactions Power Electron, 2006: 32-37.

[2] Jyoti Saaty, Olorunfemi Ojo, "High-Performance Control of a Boost AC-DC PWM Rectifier/Induction Generator System," IEEE Transactions on IND APP, 2006, pp. 1146-1154.

[3] Tarek Ahmed, Mutsuo Nakaoka, "Advanced Control of a Boost AC-DC PWM Rectifier for Variable-Speed Induction Generator," IEEE 2006, pp. 956-962.

[4] Fang Yu, Xie Yong, Xing Yan, "Modelling and Simulation of Three Phase High Power Factor PWM Rectifier," IPEMC, 2006, pp. 956-962.

[5] Liwei Shao, Xiaozhong Liao, Xixi Wang, "Application of Active Disturbance Rejection Controller in Stator Flex Oriented Vector Control System," 2006 2nd International Conference on Power Electronics System and Applications, Hong Kong, 2006, pp. 132-138.

Biography

Liao Xiaozhong was born in Guangdong, China, in 1962. She received her BSc and PhD degrees respectively from the Tianjin University in electrical and automation engineering and the Beijing Institute of Techonology in control engineering. She is currently a professer in Beijing Institute of Technoloyg. Her research interests are the electric drive systemn and energy converter control.