Experiment Research on a Compound Control Strategy for D-STATCOM

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Abstract:- Distribution Level Static Compensator (D-STATCOM) is one of the most cost-effective solutions for the power quality problems caused by voltage sags and swells, lightning strikes, and other distribution system related disturbances. In this paper, the control principle for D-STATCOM is deduced in detail. According to the difference between STATCOM and D-STATCOM in structure and function, a compound control strategy for D-STATCOM to achieve the purpose of rapid-response compensation is proposed correspondingly. Experimental results verified the validity of the control strategy.

Keywords: -Transmission system, Distribution system, STATCOM, D-STATCOM, Control principle, Control strategy, Experiment

1 Introduction

The static synchronous compensator (STATCOM) is one of the most important FACTS device based on the use of self-commutated semiconductors, it is a synchronous voltage source that works similarly to a generator [1]. It is used to stabilize system, to maintain efficiency and to maximize the ability of existing transmission line [2]. STATCOM is often used in transmission system. When it is used in distribution system, it is called D-STATCOM （STATCOM in Distribution system）。

D-STATCOM is a key FACTS controller and it utilizes power electronics to solve many power quality problems commonly faced by distribution systems. Potential applications of D-STATCOM include power factor correction, voltage regulation, load balancing and harmonic reduction. Comparing with the SVC, the D-STATCOM has quicker response time and compact structure. It is expected that the D-STATCOM will replace the roles of SVC in nearly future

D-STATCOM and STATCOM are different in both structure and function, while the choice of control strategy is related to the main-circuit structure and main function of compensators [3], so D-STATCOM and STATCOM adopt different control strategy. At present, the use of STATCOM is wide and its strategy is mature, while the introduction of D-STATCOM is seldom reported. Refer to the strategies for STATCOM, in this paper, a compound control strategy used in D-STATCOM is presented to achieve the purpose of rapid-response compensation. In this strategy, it first proceeds direct-voltage close-loop control and adjusts λ (the modulation of PWM) to achieve the control aim ,then in order to improve the characteristics of distribution system further , introduces double-close-loop system to reduce steady-state error in distribution system. The compound control strategy can achieve the purpose of rapid-response compensation of D-STATCOM. Experimental results proved the validity of the control strategy mentioned above.

2 Control Principle of D—STATCOM

2.1 Deduction of Control Principle

Fig.1 (a) is the single-phase equivalent circuit and operating phasor diagram of D—STATCOM. (The phasor diagram is related to whether the DC side absorbs electricity power. Fig.1 (a) belongs to the condition that the DC side absorbs electricity power.)
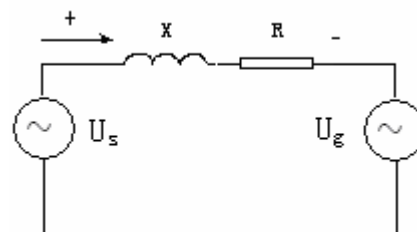

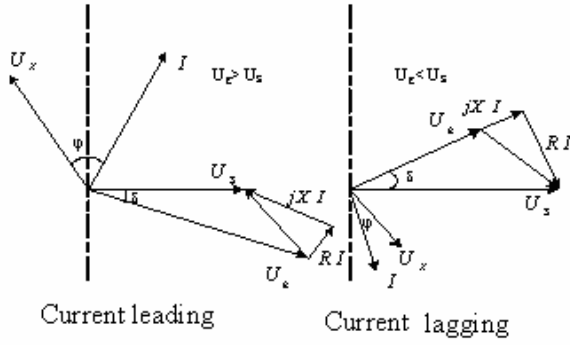Fig. 1 (a) Single-Phase Equivalent Circuit

Fig. 1（b）Operating Phasor Diagram

Where,

U_S: AC source phase voltage;

U_g : the output voltage of inverter;

U_{dc}: DC side voltage;

I_g: DC side current;

δ: angle between U_g and U_S

R: resistance of the line reactor;

X: inductance of the line reactor；

Analyze the single-phase equivalent circuit of D－STATCOM shown in fig. 1(a), from circuit principle we get:

$$\frac{U_L}{\sin\delta} = \frac{U_s}{\sin(90°+\varphi)} = \frac{U_g}{\sin(90°-\varphi-\delta)} \quad (1)$$

$$U_L = \frac{U_s \sin\delta}{\cos\varphi} \quad (2)$$

else, from Fig.1 (b), we can also know the angle between source voltage Us and DC side current I is 90°-δ, and their active current component is in phase while reactive current component is orthogonal, so we will get:

$$I_P = I\cos(90°-\delta) = \frac{U_L}{\sqrt{X^2+R^2}}\cos(90°-\delta) \quad (3)$$

$$I_q = I\sin(90°-\delta) = \frac{U_L}{\sqrt{X^2+R^2}}\sin(90°-\delta) \quad (4)$$

by applying （2）to （3） and （4），we will get,

$$I_P = \frac{U_s}{R}\sin^2\delta \quad (5)$$

$$I_q = \frac{U_s}{2R}\sin 2\delta \quad (6)$$

then we have the expressions of active power and reactive power in steady-state separately:

$$P = 3 \cdot U_s \cdot I_p = \frac{3U_s^2}{R}\sin^2\delta \quad (7)$$

$$Q = 3 \cdot U_s \cdot I_q = \frac{3U_s^2}{2R}\sin 2\delta \quad （8）$$

And according to the equation (1), we can deduce the equation as follow:

$$U_g = \frac{U_s \cos(\delta+\varphi)}{\cos\varphi} \quad （9）$$

From power electronics principles, the voltage U_g can also be expressed as follow:

$$U_{dc} = \frac{3\sqrt{6}U_g}{\pi \cdot \lambda} \quad （10）$$

Where,

λ: the modulation depth of PWM；

by applying （9）to （10）we get:

$$U_{dc} = \frac{3\sqrt{6}U_s \cos(\delta+\varphi)}{\pi \cdot \lambda \cdot \cos\varphi} \quad (11)$$

2.2 Content of the Control Principle for D—STATCOM

a. From equations (7) and (8) above, we know the capacity and characteristics of reactive power produced by D—STATCOM can be controlled by δ. That is δ can be viewed as a control variable of D—STATCOM.

b. From （11）we know: By adjusting δ, the dc voltage U_{dc} can be controlled, thus by adjusting U_g , the characteristics and capacitance of reactive power Q can be controlled (in fact adjusting the characteristics and capacitance of reactive power Q is equivalent to adjusting the characteristics and capacitance of reactive current I_q) . Besides, U_g can also be adjusted by the modulation depth λ of PWM. So λ can also be viewed as another control variable of D—STATCOM.

c. From a. and b., we know δ and λ can both viewed as control variables of D—STATCOM, so they can form DC side voltage close-loop. By adjusting DC side voltage given, adjusting control variable δ indirectly, and adjusting control variable λ coordinately, the control requirements of D—STATCOM can be achieved.

3. Proposition of Compound-Control Strategy

D-STATCOM and STATCOM are different in both structure and function, while the choice of control strategy is related to the main-circuit structure and main function of compensators, so D-STATCOM and STATCOM should adopt different control strategy.

At present, the use of STATCOM is wide and its strategy is mature, while the introduction of D-STATCOM is seldom reported. Refer to the

strategies for STATCOM, in this paper, a compound strategy used in D-STATCOM is proposed to achieve the purpose of rapid-response compensation.
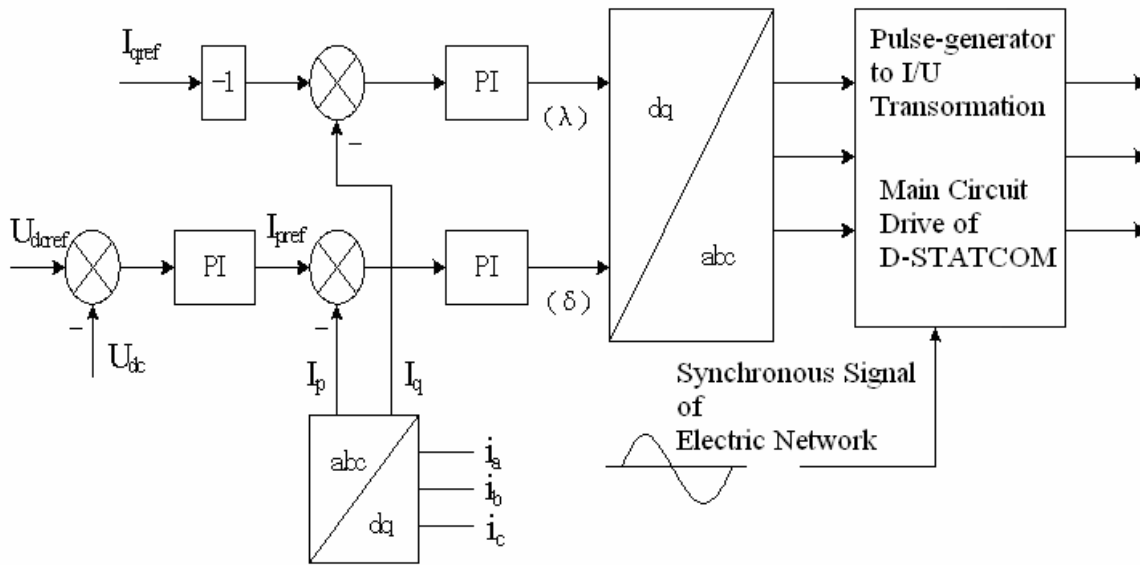

Fig.2 double-close-loop block diagram of direct-current-control

In this scheme, because the reference value I_{qref} 、 I_{pref} and the feedback value I_q (i.e. $-I_q$)、I_p (i.e. I_d) are current signal , consequently current-tracking control without steady state error can be achieved by PI adjuster. In addition, feedback control absorbing reactive and active current is introduced in this scheme. And this scheme adopts d-q coordinate-conversion to examine the active and reactive power absorbed by D-STATCOM [4]. For the reason that d axis and source voltage Us are in

phase when conversing coordinate, d axis active current component I_p reflects the capacity absorbed by D-STATCOM from electric network; $-I_q$ express the capacity of reactive current absorbed by D-STATCOM from electric network considering q axis leads 90°before d axis (if we suppose absorbed reactive power by D-STATCOM is positive).

3.2 Combination of Direct–current- control and Indirect- current-control
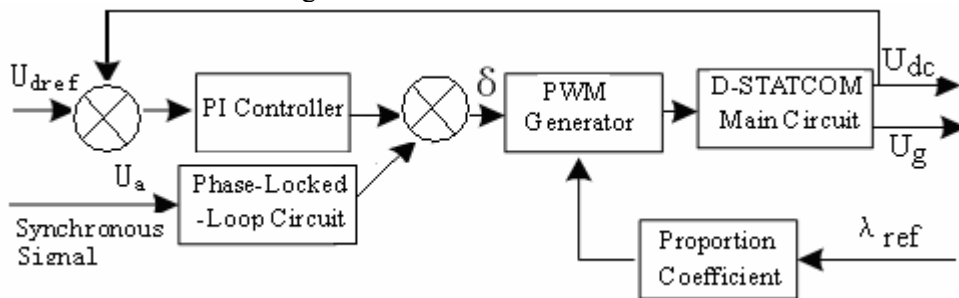

Fig. 3 Single-Close-Loop Block Diagram of Indirect-Current-Control

According to the control principle deduced above in this paper, we can first form DC voltage close-loop-control (Fig.3) [5], and adjust λ coordinately to achieve the control purpose of D-STATCOM. In order to improve the characteristics of D-STATCOM further, we introduce double-close-loop control (Fig.2.) secondly, and viewed objective control variable I_q as the given input value of D-STATCOM to eliminate the steady-state error of D-STATCOM. This compound-control strategy can

satisfy the rapid-response characteristics of D-STATCOM.

4 Experiments and Results
4.1 Experiment Cases
To verify the validity of the control strategy proposed above, two experiment cases were investigated as follows:

Experiment parameters are listed as:

DC side capacitor: C is 470uF/1000V capacitance;
AC side induction: L=100mH;
AC side resistance: R=15Ω;
AC source phase voltage: Us=28V;

a. When λ=0.85, δ varies from -30°to -82°, the operating state of D-STATCOM varies from inductive state to capacitive state. Waveforms of U_S and I_g are showed in Figure 4.
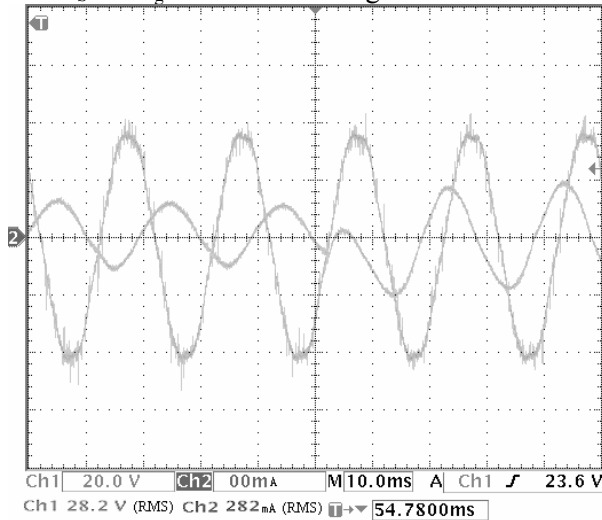

Fig.4 Waveforms of U_S and I_g from $U_g < U_S$
to $U_g > U_S$

b. When λ=0.85, δ varies from -82°to -30°, the operating state of D-STATCOM varies from capacitive state to inductive state. Waveforms of U_S and I_g are showed in Figure 5.
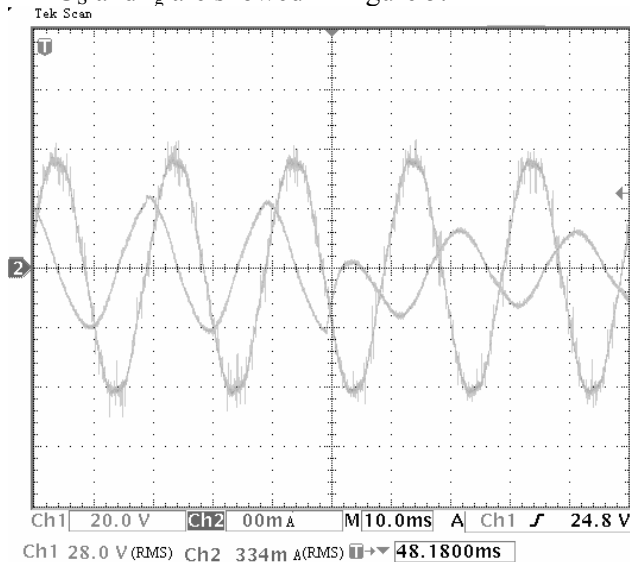

Fig.5 Waveforms of U_S and I_g from $U_g > U_S$ to
to $U_g < U_S$

4.2 Experimental Conclusions

From the experiment waveforms (in Fig. 4. and Fig. 5), we know: transition time is in one fundamental frequency cycle, whether the operating state of D-STATCOM varies from inductive state to capacitive state or from capacitive state to inductive state, which means the compound control strategy proposed in section 3 can make D-STATCOM achieve rapid-response compensation, verifying the validity of theoretical analysis in section 2.

Acknowledgment

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