

CONTROL METHOD FOR TRANSFORMERLESS H-BRIDGE CASCADED STATCOM WITH NEW CONFIGURATION

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ABSTRACT—This paper introduces a transformerless static synchronous compensator (STATCOM) framework taking into account multilevel H-span converter with star setup. This proposed control strategies dedicate themselves to the present circle control as well as to the dc capacitor voltage control. With r circle control, a nonlinear controller in light of the lack of involvement based control (PBC) hypothesis is utilized as a part of this fell structure STATCOM interestingly. With regards to the dc capacitor voltage control, general voltage control is acknowledged by embracing a relative resounding controller. Grouped adjusting control is acquired by utilizing a dynamic unsettling influences dismissal controller. Singular adjusting control is accomplished by moving the tweak wave vertically which can be effectively actualized in a field-programmable door exhibit. Two real H-span fell STATCOMs appraised at 10 kV 2 MVA are developed and a progression of confirmation tests are executed. The exploratory results demonstrate that H-span fell STATCOM with the proposed control strategies has brilliant element execution and solid strength. The dc capacitor voltage can be kept up at the given esteem viably. Record Terms—Active aggravations dismissal controller (ADRC), H-span fell, inactivity based control (PBC), corresponding resounding (PR) controller, moving .

INTRODUCTION:

Adaptable air conditioning transmission frameworks (FACTS) are being increasingl utilized as a part of force framework to upgrade the framework usage, power exchange limit and in addition the force nature of air conditioning framework interconnections [1],

[2]. As a ty gadget, static synchronous compensator at the purpose of regular association (PCC) the required receptive force, through which the of PCC is enhanced [3]. As of late, numerous been connected to the STATCOM. Among these There are two specialized difficulties which exist fell STATCOM to date. To begin with, the control current circle is a critical variable impact execution. Be that as it may, numerous nonideal components, the restricted data transmission of the yield current circle, instigated by the sigal recognizing circuit, and the recommend current era procedure, will deffect. Second, H-span fell STATCOM is entangled framework with numerous H-span cell the dc capacitor voltage unevenness issue which dynamic force misfortunes among the cells, distinctive s designs for various cells, parameter varieties aloof segments inside cells will impact the framework and even prompt the breakdown plots of examines have concentrated on looking for.As far as present circle control, the larger part include the conventional direct control strategy, in which the nonlinear conditions of the STATCOM model are linearized with a particular balance. The most generally utilized direct control plans are PI controllers [9], [10]. In [9], to direct responsive force, just a basic PI controller is done. In [10],through a decoupled control system, the PI controller is utilized in a synchronous d–q outline. Be that as it may, it is elusive the reasonable parameters for planning the PI controller and the execution of the PI controller may controller is utilized. -span cell the dc capacitor voltage unevenness issue which dynamic force misfortunes among the cells, distinctive s designs for various cells, parameter varieties aloof segments-span cell the dc capacitor voltage unevenness issue which

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I. CONFIGURATION OF THE 10 KV 2 MVA

STATCOM SYSTEM

Fig. 1 shows the circuit configuration of the 10 kV 2 MVA star-configured STATCOM cascading 12 H-bridge pulse width modulation (PWM) converters in each phase and easily according to the requirement. By current of STATCOM directly, it can absorb or required reactive current to achieve the purpose current compensation. Finally, the power quality grid is improved and the grid offers the active The power switching devices working in ideal assumed. u_a, u_b , and u_c are the three-phase u_a, u_b , and u_c are the three-phase voltage of current of grid. i_a, i_b , and i_c are the three-phase current of STATCOM. i_{la}, i_{lb} , three-phase current of load. U_{dc} is the reference capacitor. C is the dc capacitor. L is the Table I summarizes the circuit parameters. The of $N = 12$ is assigned to H-bridge cascaded in 36 H-bridge cells in total. Every cell is equipped nine isolated electrolytic capacitors which the except for the dc capacitor and the voltage an ac inductor supports the difference between the control of the dc capacitor voltage balancing, the keep the dc mean voltage of 12 cascaded cluster equaling the dc mean voltage of the three is adopted to achieve it. Then, it requires several the design of ADRC for H-bridge cascaded 1) According to (1), H-bridge cascaded STATCOM is a first order system; thus, the first-order ADRC is designed. of each cluster as the controlled object for analysis, the clustered balancing control the input and output variables and the controlled controlled object are determined.2) By using the nonlinear tracking differentiator is a component of ADRC, the transient process input of the controlled object is arranged and its Selecting the mean value of overall voltage U^* - span cell the dc capacitor voltage unevenness issue which dynamic force misfortunes among the cells, distinctive s designs for various cells, parameter varieties aloof segments-span cell the dc capacitor voltage unevenness issue which dynamic force misfortunes among the cells, distinctive s designs for various cells, parameter varieties aloof segments

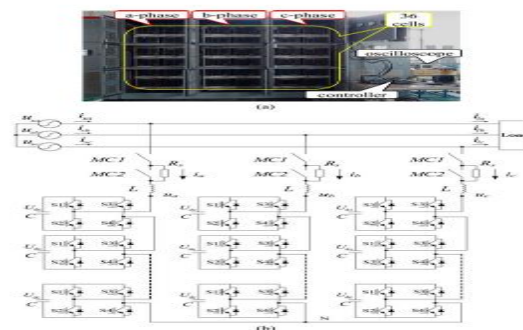
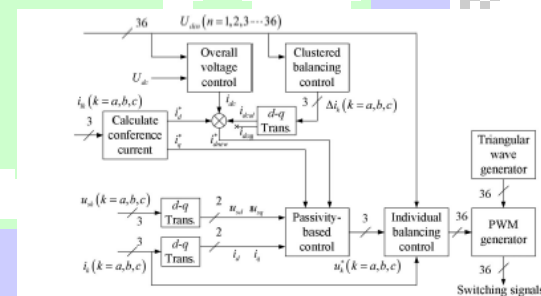


Fig. 1. Actual 10 kV 2 MVA H-bridge cascaded STATCOM. (a) Experimental hardware view. (b) Configuration of the experimental system.

voltage of the grid and the ac PWM voltage of The ac inductor also plays an important role in switch ripples caused by PWM. For selecting bipolar transistor (IGBT), considering the complexities of practical industrial fields, there might be the problems of current and over load. Consequently, in order to and reliability of H-bridge cascaded improve the over load capability, the current rating of the IGBT should be reserved enough safety margin. proposed system, 1.4 times rated current the peak current under the 1.4 times over load s 224 A, the additional 76 A (30– 224 A = 76 A) is margin of IGBT modules. Due to the previous the voltage and current ratings of IGBT which is the switching element in main circuit are 1.7 kV (Infineon EF300R17KE3). The modulation technology adopts the carrier sinusoidal PWM (abbreviated as CPS-SPWM)



modeling technology. It defines the energy the general variable and harnesses the known f H-bridge cascaded STATCOM.

Referring to [54], along with selecting i_d and i_q variables, it gives the following EL system model of (3):

$$M \dot{x} + Jx + Rx = u \quad (4)$$

where $x = [i_d \ i_q]$ is the state variable. $M = [L \ 0 \ 0 \ L]$ is the positive definite inertial matrix and $M = MT$.

$J = [0 \ -\omega L \ \omega L \ 0]$ is the dissymmetry interconnection matrix and $J = -JT$. $R = [R \ 0 \ 0 \ R]$ is the positive definite symmetric matrix which reflects the dissipation characteristic of the system. $u = u_d - u_q$ is the external input matrix which reflects the between the system and environment.

As to a system, if there is positive semidefinite function $V(x)$ and positive definite function condition of $\forall T > 0$, the dissipative inequality (5) the input u of the system, the output y of the energy supply rate uTy . This system is strictly can be defined as the rate of energy supply along u injected into the system from the external. V is storage function of the system

$$\dot{V} \leq uTy - Q(x). \quad (5)$$

For the strict passive system, if there is smooth and differentiable positive-definite energy storage asymptotically stable equilibrium point for this the storage function can be written as Lyapunov Assume the energy storage function as (6) for H- STATCOM

$$\begin{aligned} V &= \frac{1}{2} x^T M x \\ &= \frac{1}{2} L i_d^2 + \frac{1}{2} L i_q^2 + \frac{1}{2} C (u_d - u_q)^2 \end{aligned} \quad (6)$$

By taking the derivative of V and utilizing characteristic of J , (7) is obtained as follows:

$$\dot{V} = x^T M \dot{x} = x^T (u - Jx - Rx) = x^T u - x^T R x. \quad (7)$$

Setting $y = x$ and $Q(x) = x^T R x$, the forms of (7) are the same. Thus, H-bridge cascaded STATCOM is the strictly passive. The controller can be designed for H-bridge cascaded STATCOM with the passivity theory.

When H-bridge cascaded STATCOM works in conditions, because of the switching loss, the equivalent resistance loss and the loss of the capacitor itself, it will decline of the dc capacitor voltage. Thus, it dc capacitor voltage at the given value while grid. And it has three expected stable equilibrium points: U_{dc} is the dc capacitor reference voltage. The reference current of the d-axis. i_d^* is the Generally, the dc capacitor voltage of H-bridge STATCOM is maintained at the given value through absorbing the active current from the grid that can be y controlling the d-axis active current. This d-axis active current

$i_d^* = i_{dc} + i_{dcd}$ (as shown in Fig. 3) can be added to the d-axis reference current. The newfound d-axis reference current is $i_d^{*new} = i_d^* + i_{dcd}$. Now, the three expected points of the system can be revised two: $x^* 1 = i_d^{*new}$ and $x^* 2 = i_q^*$.

Error system is established as follows:

$$\dot{x}_e = x - x^* = [i_d - i_d^{*new} \ i_q - i_q^*]^T \quad (8)$$

where x^* is the expected stable equilibrium point of the system.

Substituting (8) into (4), the error dynamic system can be obtained as follows:

$$M(\dot{x}_e + \dot{x}^*) + J(x_e + x^*) + R(x_e + x^*) = u \quad (9)$$

$$M\dot{x}_e + Jx_e + Rx_e = u - (M\dot{x}^* + Jx^* + Rx^*).$$

To improve the speed of the convergence, from make error energy function reach zero, (10) is damping. It can accelerate energy dissipation of make the system converge the expected stable The injected damping dissipation term as

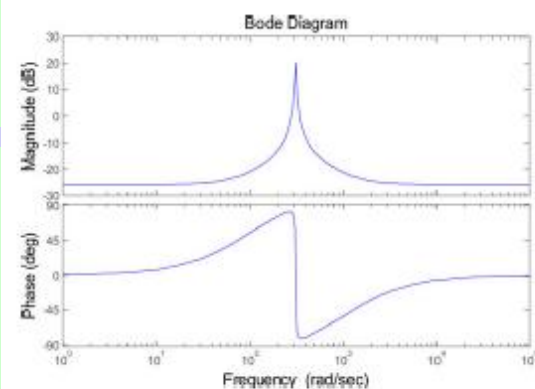


Fig. 5. Bode plots of the PR controller.

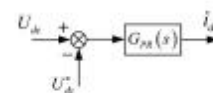


Fig. 6. Block diagram of overall voltage control.

I. IV. EXPERIMENTAL RESULTS

To verify the correctness and effectiveness of part of this paper. Two H-bridge cascaded running simultaneously. One generates the set compensating current that prevents is divided into two parts: the current loop control control loop control experiment,

the measured is the current of a-phase cluster and it is recorded In dc capacitor voltage balancing control the value of dc capacitor voltages are transferred into a signal acquisition system and they can be by CCS software in computer. Finally, with the experimental data from CCS, experimental by using MATLAB.

A. A. Current Loop Control Experiment

The current loop control experiment is divided into four processes: steady-state process, dynamic process, startup Fig. 12 shows the experimental results verifying PBC in steady-state process. As shown in Fig. result of the full load test. With the proposed method, the reactive current is compensated effectively. The error of the compensation is very small. The residual grid is also quite small. The phase of the of the reactive waveforms of the compensating are smooth and they have the small distortion the result of the over load test. When STATCOM load state (about 1.4 times current rating), due to IGBT has been reserved the enough safety margin, STATCOM still can run continuously and steadily. The over of STATCOM is improved greatly and the STATCOM in practical industrial field is steady-state process, dynamic process, startup Fig. 12 shows the experimental results verifying PBC in steady-state process. As shown in Fig. result of the full load test. With the proposed method, the reactive current is compensated of the compensation is very small. The residual grid is also quite small. The phase of the is basically the same as the phase of the reactive waveforms of the compensating current and the are smooth and they have the small distortion sinusoidal shape. As shown in Fig. 12(b), it is result of the over load test. When STATCOM is load state (about 1.4 times current rating), due to IGBT has been reserved the enough safety still can run continuously and steadily. The over load STATCOM in practical industrial field is However, considering the over load capability

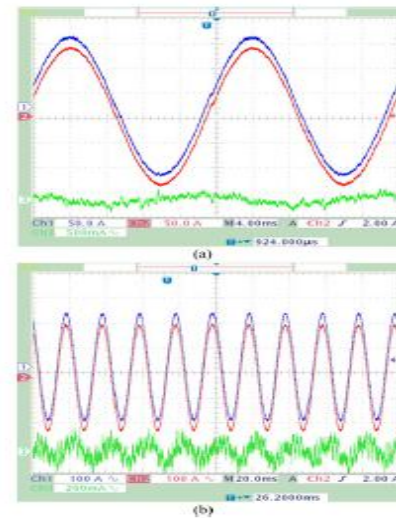


Fig. 12. Experimental results verify the effect of PBC in steady-state process. (a) Ch1: reactive current; Ch2: compensating current; Ch3: residual current of grid. (b) Ch1: reactive current; Ch2: compensating current; Ch3: residual current of grid.

in STATCOM and the capacity of STATCOM is not suggested for long-term operation in over Fig. 13 shows the dynamic performance of the dynamic process. When two STATCOMs steady-state process, at some point, the one generating current decreases output current the other one which generates the compensating same mutative value. The residual current of the distortion and then returns to the steady state The dynamic response of STATCOM is very Fig. 14 shows the experimental results in the and stopping process. As shown in Fig. 14(a), when other STATCOM which generates the also starts running right away and generates the compensating current to compensate the reactive compensating current also stops running at once significant overcompensation. When the system or stops running, the residual current of the grid has a very small process. The cells in each cluster can attain consistent with U^* dc rapidly. The dc voltage deviation is no more than 10 V. After reaching steady state, U_{kdc} ($k = a, b, c$) have less deviation compared with U^* dc and the steady-state error is less than 5 V. In Fig. 16(b), when the output current of STATCOM has a sharp change, U^* dc is maintained at the reference voltage value.

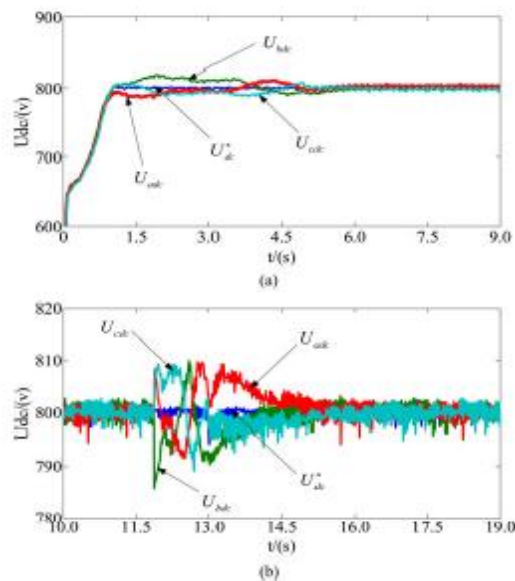


Fig. 16. Experimental waveforms for testing clustered balancing control in the startup process and dynamic process. (a) DC mean voltage of all converter cells U_{dc}^* ; dc mean voltage U_{kdc} ($k = a, b, c$) of 12 cascaded converter cells in each cluster. (b) DC mean voltage of all converter cells U_{dc}^* ; dc mean voltage U_{kdc} ($k = a, b, c$) of 12 cascaded converter cells in each cluster.

VI. FUTURE WORK

The balanced and no distorted grid only lies sequence component and the harmonic in the unbalanced and distorted grid, but they do not the balanced and no distorted grid. So, on basis results in this paper, H-bridge cascaded achieve the satisfactory performance under unbalanced controller and the harmonic component restraining the impact of the negative sequence dc capacitor voltage balancing control.

To achieve this objective, in further investigation, the authors

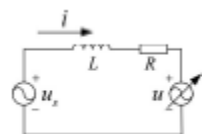


Fig. 18. a-phase cluster equivalent circuit of H-bridge cascaded STATCOM.

Dissipativity is the fundamental property of closely related to energy losses and energy. The typical example of energy dissipation which partial electric energy and magnetic energy the resistor in the form of heat. To accurately define it requires two functions:

one reflects the rate of that flow into the system, namely supply rate; is energy storage function that measure the system. These functions are connected by dissipative “dissipative inequality,” we mean that the supply energy storage along with the time track of the dissipation system. This means that the should be no more than that of the external supply and the difference between the energy. Now, we introduce the dissipation system theory circuit of H-bridge cascaded STATCOM which is shown.

APPENDIX

The dissipation system theory, it is necessary to know the definition of the dissipation system to prove that H-bridge cascaded STATCOM is strictly passive. Moreover, the energy storage function of system should be selected properly. Let us first recall the definition of the dissipation system. Then, we will introduce that how to select the energy storage function of the system in this paper. Fig. 16. Experimental waveforms for testing clustered balancing control .the startup process and dynamic process. (a) DC mean voltage of all converter cells U_{dc}^* ; dc mean voltage U_{kdc} ($k = a, b, c$) of 12 cascaded converter cells in each cluster. (b) DC mean voltage of all converter cells U_{dc}^* ; dc mean voltage U_{kdc} ($k = a, b, c$) of 12 cascaded converter cells in each cluster. U_{kdc} ($k = a, b, c$) are shown clearly as three. Then, the clustered balancing control is triggered. curves converge as one quickly. U_{kdc} ($k = a, b$, consistent with U_{dc}^* . The max deviation is no 15 V and the steady-state error is less than 5 V. verify that the proposed method of clustered is effective for balancing dc voltages among it avoids the overvoltage protection of dc make. Fig. 17 shows the experimental waveforms of 12 cluster for testing individual balancing control realized by shifting the modulation wave vertically in steady state

V. CONCLUSION

This paper has analyzed the fundamentals of STATCOM based on multilevel H-bridge converter with star configuration. And then, the actual H-bridge cascaded STATCOM rated

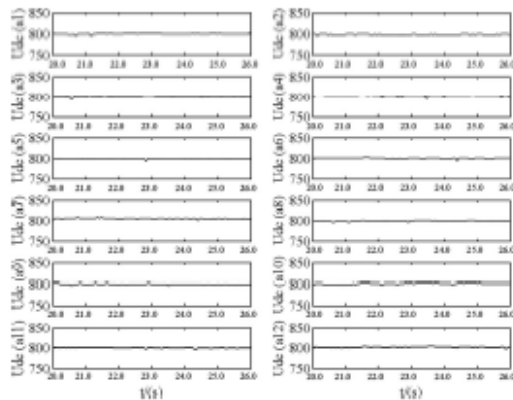


Fig. 17. Experimental waveforms of 12 cells in a-phase cluster for testing individual balancing control in the steady-state process.

10 kV 2 MVA is constructed and the novel also proposed in detail. The proposed methods has the following characteristics.

1) A PBC theory-based nonlinear controller is STATCOM with this cascaded structure for the loop control, and the viability is verified .

2) The PR controller is designed for overall voltage control and the experimental result proves that it has better performance in terms of response time and damping profile

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