Virtual DC Generator Control Strategy for Load DC-DC converter

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Abstract

DC distribution can reduce the converter link, improve power efficiency, while make renewable energy access convenient, and there is no need to consider the stability of frequency, reactive power and other issues. As a micro-grid power feed part, DC/DC converter's control method is particularly important. A control method of DC generator that suitable for the DC/DC converter connect to energy storage and load has been proposed, which inherits inertia characteristics of rotation motor. This strategy will try to eliminate the effects of load's output and restore disturbed load side voltage softly while the device put in or cut off from the bus. DC/DC small-signal model has been established, proving that power response of DC/DC converter controlled by virtual DC generator strategy in DC bus voltage fluctuation process is inversely proportional to its damping parameters. Therefore the absorption of the bus power can be adjusted automatically according to the change of the bus voltage, response the fluctuations of the bus voltage and support the recovery of bus voltage Simulation and experimental results verify the feasibility and correctness of the proposed control strategy.

Keywords: DC microgrid; virtual DC generator control strategy; Small-signal model; DC bus voltage

Introduction

In recent years, micro-grid[1] which can provide combined cooling heating and power to the load within the region , but also can runs parallel with the grid is a growing concern. DC micro-grid[2] means a micro-grid which consisting of micro power, power electronic interfaces, storage and load In DC mode transmission. Without the specific issues in AC distribution network, DC bus voltage and active power's balance on the DC bus has become an important criterion to judge whether the system operated stable.

DC/DC converter is the power electronic devices connected to the bus, load and important micro-power. Under normal circumstances, DC/DC converter bus's voltage or micro-power's voltage can be converted to a level that load or DC bus acceptable, however, in order to maintain the stability of the DC micro-grid operation, DC micro-grid PV Interface Unit Control based on the voltage droop control and MPPT control and power feed forward control strategies which can suppress bus voltage fluctuation have been proposed[3]. Although the above method can be maintained the stable of bus voltage to a certain extent, but the strategy for a small range of DC bus voltage fluctuations and mutations did not mention. Paper [4] proposed using feed forward plus feedback control strategy to eliminate the influence of the DC bus voltage fluctuations on the output load. But its control strategy can only eliminate the impact of load caused by change on the bus, Unable to control access to the bus when the bus power disturbances to support bus voltage recovery, and its load voltage recovery process is not a flexible process. Currently control strategy for Load DC-DC converter still lacks flexibility, lack the ability to share bus power automatically, therefore, we need to search a flexible robust strategy for DC/DC converter.

The paper presents a Virtual DC Generator Control Strategy[5] for Load DC-DC converter, and use Virtual DC Generator Control Strategy to simulate the armature current of DC generator, speed, electromagnetic torque of the motor, etc., that enable DC/DC converter output characteristics consistent with the DC generator. DC converter with Virtual DC Generator Control Strategy can maintain the load side voltage as ratings, less access to power at the bus when bus voltage drop, support bus voltage recovery. At the bus side, change process of load-side voltage is an ease shock process, doesn't have a strong impact, enhance the stability of the DC grid effectively.

Boost converter

In the DC micro-grid system, the DC bus voltage and load voltage value are uniform, therefore need to load DC converter DC bus access, therefore we need a Buck converter or Boost converter connect to load. Because this paper focuses on the control strategy of DC/DC converter, therefore, only use Boost converter in the simulation and experiment. Boost converter topologies and its control methods is shown as below:

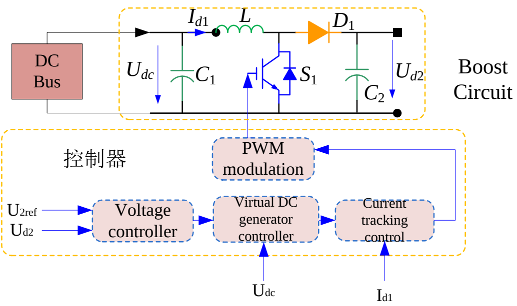


Fig.1 Boost type DC/DC converter and its control

Boost converter connected to the high voltage DC load and DC bus, it control the bus voltage fluctuations, maintain the load side voltage stability, response to disturbances of bus voltage by collecting the load side voltage and bus side current through voltage current controller and Virtual DC Generator controller generate PWM wave.

Virtual DC generator control strategy

DC generator equivalent equation

Electrical excitation DC generator mainly through other current flows through the excitation coil produces a magnetic flux to provide the required excitation for generator. For electrical excitation DC generators, when the generator load carried or speed changes, it maintains the generator output voltage constant by adjusting the size of the generator excitation current[6]. Its mechanical torque provides a relative inertia to voltage fluctuations, providing a buffer for the fluctuations. Because of DC generator has characteristics like adjusting voltage and inertia conveniently, this paper simulates the mechanical properties and electromagnetic properties of DC generator to control the DC/DC converter to make the output voltage stability. AS Figure2 shown dual relationship exists between the DC generator and DC/DC converter's two-port network[7].

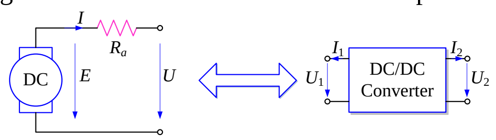


Fig.2 Principle of virtual DC generator

DC generator is an electrical equipment, It consists of two parts, both electrical and mechanical:

Mechanical equation:

$$J\frac{d\omega}{dt} = T_m - T_e - D(\omega - \omega_0)$$

(1)

$$T_m = P_e/\omega = EI/\omega$$

(2)

Among them: J: Moment of inertia; D: Damping; T_m,T_e: Mechanical and electromagnetic torque; ω: The actual angular velocity; ω0: Rated angular velocity.

Equation (1), (2) shows that, virtual electromagnetic torque of DC generator is brake nature to the virtual machine torque which supplied by DC bus. When the power balanced, there is no power exchange so that the bus voltage is stable, the power exchange of DC/DC converter and DC bus voltage will result the change of EMF and armature terminal voltage, which means the changes of load terminal voltage. Its mechanical torque can provide a inertia that can make the DC converter combine with DC bus flexibility, provide a buffering for the bus voltage fluctuation.

Armature equation:

$$E = C_T\emptyset\omega$$

(3)

$$E = U + IR_a$$

(4)

Among them: E: Armature EMF; I: Armature current; C_T: Torque coefficient; U: Terminal voltage;

R_a: Equivalent resistance of armature;Φ: Flux.

By equation (3) shows that, when the field current is constant, induced electromotive force is proportional to the angular velocity, this paper adjust the actual angular velocity based on the mechanical equation of DC generator, thereby adjusting the EMF E, maintain EMF stability, thus ensuring the output voltage constant, which means maintain the balance of load terminal voltage.

We can get the Virtual DC generator control strategy shown in Figure 4 by the equation (1) to (4). I_{ref} is DC current reference of DC converter through Virtual DC generator control strategy; I_1 is the real load side current of DC/DC converter; U_{2ref} is the reference value of load-side voltage; U_2 is the actual value of the load-side voltage; D is the damping coefficient; ω is the actual angular velocity; ω_0 is rated angular velocity.

Virtual DC generator control strategy

Shown in Figure 3, the control system is divided into three parts. In the voltage regulator control section, after compare the load voltage U2 detected in load side to Voltage reference value, through PI control and multiplied by Voltage reference value we can get the difference between mechanical power and the output active power of DC/DC converter by calculated, adding to the P_{ref} we can get mechanical power P_m. In the Virtual DC generator control section, we can build the model of Virtual DC generator according to the mechanical equation and armature equation of DC generator. Mechanical equation make the model has the same moment of inertia as DC generator. Because of the existence of such inertia, bus voltage would produce a certain ease shocks when subjected to a load change impacts, and the voltage drop of boost converter under Virtual DC generator control is much smaller than under PI control.

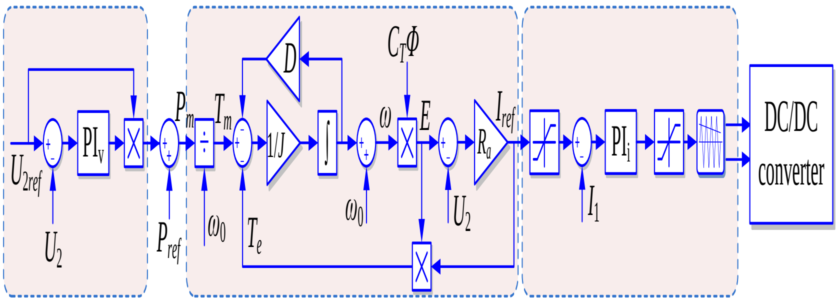


Fig.3 Virtual DC generator control strategy

Mechanical torque is obtained by dividing the mechanical power P_m, and nominal angular velocity, angular velocity ω can be obtained by simulating the actual DC generator's mechanical properties. By the armature characteristics described in equation (3), (4) we can obtain current reference value I_{ref}, Reference armature current through the current tracking control generates PWM signal to control DC/DC converter. Virtual DC generator control strategy can calculate appropriate and stable operating point of load side voltage under the current circumstances when the bus voltage disturbance occurs, angular velocity is adjusted by adjusting the output torque and thus control the output of armature voltage, In the inertia property of virtual DC generator the voltage of load side would at its nominal value through a cushion shock process.

After the virtual DC generator control strategy shown in Figure 3, we can make two-port external characteristics of DC/DC converter consistent with the output of the DC generator.

Small-signal model of virtual DC generator

Based on the explain of the virtual DC generator control strategy in the second part, we can obtain a small signal of mathematical model about power fluctuations when bus voltage changes which shown in Figure 5.

$$P = \frac{E-U}{R}E = \frac{(C_T\phi\omega)^2}{R} - \frac{UC_T\phi\omega}{R} \quad (5)$$

$$\frac{\partial P}{\partial \omega} = \frac{2(C_T\phi)^2\omega_0}{R} - \frac{UC_T\phi}{R} \quad (6)$$

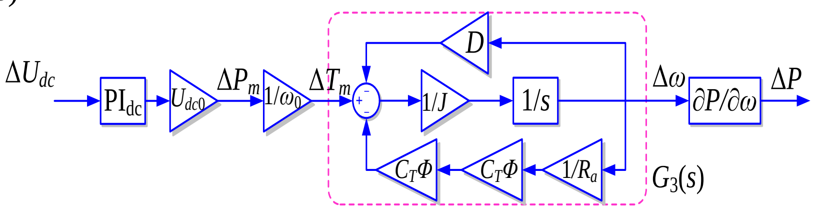


Fig.4 Small-signal model of a virtual DC generator

Based on the small-signal model shown in Figure 5, small-signal model can be simplified as what shown in Figure 5.

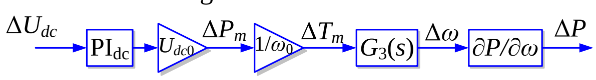


Fig.5 Simple virtual DC generator small-signal model

Because Figure 4 and Figure 5, we can get the transfer function between the DC bus voltage deviation ΔUdc and load switching power deviation ΔP.

$$G'(s)|_{s=0} = \frac{\Delta P}{\Delta U_{dc}}|_{s=0} = \frac{U_{dc0}}{\omega_0} PI_{dc} G(s) = \frac{U_{dc0}}{\omega_0} k_p \frac{R_a}{D(C_T\phi)^2}\left[\frac{2(C_T\phi)^2\omega_0}{R_a} - \frac{UC_T\phi}{R_a}\right] \propto \frac{1}{D} \quad (7)$$

Visibly, power responses of DC converter interface that under the virtual DC generator control inversely proportional to its damping parameter D in the DC bus voltage fluctuation process. From this, we know Virtual synchronous generator control strategies can be self-regulating on the power access on bus and response to the bus voltage disturbances.

Simulations

In this paper, simulation based on PSCAD / EMTDC used to validate the proposed control strategy. DC bus voltages operate stability on 400V initially, after 1s DC bus voltage drops because of disturbances.

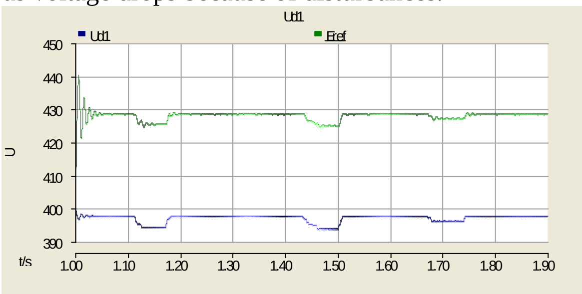
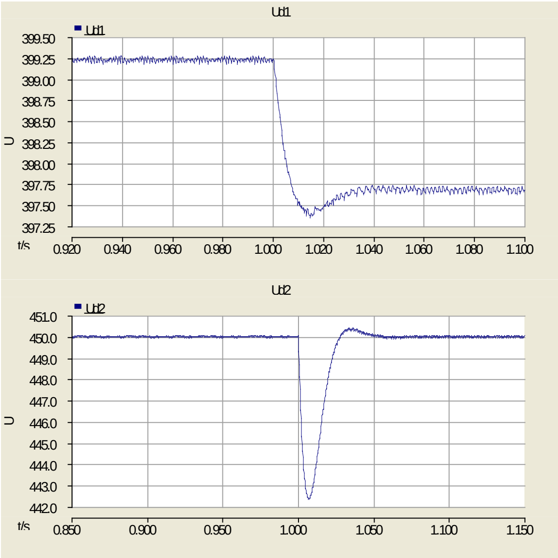


Fig.6 Bus voltage and terminal voltage while disturbed

Figure 6 shows that, when DC bus voltage drops because of disturbances, virtual armature electromotive force of Boost converter will change based on the changes of DC bus, thereby reducing the power access of the DC bus, support bus voltage recovery effectively.

PI control and virtual DC generator control were used with the boost circuit in the same conditions. The initial bus voltage stable operates at 400V, at 1S systems continue to invest load, causing the system DC bus voltage disturbances. Among them, series inductance is 1mH, output filter capacitor is 3.3mF; load is paralleled by constant load 100Ω and 50Ω; simulation time is 2s, step is 250μs. Initially only supply power to one group of load, increases another group of load at 1s, two group of load parallel operation.

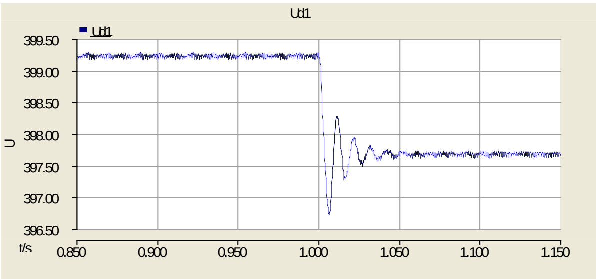
(1) PI control: curve of bus voltage and load voltage when the boost converter under the control of PI control is shown in Figure 7 (a), (b). When there are fluctuations on load power, the bus voltage which disturbed will has a reply trend under PI control, bus voltage values eventually stabilize at 397V only produces a small range of voltage drop, the load-side voltage can be stabilized at rating 450V. Conventional PI control strategy can maintain the balance of voltage at the load side, but the change of the voltage is still very awkward.

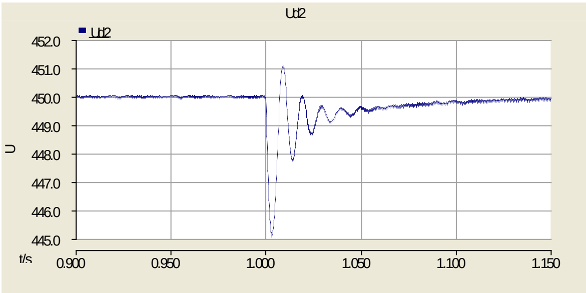


(a) The bus voltage under PI control (b)The load-side voltage under PI control

Fig.7 DC micro-grid and load-side voltage bus voltage when PI controlled

(2) Virtual DC generator control strategy: curve of DC bus voltage and load side voltage under virtual DC generator control is shown in Figure 8 (a), (b). When the bus voltage drops due to the virtual DC generator control the boost converter will reduce the access of bus voltage's power, so we can maintain the value of bus voltage stable at 397V. And Compared to PI control, Virtual DC generator control increase inertia, so that the voltage will through an eased and shock process to recovery without produce a strong impact on other devices on the bus. The overshoot of Virtual DC generator control strategy is more superior compared to the PI control.





(a)DC bus voltage under virtual DC generator control (b) Load side voltage under virtual DC generator control

Fig.8 DC bus voltage and micro-grid load side voltage when virtual DC generator controlled

Experiments

In order to verify the feasibility of the virtual DC generator control strategy in practical systems, this paper built a conventional 10KW Boost converter prototype, and access in micro-grid of laboratory for single-phase boost control experiments. In the prototype, DC voltage is 400V, load is constant impedance load, and boost circuits were tested under PI control and virtual DC generator control. The results of experiments prove the feasibility of the control strategy this paper proposed. Experimental prototype is shown as below:

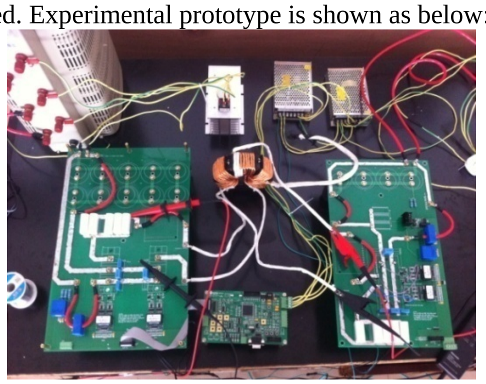
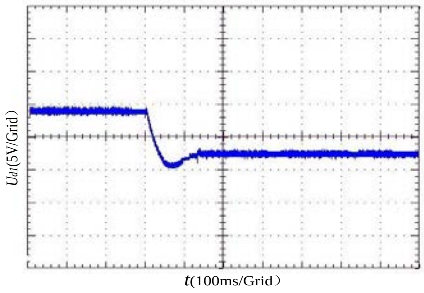
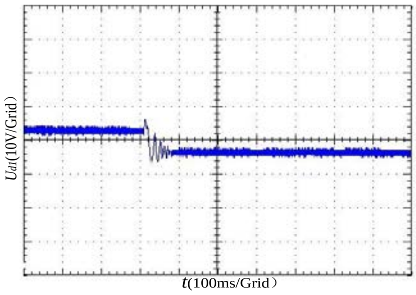


Fig9 Experimental prototype

The test result of bus voltage on oscilloscope is shown in Figure 10. Figure 10 (a) is the DC bus voltage waveforms under PI control, when the load changes, bus voltage will produce a direct voltage drop, which will have some impact on other electrical equipment. Figure 10 (b) is the DC bus voltage curve under the virtual DC generator control, boost converter under virtual DC generator control improves the inertial of micro sources, improves the transient performance, so that the voltage will recovery at a moderate concussion process. Virtual DC generator control strategy makes the converter has ability to respond to the bus voltage disturbances, similar to the simulation results.





(a) DC bus voltage waveforms under PI control (b) DC bus voltage waveforms under the Virtual DC generator control

Fig.10 Experimental waveforms

Conclusions

In DC micro-grid, when the bus voltage occurs disturbance, need load DC converter has the ability of stabilizing the load side voltage and support bus voltage recovery; reduce the impact of voltage drop. This paper proposed a control strategy based on virtual DC generator, Virtual DC generator control strategy is a robust, flexible DC/DC converter control strategy. The strategy can solve the problem of the DC bus voltage fluctuation problem which lead by load changes effectively and make the load side voltage return to its rating voltage softly. When the bus voltage drops, boost converter will reduce the access power on bus automatically support bus voltage recovery.

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