Sliding Mode Control Strategy of Dynamic Voltage Restorer

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***Abstract*—The dynamic voltage restorer (DVR) is great significance for improving power quality as a cost effective solution for the protection of sensitive loads from voltage sags. This paper summarizes Sliding Mode Control (SMC) method used in current control strategies for DVR including forward-feed control and PI feedback control. After this paper, it presents SMC for DVR including the design of switch function and control regulation. And the experiment results are presented to demonstrate the efficacy of proposed DVR controller for various voltage sags.**

***Index Term*—Dynamic Voltage Restorer (DVR); Sliding Mode Control; Feedback Control**

I. INTRODUCTION

With the increasing of demand for industry automation, various automation control equipment is widely used in different major area. However, some special equipment make it sensitive to change voltage, especially during the several periods for voltage sags, the circuit does not work, which directly causes that users lose abundance benefit. Therefore, it is necessary to solve the above problem by using advanced control idea.

Dynamic Voltage Restorer (DVR), as one of the devices to solve those problems, prevents the voltage sags and improves effectively application quality of electrical energy. It realizes that during the time that electrical equipment is running, DVR compensates the difference between general voltage and fault voltage, to make them run normally[1].

Until now, DVR control strategy consists of two kinds: forward feed control and feedback control. The feedback control methods mainly use PI control which include output voltage feedback for single loop control, and voltage and current feedback for double loop control.

Forward feed control is defined as the difference between reference voltage and measuring voltage for system. According to the calculation of inverter to obtain the benchmark signal of voltage compensation, drive inverter injects the voltage compensation to system by the drive pulse with PWM. The above method have some advantages, such as swiftness speed response for dynamics quality and easy control[2]. However, based on the open loop control that influences the stabilization for system, the control strategy application cause instability for DVR system and aberrance output wave form. Similarly, there are attenuation for the range of wave form and excursion for phase, after the output voltage of inverter is filtered by filters and transformed by series transformer. The above method realizes that feedback system is use in DVR control system.

Feedback control comprises two spices: voltage feedback control and current feedback control. Single loop voltage control and double loop current control is widely used, most of which apply forward feed control combined with feedback control. By reviewing other paper[3], DVR adopts voltage instantaneous feedback control strategy that improves dynamic quality of system, but fits for nonlinear system and decreases the steady range of the system. In many cases, the application of voltage feedback control combining with forward feed control is widely adopt, because it mends the effect of voltage compensation and leads swift response, whereas curtails the steady range of the system[4].

Current control, as the state feedback control, that improves the dynamic and steady quality for system, is gradually applied. For its application, forward feed control with voltage feedback or current feedback control is more general[5][6]. The paper[6] analyses filter inductance current and filter capacitance current control, that indicate excellent compensation result by not only adopting the two current control separately, but also applying them together. Nevertheless, It is necessary to argue that because load current is included in inductance current, the result for compensation and regulation shows weakening quality when load brings harmonic that causes to introduce inductance not judged by controller.

The above feedback control methods are realized by PI control, though there are some lacks. This paper discusses application of sliding mode variable structure control in DVR feedback control system, provides a novel strategy to solve the above problem in which some simulation results indicate the it feasibility.

II. SLIDING MODE VARIABLE STRUCTURE FEEDBACK CONTRAL

A. Model of DVR System

DVR system mainly includes energy storage device, frequency converter, controller, filter and series transformer that are showed as Fig 1. Each phase of the three phase circuit is controlled, respectively, whose principle and block are showed as Fig.2. Let us define the following variables as: u_{sys} defined as input voltage for system, u_{load} as load voltage, u_c

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as compensation voltage, u_r as output voltage of inverter, L as filter inductance, C as filter capacitance, i_{fl} as filter inductance current, i_{fc} as filter capacitance current, i_l as load current, where inverter is regarded as linear output.

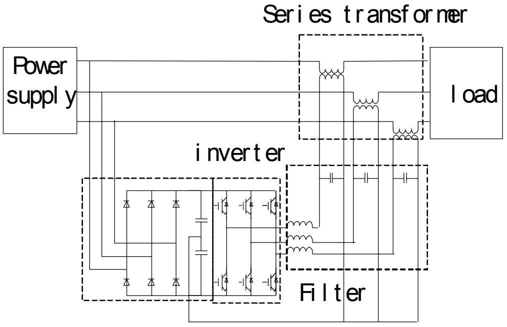

Fig. 1. Main circuit of DVR

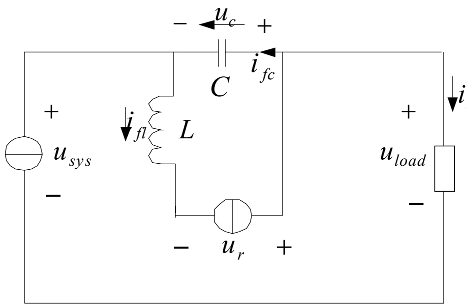

Fig. 2. Equivalent circuit of the proposed DVR

The state space representation of Fig 2,is given by:

$$\frac{du_c}{dt}=\frac{1}{C}(i_{fl}-i_l) \tag{1}$$

$$\frac{di_{fl}}{dt}=-\frac{u_c}{L}+\frac{u_r}{L} \tag{2}$$

The system can be written as: $\dot{X}(t)=AX(t)+BU(t)$ $X(t)=[u_c(t)\ \ i_{fl}(t)\ ]^{\mathrm{T}}$ $U(t)=u_r(t)$ Where:

$$A=\begin{bmatrix}0 & \frac{1}{C}\\ -\frac{1}{L} & 0\end{bmatrix} \qquad B=\begin{bmatrix}0 & \frac{1}{L}\end{bmatrix}^T$$

B. *The design of switch function for sliding mode controller*

It is necessary to satisfactory the three conditions[7~9]:

Condition 1: For all linear control system, dynamic of sliding mode $S=C'X=0$ is decided by C' in sliding mode surface.

Condition 2: For all linear control system, only when $\det[C'\ \ B]\neq 0$, sliding mode surface is present and attainable.

Condition 3: The radix for eigenequation of sliding mode differential eguation is negative real number, to keep the steady for sliding mode movement in sliding mode surface $S=0$.

Where $C'=[C_1\ \ \ 1]$ Sliding mode differential equation can be written as $\dot{x}_1=(A_{11}-A_{12}C_1)x_1$, when the system moves to sliding mode surface. Where the culmination of sliding mode is –2000, and there is the equation written as: $C_1=2000C$, therefore, three conditions will be reached.

C. *Design of control law*

Let us apply exponential direction principle:

$$\frac{dS}{dt}=-kS-\varepsilon\,\mathrm{sgn}(S) \tag{3}$$

where the sum of k and ε is positive real number. By calculating differential equation $S=C'X$, the system model will be written by:

$$\frac{dS}{dt}=C'\frac{dX}{dt}=C'AX+C'BU=-kS-\varepsilon\,\mathrm{sgn}(S)$$

Therefore, the control law can be described as:

$$U=-(C'B)^{-1}(C'AX+kS+\varepsilon\,\mathrm{sgn}(S)) \tag{4}$$

Hence, sliding mode variable controller can be decided by C' and equation (4), where the selection of parameter k depend on dynamic of sliding mode surface; the selection of parameter ε is purpose to reduce the error by friction and similar linearization, to get excellent robust quality for the system.

Meanwhile, in the application system, capacitance voltage is obtained by the difference between reference voltage and load voltage, that forms voltage feedback loop; inductance current is load current. Fig.3 demonstrates the control law for DVR system that adds forward feed control.

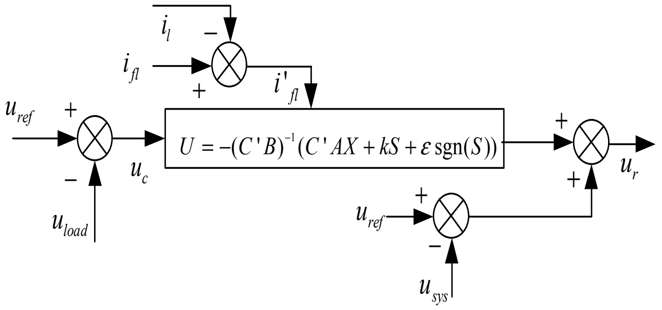

Fig. 3. Block diagram of the DVR system controller

III. EXPERIMENT RESULT

DVR system is run by PSCAD/EMTDC software, applies completeness compensation strategy, where applying uncontrollable rectifier load with parallel connecting filter. At 0.7 sec, a voltage fault happens, which caused voltage sags instantaneously. Fig 4, Fig 5, and Fig 6 show the result of experiment, where Esa, Esb and Esc are defined as system voltage, as well as Eya , Eyb and Eyc as load voltage. The following diagrams shows the excellent compensation effect and dynamic response by using sliding mode control.

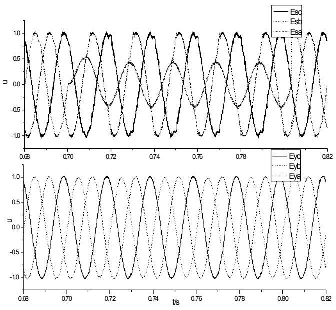

Fig. 4. Compensation of single-phase voltage sag

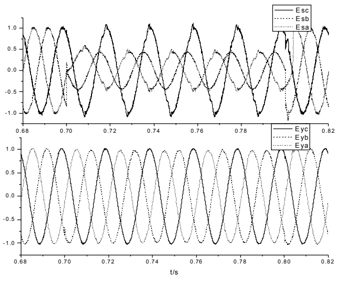

Fig. 5. Compensation of two-phase voltage sag

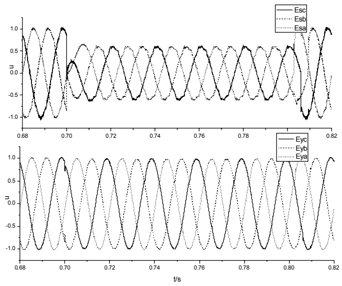

Fig.6 Compensation of three-phase voltage sag

IV. CONCLUSION

This paper analyze the control strategy of DVR system that use sliding mode variable structure control, and shows the excellent control result by experiment wave form. By the above discussion, we can get the conclusion that sliding mode variable control provided with practicality and simple design.

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