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Modeling and Dynamic Characteristics Analysis of DVR Inverter

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Abstract

Dynamic voltage restorer (DVR) can rapidly output a compensation voltage with required amplitude and phase angle when voltage disturbance occurs in the grid. So it is equivalent to a controlled AC controlled power source and its core part is an inverter. Modeling and dynamic characteristics is the basis and premise of DVR design. The paper constitutes the mathematic model and deduces the equivalent circuit of H bridge inverter of DVR used in low-voltage distribution grid. By virtue of the model, this paper analyses the key factors related to dynamics characteristics of DVR inverter. Based on theoretical analysis, transient process is simulated under various situations. Simulation results indicate three-H bridge DVR inverter has high response speed and can meet the demand of voltage compensation.

Keywords: DVR; Inverter; Math model; Dynamic characteristics

Introduction

In medium-voltage or low-voltage distribution grid, there are some fast and short-time voltage faults such as sag and swell, which will cause fatal damage for some sensitive loads. While DVR is compensation equipment aiming at grid voltage fault mentioned above. Generally, DVR locates between the grid and the load and it will output the difference between rated voltage and faulty voltage when voltage disturbances occur. So, DVR must rapidly and accurately generate the compensation voltage, which largely depends on the inverter, the core part of DVR.[1]

For DVR used in low-voltage distribution grid, there are three optional topologies: three-phase four-line half bridge, three-phase four-leg bridge, three-H bridge. By analysis and calculation, we can concludes that three-H bridge has the highest DC voltage utilization ratio, the strongest adaptive capability to unbalance, the most flexible and simple control strategy. And it is the only topology can remove the transformer. So, three-H bridge is preferred topology for low-voltage DVR.

To guarantee DVR can fully compensate voltage fault in the grid, the inverter should have satisfactory static characteristics as well as dynamic characteristics, which all are related to main circuit parameters and control strategy. While accurate math model and reasonable dynamic characteristics analysis are the basis and premise of DVR inverter design.

As for three-H bridge inverter, each one of three single phase full bridge is independent with other ones. And three phases are symmetry and balance as a whole. So, in the process of modeling and analysis, three phases can be simplified to one phase, that is one single H bridge[3].

This paper constitutes math model and analyses dynamic characteristics of the separated inverter and the inverter connected in DVR respectively.

Modeling and Dynamic Characteristics Analysis of DVR Inverter [2-5]

Shown as Fig. 1, three-H bridge DVR inverter has three identical single full bridges and each bridge is composed of four power semiconductor devices. Because of the symmetry and the independence of DVR inverter in respect of structure and performance, three-H bridge topology can be simplified and illustrated by Fig. 2.

Next, the paper mainly focuses on the independent single phase H bridge in detail. In power system with DVR, the load voltage is the sum of grid voltage and DVR inverter voltage. According to superposition principle, when researching sole inverter, we can regard grid voltage as zero and independently analyze the function of inverter. Fig. 3 is the circuit of single phase H bridge, where R_L is inductor parasitic resistance; R_C is capacitor parasitic resistance.

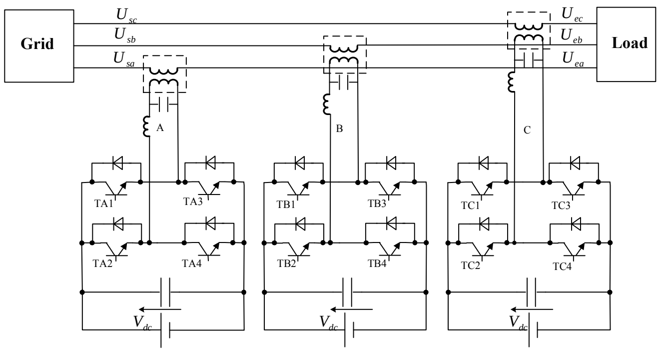


Fig. 1 Three-H bridge

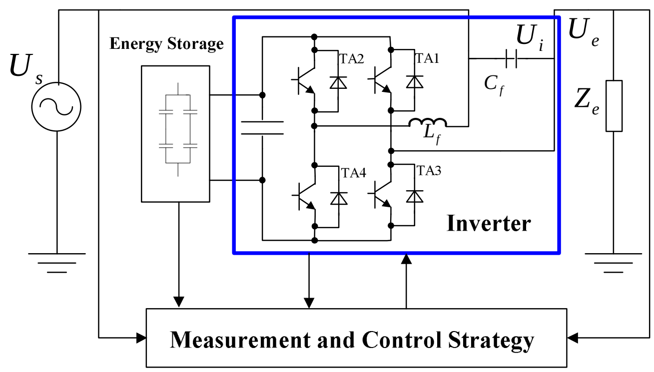


Fig. 2 Simplified structure diagram of DVR

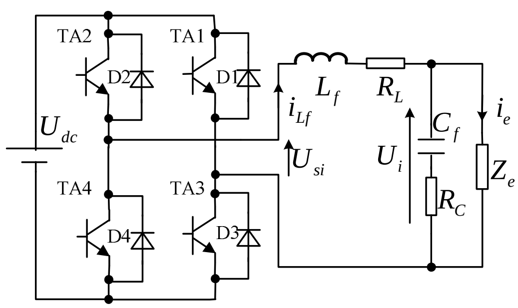


Fig. 3 Single phase H bridge

Mathematical Description of Switch Array

One single H bridge is composed of four fully controlled power devices T1~T4 and their anti-parallel diodes D1~D4, which is shown by Fig.3. Switch array is controlled by SPWM pulses and changes DC voltage to various pulses series.

For example, if T2 together with T3 (or D2 together with D3) are switched on simultaneously, their output is : $u_{si}(t) = 1 \cdot u_{dc}(t)$;

If T1 together with T4 (or D1 together with D4) are switched on simultaneously, the output is : $u_{si}(t) = -1 \cdot u_{dc}(t)$;

If T1 together with D2 (or T3 together with D4) are switched on simultaneously, their output is : $u_{si}(t) = 0 \cdot u_{dc}(t)$.

In a general way, the relation between the input and the output of switch array is expressed as:

$$u_{si}(t) = f_s(t) \cdot u_{dc}(t) \tag{1}$$

where $f_s(t)$ is switch function and :

$$f_s(t) = \begin{cases} 1 & ,C1 \\ 0 & ,C2 \\ -1 & ,C3 \end{cases}$$

, where C1~C3 are switching states of switch array.

The situation mentioned above is illustrated by Fig. 4.

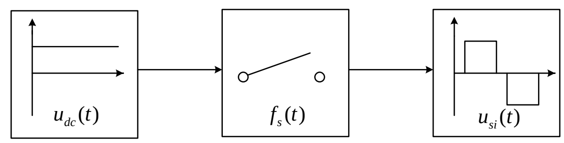


Fig. 4 Switch array model

The output of switch array is filtered by LC filter then it will become AC sine voltage.

Model of DVR Inverter

DVR is installed between the grid and the load and its current is same as load current. In analysis process, we regard the load as a current source shown as Fig. 5. Based on Fig. 5, the current of filter inductor i_{Lf} and the voltage of filter capacitor u_{cf} are chosen state variables, then state vector equation is obtained as follow:

$$\begin{bmatrix}\dot{u}_{Cf}\\ \dot{i}_{Lf}\end{bmatrix} = \begin{bmatrix}0 & \frac{1}{C_f}\\ -\frac{1}{L_f} & -\frac{R_C+R_L}{L_f}\end{bmatrix}\cdot\begin{bmatrix}u_{Cf}\\ i_{Lf}\end{bmatrix} + \begin{bmatrix}-\frac{1}{C_f}\\ \frac{R_C}{L_f}\end{bmatrix}\cdot i_e + \begin{bmatrix}0\\ \frac{1}{L_f}\end{bmatrix}\cdot u_{si}$$

(2)

According to (2), transfer function in S area can be obtained as (3).

$$\begin{aligned} U_i(s) = {} & \frac{1+sC_fR_C}{s^2L_fC_f + sC_f(R_L+R_C)+1}\cdot U_{si}(s) \\ & + \frac{-(s^2L_fC_fR_C + s(L_f + C_fR_LR_C) + R_L)}{s^2L_fC_f + sC_f(R_L+R_C)+1}\cdot I_e(s) \end{aligned} \tag{3}$$

Thereby, we can obtain the block diagram of separate inverter shown as Fig. 6.

And the block diagram of DVR inverter connected into power system is illustrated by Fig. 7.

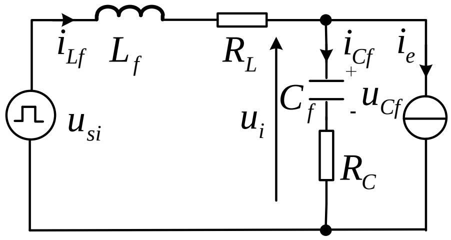


Fig. 5 Switch array

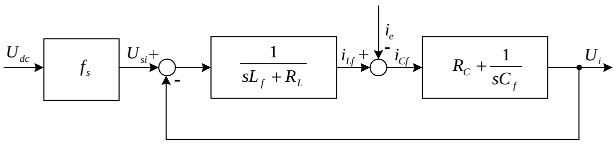


Fig. 6 Block diagram of separate inverter

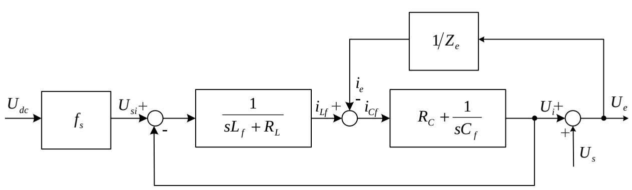


Fig. 7 Block diagram of DVR inverter connected into power system

Dynamic Characteristics Analysis of DVR Inverter

In the process of dynamic analysis, the load is simplified as a resistance. Suppose the initial values of inductor current and capacitor voltage all are zero. Inverter is analyzed by Laplace transformation method. Ignoring high frequency harmonics in inverter voltage, the equivalent circuit of DVR inverter in Laplace area is shown as Fig.8.

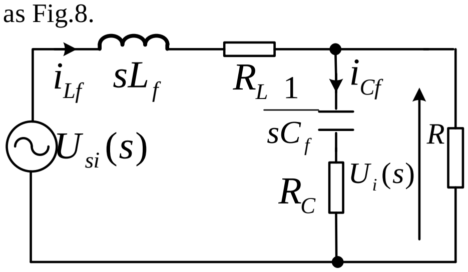


Fig. 8 Block diagram of DVR inverter connected into power system

Suppose inverter voltage in time area is :

$$u_{si} = A\sin(314t + \phi) \quad (4)$$

where A is its amplitude and ϕ is initial angle.

Translated by Laplace transformation, (4) become as:

$$U_{si}(s) = \frac{A(s\sin\phi + 314\cos\phi)}{s^2 + 314^2} \quad (5)$$

According to Fig.8, the output voltage of DVR inverter is:

$$U_i(s) = \frac{A(s\sin\phi + 314\cos\phi)}{s^2 + 314^2} \times \frac{sRR_C C_f + R}{s^2 L_f C_f (R + R_C) + s[C_f (R_L R + R_L R_C + R_C R) + L_f] + R_L + R} \quad (6)$$

Based on (6), DVR inverter is simulated by MATLAB. Fig.9~Fig10 are simulation results with different filter inductors and filter capacitors.

Case 1: The situation with L_f of different values, key parameters are:

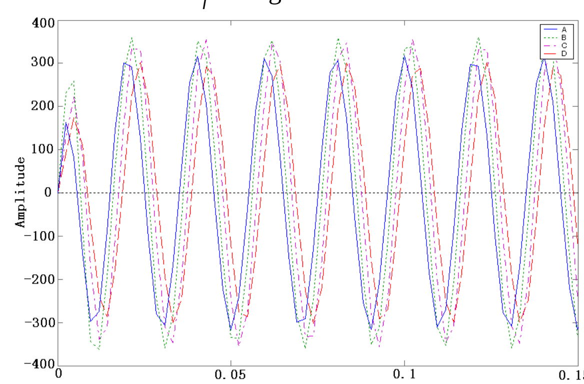
$$A = 311V, \phi = \pi/2, R_L = 0.001\Omega, R_C = 0.02\Omega,$$
$$C_f = 1000uF, R = 1\Omega, L_f = 100uH \sim 3mH$$

Fig. 9(a) is transient response of DVR inverter in 150 milliseconds; Fig. 9(b) is transient response of DVR inverter in 20 milliseconds. Table 1 is adjustment time of DVR when L_f changes.

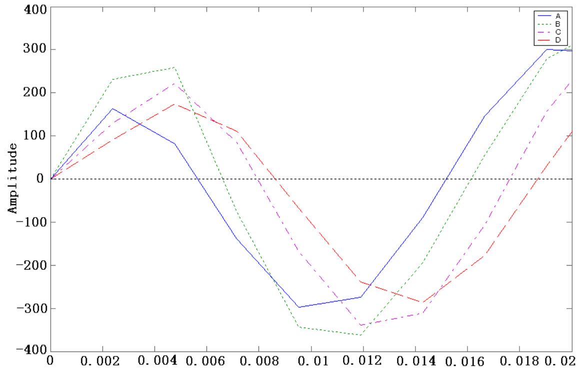
Case 2: The situation with C_f of different values, key parameters are:

$$A = 311V, \phi = \pi/2, R_L = 0.001\Omega, R_C = 0.02\Omega,$$
$$L_f = 1mH, R = 1\Omega, C_f = 500uF \sim 2500uF$$

Fig. 10(a) is transient response of DVR inverter in 150 milliseconds; Fig. 10(b) is transient response of DVR inverter in 20 milliseconds. Table 2 is adjustment time of DVR when C_f changes.



(a) Transient response in first 150 milliseconds

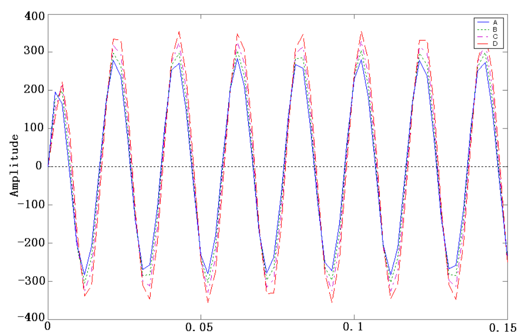


(b) Transient response in fist 20 milliseconds.

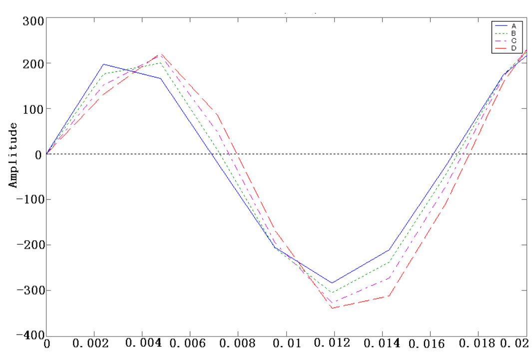
Fig. 9 DVR inverter transient response when L_f changes from small value to bigger one

Table 1Adjustment time of DVR inverter with different L_f

$L_f(mH)$	0.3	1	2	3
$t_s(ms)$	2.2	5.5	6.5	7



(a) Transient response in first 150 milliseconds.



(b) Transient response in fist 20 milliseconds.

Fig. 10 DVR inverter transient response when C_f changes from small value to bigger one

Table 2 Adjustment time of DVR inverter with different C_f

$C_f(uF)$	500	1500	2000	2500
$t_s(ms)$	2.5	5.5	5.8	6

Conclusion

The paper constructs mathematic model of DVR inverter and analyzes dynamic characteristics of the inverter. Simulation results indicate that DVR inverter dynamic performance directly relates to filter parameters. The bigger the values of filter inductor or capacitor are, the longer response time of DVR inverter is. With reasonable parameters, three-H bridge DVR inverter has high response speed and can meet the demand of voltage compensation.

Acknowledgments

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