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# Analysis on Topology of DVR Used in Low-voltage Distribution Grid

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## Abstract

Dynamic voltage restorer (DVR) is a series-connected transient voltage compensation equipment used in distribution grid aiming at dynamic power quality problems such as voltage sag and swell. The topology of DVR directly influences the output characteristics, the structure and the cost of overall DVR. This paper analyzes and compares three topologies applicable to low-voltage DVR in respect of DC voltage utilization ratio, adaptive capability to unbalance, flexibility and so on. The conclusion is reached that three-H bridge is the optimal topology for DVR used in low-voltage distribution grid.

**Keywords**: DVR; Three-phase four-line half bridge; Three-phase four-leg bridge; Three-H bridge.

## Introduction

DVR is a power quality control equipment aiming at transient voltage disturbance such as voltage sag and swell in distribution grid. According to its compensation types, DVR is classified into two categories: DVR based on line voltage compensation and DVR based on phase voltage compensation. Applied occasions and topologies of both DVR are different. As for DVR based on line voltage compensation, three phases are coupled with each other. So, this kind of DVR only outputs symmetry three phase line voltage and is difficult to compensate unbalanced power quality problems. While three phases in DVR based on phase voltage compensation are independent with each other. Thus the second kind of DVR can independently control the amplitude and the phase of compensation voltage and can be applied to adjust various voltage quality problems including asymmetry faults.

Medium-voltage distribution grids in China universally adopt non-ground neutral system [1], in which many loads such as synchronous machine with three-phase three-line only need symmetry line voltages. Hence, DVR based on line voltage compensation is suitable to medium-voltage distribution grid. Low-voltage distribution grids in China widely use three-phase four-line connection and unbalanced power quality problems frequently occur. Given this situation, DVR based on phase voltage compensation is appropriate for low-voltage distribution grid.[1]

According to the characteristics of low-voltage distribution grid, the paper researches and compares three suitable inverter topologies in respect of connection type and compensation property. Then, three-H bridge structure is determined to be the optimal topology.

## Operation Principle of DVR

To effectively compensate transient voltage disturbance in distribution grid, DVR is generally installed between the grid and the load in series illustrated by Fig. 1.

In the case of a grid voltage disturbance, DVR outputs the difference between faulty voltage and ideal one. As a result, the load voltage can remain normal. So, DVR is equivalent to a dynamic controlled AC voltage source. And its core part is an inverter which can output required voltage with specific amplitude and phase.

Shown as Fig. 2, if grid voltage is $\dot{V}_S$, load voltage keep normal value $\dot{V}_L$, then compensation voltage from DVR is: $\dot{V}_C = \dot{V}_L - \dot{V}_S$. The compensation voltage is generated by the inverter.

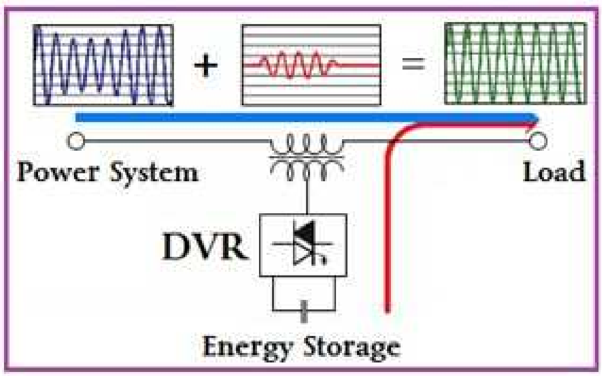


**Fig. 1 Schematic diagram of DVR**

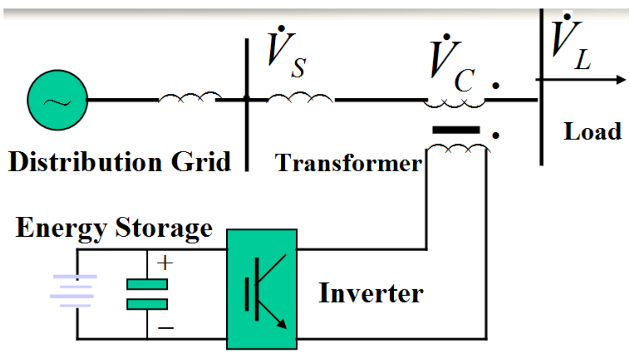


**Fig. 2 Overall structure of DVR**

## Analysis on Inverter Topology of DVR Based on Phase Voltage Compensation

As mentioned above, to meet the requirement of asymmetry voltage fault compensation, low-voltage distribution grids in China universally adopt DVR based on phase voltage compensation.

In DVR based on phase voltage compensation, amplitude and phase angle of each phase should be controlled independently. To realize the decoupling of three phases, there are several topologies and structures of DVR as follow:

(1) Three-phase four-line half bridge inverter connects the gird by star-connection transformer, in which neutral point of transformer is connected with neutral point of DC capacitor[2]. This case is shown as Fig. 3.

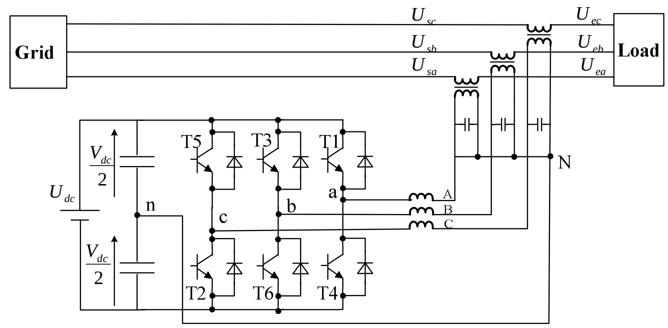


**Fig. 3 Three-phase four-line half bridge**

(2) Three-phase four-leg bridge inverter whose fourth leg makes up neutral point connects the gird by star-connection transformer, in which neutral point of transformer is connected with neutral point of fourth leg[3]. The situation is shown as Fig. 4.

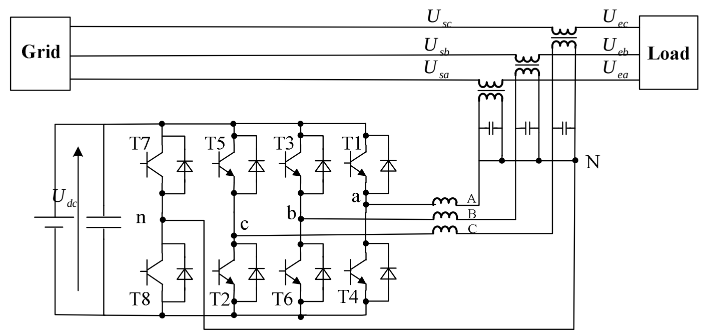


**Fig. 4 Three-phase four-leg bridge**

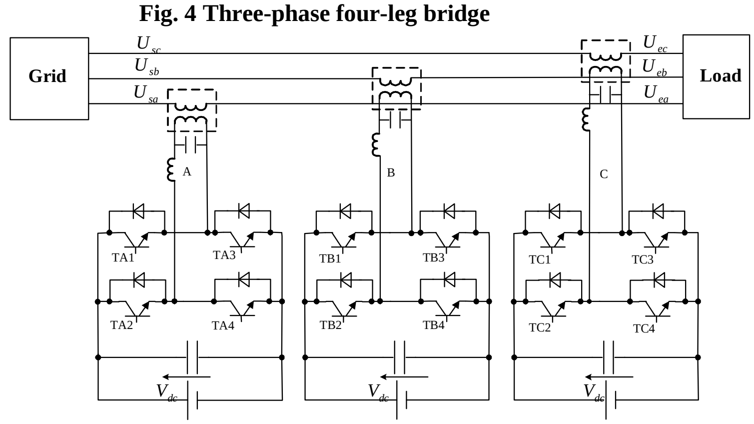


**Fig. 5 Three-H bridge**

(3) Three independent full bridges inverter which also is called three-H bridge can connect the gird by transformer or by filter capacitor. The situation is shown as Fig. 4.

Three-phase four-line half bridge is composed by 6 power semiconductor devices and has compact structure. Nevertheless, it has inherent drawbacks: Its DC terminal need two enormous capacitors in series to restrain the fluctuation of neutral voltage. When some asymmetry three-phase voltage disturbance occurs, the balanced current will flow to the neutral point, which

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possibly leads to voltage fluctuation of neutral point. As a result, compensation voltage from DVR inverter maybe deviates from required value. In addition, unbalanced current will reduce working life of DC capacitor.

Compared to three-phase four-line half bridge, three-phase four-leg inverter has a fourth leg composed by two power devices. The fourth leg can alleviate neutral point voltage unbalance to some extent. But, at the same time, the fourth leg is a common leg and is coupled with other three legs, thus, the control strategy is very complicated.[4-5]

Three-H bridge inverter combines three relatively independent full bridges to output three phase voltages, in which, there is no coupling within three phases. So, three-H bridge inverter has the strongest ability to compensate asymmetry and unbalanced voltage faults in three phase grid. Additionally, its control strategy is the simplest. Its drawback is that it comprises 12 power devices and has comparatively scattered structure.

[6] defines maximum available peak voltage per leg ratio $K_{MVPL}$ by (1), which indicates utilization ration of leg and DC voltage in various topologies. Controlled by conventional SPWM, $K_{MVPL}$ of each topology mentioned above is shown as table 1.

$$K_{MVPL} = V_{\max} \cdot \frac{N}{n} \cdot \frac{1}{U_{dc}} \tag{1}$$

Where: $V_{\max}$ is maximum amplitude of single phase voltage of an inverter; $N$ is phase number which can be controlled independently; $n$ is the number of legs; $U_{dc}$ is the voltage of DC bus.

**Table 1 Maximum available peak voltage per leg ratio**

| Topology | $K_{MVPL}$ |
|---|---|
| Three-phase four-line half bridge | $\frac{U_{dc}}{2} \cdot \frac{3}{3} \cdot \frac{1}{U_{dc}} = 0.5$ |
| Three-phase four-line bridge | $(\frac{U_{dc}}{\sqrt{3}} + \frac{U_{dc}}{2} - \frac{U_{dc}}{4\sqrt{3}}) \cdot \frac{3}{4} \cdot \frac{1}{U_{dc}} = 0.69$ |
| Three-H bridge | $U_{dc} \cdot \frac{3}{6} \cdot \frac{1}{U_{dc}} = 0.5$ |

Supposed voltage compensation capability which also is maximum output voltage of DVR inverter is confirmed. And note the maximum voltage as $U_{i\cdot\max}$.

According to the definition of $K_{MVPL}$ by (1) and Table 1, if DVR adopts the topology of three-phase four-line half bridge, the voltage of DC bus should be:

$$U_{dc}(1) = \frac{3}{3} \cdot \frac{1}{0.5} \cdot U_{i\cdot\max} = 2U_{i\cdot\max} \tag{2}$$

If DVR adopts the topology of three-phase four-leg bridge, the voltage of DC bus should be:

$$U_{dc}(2) = \frac{3}{4} \cdot \frac{1}{0.699} \cdot U_{i\cdot\max} \approx 1.073 U_{i\cdot\max} \tag{3}$$

If DVR adopts the topology of three-H bridge, the voltage of DC bus should be:

$$U_{dc}(3) = \frac{3}{6} \cdot \frac{1}{0.5} \cdot U_{i\cdot\max} = U_{i\cdot\max} \tag{4}$$

Based on calculation above, for a DVR with specific voltage compensation capability, three-phase four-line half bridge inverter requires minimum power devices, but the voltage stress of power devices in it is about twice as high as that in the later topologies.

The transformer in DVR can reduce voltage stress of power devices in the inverter and isolate grid voltage. But the nonlinear characteristics of transformer will lead to some problems: (1) There is transient inrush current or surge current caused by saturation and voltage sag, which will bring security risks for system operation; (2) The transformer generates extra harmonics, which add design difficulty of DVR filter; (3) The transformer increases the volume and weight of DVR.[7]

Given the drawbacks of transformer, in low-voltage distribution grid, the ideal situation is that DVR directionally connects the grid by filter capacitor and takes off the transformer. Next, the paper will analysis if each topology mentioned above is can be used in the DVR without transformer.

For example, nearby the point D in distribution grid shown in Fig. 6, there are various loads including single phase and three phases which comprise delta connection and star connection. And a DVR is installed between the point D and the loads. DVR topology may one type of among three ones mentioned above. If the transformers in the first two type of DVR are removed, the grid voltage and the load voltage both will turn faulty. Firstly, taking three-phase four-line DVR as example, the paper analysis the reason why the system can not work normally when the transformer is removed.

DVR without transformer connect the grid by filter capacitor. Six power devices T1~T6 in three-phase four-line inverter is controlled by SPWM pulses. In one moment, there is one and only one power device in each leg which is on. So, there always are three power devices that are on simultaneously in the whole inverter. Suppose T1, T2 and T3 of three-phase four-line inverter shown as

Fig. 3 are simultaneously switched on, then the phase voltage $u_a$ and $u_b$ will be develop short circuit via filter inductors, which is a severe fault. At the same time, two of three phase loads likely are connected with neutral line simultaneously for there is no isolation of transformer, which will lead to load failure.

The case of three-phase four-leg DVR without transformer is similar to three-phase four-line. Hence, for three-phase four-line DVR and three-phase four-leg DVR, the transformer is indispensable. This also is their major defect which reduces DVR's flexibility.

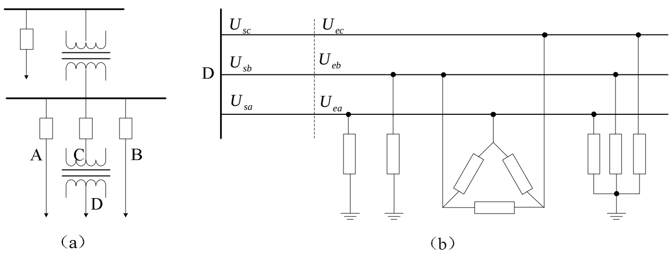


**Fig. 6 The load in distribution grid**

**Table 2 The characteristics of three types of DVR**

| Topology | Devices Number | DC Capacitor | Transfor -mer | Control Strategy | Adaptive capability to unbalance |
|---|---|---|---|---|---|
| Three-phase four-line half bridge | 6 | big | indispensable | most complicated | bad |
| Three-phase four-line bridge | 8 | small | indispensable | complicated | better |
| Three-H bridge | 12 | small | optional | simple | best |

While for three-H bridge DVR illustrated by Fig. 5, the DC bus, the inverter circuit and the filters of three phase all are independent with each other, so DVR is not possible to lead to short circuit problems of the grid and the loads as mentioned above. Consequently, three-H bridge DVR can remove transformer, which is an obvious superiority. The characteristics of three types of DVR are summarized and contrasted as Table 2.

According to analysis above, for DVR in low-voltage distribution grid, three-H bridge topology should be the most preferential choice with the best performance and flexibility.

## Conclusion

Based on the research and comparison of three topologies used in low-voltage DVR, we can reach the conclusion 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 the optimal topology for DVR used in low-voltage distribution DVR.

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