양방향 스위치를 이용한 동위상 전압보상장치

ANCHENG LIU[1], 김소정[1], 김우준[1], 안준재[1], 박성준[1]
전남대학교[1]

In-phase Voltage Compensation Device using a Bidirectional Switch

ANCHENG LIU[1], So-Jeong Kim[1], Woo-Joon Kim[1], Jun-Jae An[1], Sung-Jun Park[1]
Chonnam National University[1]

ABSTRACT

The demand for electrical equipment that is highly sensitive to power quality is growing rapidly with advances in power electronics and increased functionality of automated equipment, which has led to higher expectations of power consumers regarding the quality of power supply. To meet this demand, various power conversion devices have been developed to improve power quality. Among them, the dynamic voltage restorer (DVR) is widely recognized as an effective device for addressing voltage quality issues. In this paper, a novel DVR topology is presented, which utilizes bidirectional switches for in-phase voltage compensation. In addition, the paper demonstrates the feasibility and effectiveness of this novel DVR system-based voltage detection and compensation method through simulation results.

1. Introduction

Fig. 1 illustrates the main circuit structure of a typical DVR. In this structure, the DC source acts as an energy storage unit responsible for providing the necessary energy when the system voltage drops. The inverter converts the DC power received from the energy storage unit into the required compensating AC voltage. Subsequently, the compensated voltage output from the inverter is filtered through a filter to ensure the quality of the output voltage. The transformer, as the coupling element of the system, is responsible for delivering the compensating voltage to the system, thereby maintaining the stability of the load-side voltage and protecting the sensitive loads in the system from voltage dips. However, the duration and magnitude of the voltage compensation are limited by the capacity of the energy storage, such as the use of batteries or capacitor banks. The power capacity of these devices, if increased, becomes correspondingly larger.[1]

To address this disadvantage, many DVR technologies based on direct AC-AC conversion have been developed in recent years. This new DVR topology utilizes a direct AC-AC converter instead of a conventional inverter and avoids the use of energy storage devices.[2] This improvement brings multiple benefits: reduced cost, reduced weight, and reduced size, making DVR systems more efficient and easier to deploy.

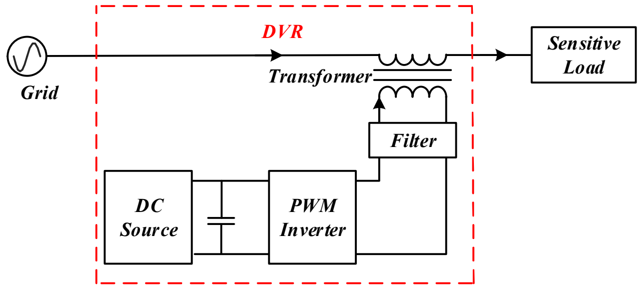


Fig. 1 The DVR architecture employed in this paper

2. Proposed DVR topology and PWM control methods

2.1 Proposed DVR topology

The proposed DVR topology using a direct AC-AC converter is shown in Fig. 2. The scheme can be divided into three main components: a single-phase AC power supply, a load, and an AC-AC converter. First, the role of the AC power supply is to power the entire system, which provides the required power to both the load and the AC-AC converter. Under normal conditions, the DVR is in standby and does not inject any additional voltage into the circuit.

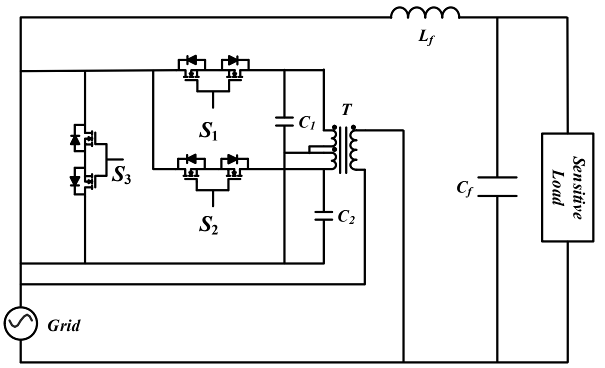
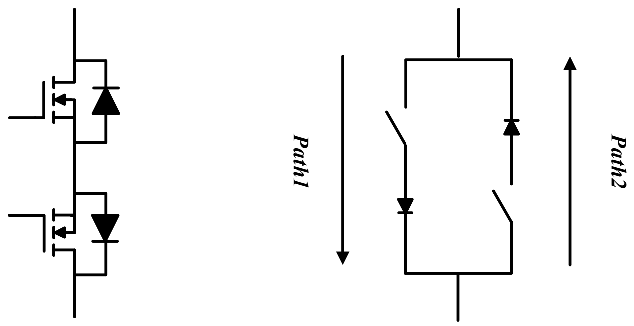


Fig. 2 Proposed DVR topology

However, in the event of a grid fault, such as a voltage drop or rise, the DVR will begin to operate. At this point, the AC-AC converter generates the required compensation voltage, which is injected into the load in series with the grid voltage, thereby correcting the voltage deviation on the load side.

The bidirectional switches (S_1, S_2 and S_3) in the designed DVR topology are shown in Fig. 3. In general, the bidirectional switch can be designed by two MOSFETs connected back-to-back.



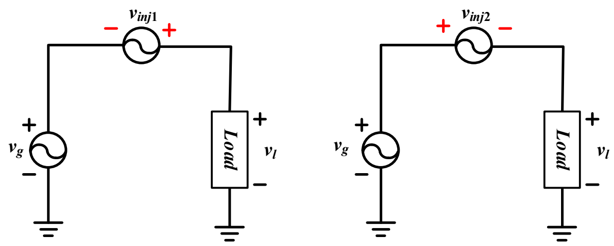
(a) (b)

Fig. 3 bidirectional switch (a) circuit diagram (b) schematic diagram

2.2 PWM control methods

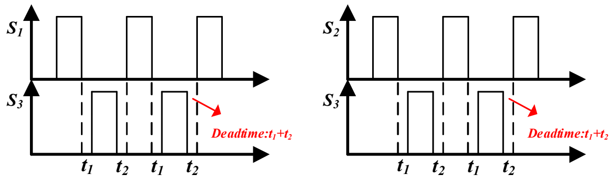
When a drop in the grid voltage occurs, in order to compensate for this drop and to keep the voltage at the load side stable, The AC-AC converter injects a voltage in the same phase as the grid voltage (v_{inj1}), as illustrated in Fig. 4(a) in the figure. In this case, switching S_1 and S_3 will be turned on and off alternately as required, as shown in schematic Fig. 5(a) of the figure. While switching S_2 remains off. By adjusting the duty cycles of S_1 and S_3, the magnitude of the injected voltage can be precisely controlled, thus realizing the effective compensation of the dropout voltage.

On the contrary, when a rise in the grid voltage occurs, i.e., the voltage is higher than the normal level, in order to reduce the voltage at the load side, the AC-AC converter injects a voltage in the opposite phase of the grid voltage (v_{inj2}), as illustrated in Fig. 4(b) of Fig. In this mode, switch tubes S_2 and S_3 will be turned on and off alternately as required, following the pattern shown in Fig. 5(b), while keeping S_1 off. Similarly, by adjusting the duty cycle of S_2 and S_3, the magnitude of the injected reverse polarity voltage can be controlled to reduce the excessive voltage.



(a) (b)

Fig. 4 DVR Injection Voltage (a) When the grid voltage drops (b) When the grid voltage rises



(a) (b)

Fig. 5 PWM generation(a) When the grid voltage drops (b) When the grid voltage rises

3. Simulation verification

3.1 Simulation model

To validate the performance of the proposed DVR topology, its simulation structure was designed using PSIM, as shown in Fig. 6. It is divided into three main parts: the DVR main circuit, the PWM generation section, and the switch selection section. The DVR main circuit includes multiple capacitors, inductors, transformers, and switching devices, which work together to regulate and stabilize the output voltage. The PWM generation section is used to produce control signals that regulate the opening and closing of the switching devices, thus controlling the circuit's current and voltage. Finally, the switch selection section is responsible for selecting the appropriate switching devices to activate, in response to changes in grid voltage, such as voltage drops or rises.

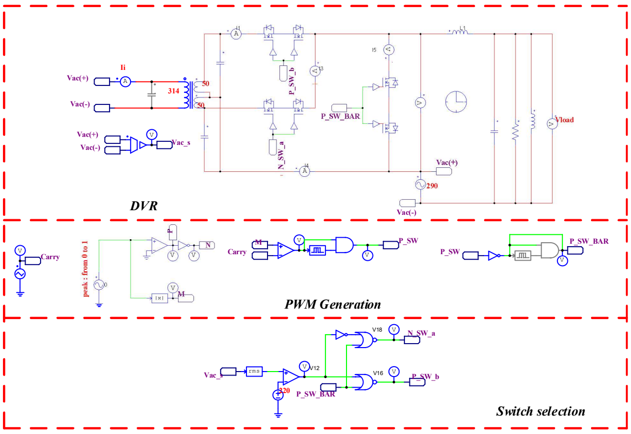


Fig. 6 simulation model

3.2 Simulation results

Fig. 7 shows that in the case of a drop in grid voltage, even if the peak voltage of the grid drops to 290 V, the load voltage is still maintained at the standard 220 V after injection by the DVR. Fig. 8 shows the waveform of the voltage injected by the DVR when the grid voltage drops, and this compensation ensures that the load voltage is stabilized.

Fig. 9 shows that when the grid voltage rises and the peak voltage reaches 330V, the DVR ensures that the load voltage remains at the standard 220V by injecting the adjusted voltage. Fig. 10 shows the waveforms of the voltage injected by the DVR when the grid voltage rises.

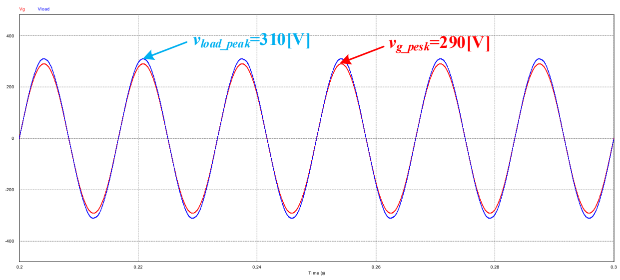


Fig. 7 Waveform analysis when the voltage drops

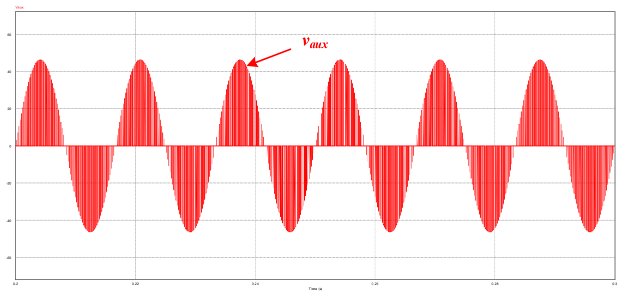


Fig. 8 Compensation voltage when the voltage drops

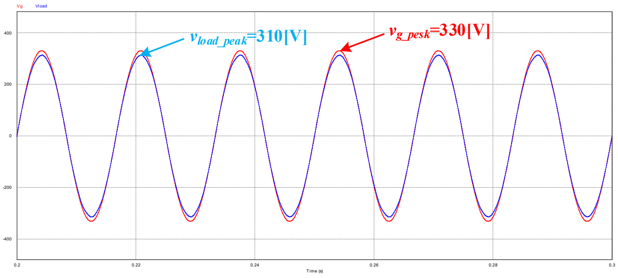


Fig. 9 Waveform analysis when the voltage rises

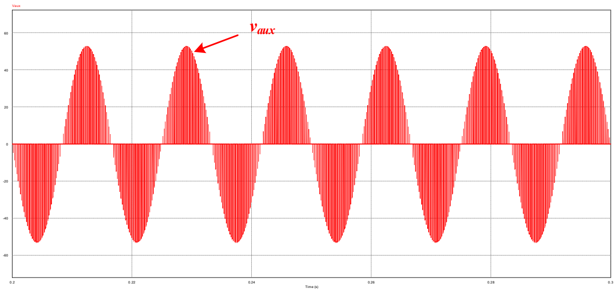


Fig. 10 Compensation voltage when the voltage rises

4. Conclusion

This paper provides an in-depth discussion on the application and importance of dynamic voltage restorer (DVR) in power systems to enhance power quality. By analyzing a novel DVR topology, we demonstrate that the technique of using bi-directional switches for in-phase voltage compensation is not only feasible but also highly effective. Simulation results further confirm the high efficiency of such a system in voltage detection and compensation. Overall, compared with the conventional DVR system, the proposed DVR system can not only cope with voltage drops, but also handle voltage rises efficiently, as well as operate more easily.

This work was supported in part by the Gwangju•Jeonnam local Energy Cluster Manpower training of the Korea Institute of Energy Technology Evaluation and Planning under Grant Korea government Ministry of Knowledge Economy (20214000000560)

References

[1] J. Wang, Y. Xing, H. Wu, and T. Yang, “A Novel Dual-DC-Port Dynamic Voltage Restorer with Reduced-Rating Integrated DC-DC Converter for Wide-Range Voltage Sag Compensation,” IEEE Trans Power Electron, vol. 34, no. 8, pp. 7437–7449, Aug. 2019.

[2] U. A. Khan, H. K. Yang, A. A. Khan, and J. W. Park, “Design and Implementation of Novel Noninverting Buck-Boost AC-AC Converter for DVR Applications,” IEEE Transactions on Industrial Electronics, vol. 68, no. 10, pp. 9346–9357, Oct. 2021.