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Control of SVPWM based LVDC grid with active Damping Control

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Abstract - *The dc symmetrical component method is introduced for the analysis and control of bipolar dc distribution systems under asymmetrical operation. This method is an extension of the classical symmetrical component theory in three-phase ac power systems. The asymmetrical voltage and current in the positive and negative poles are decomposed into symmetrical components in common and differential modes. The dc symmetrical component method is a general approach which is applicable to different aspects of system design. As an example, an enhanced common-mode voltage regulation scheme is described. It suppresses common-mode LC resonance by adding active damping control, and reduces common-mode impedance to improve power quality and voltage stability. The implemented active damping by using SVPWM based controller increases the stability. SVPWM based controllers gives faster response and accurate balance in the LVDC grid. The major theoretical conclusions are verified by simulation results.*

Key Words: **Active damping, bipolar dc distribution, common mode, differential mode, symmetrical component, SVPWM based LVDC Grid.**

1.INTRODUCTION

DC power delivery is regaining popularity recently after it was temporarily defeated by its ac opponent after century ago. The most significant development was found in high voltage dc (HVDC) transmission systems, due to its advantage in power capacity and controllability over ac transmission lines. Now the trend of dc is expanding to the bottom part of the electrical supply chains, from transmission to distribution systems. It is foreseen that dc distribution may help to accommodate a higher penetration of renewable distributed generators (DGs), increase power capacity and quality, and provide greater resilience against power surge and irregular loads.

1.1 Bipolar LVDC power distribution system

The exploration of dc distribution technologies begins at the lowest voltage level. The major reason is the relative maturity of low-voltage dc (LVDC) electric apparatus, including power electronic converters and dc circuit breakers. Primary dc distribution systems are first deployed for communication power supplies, with a rated voltage of only 48 V. This is followed by transportation power systems, such as those in more electric air- crafts and ships. Correspondingly, the dc voltage level is scaled up to several hundred volts to handle the extended power range.

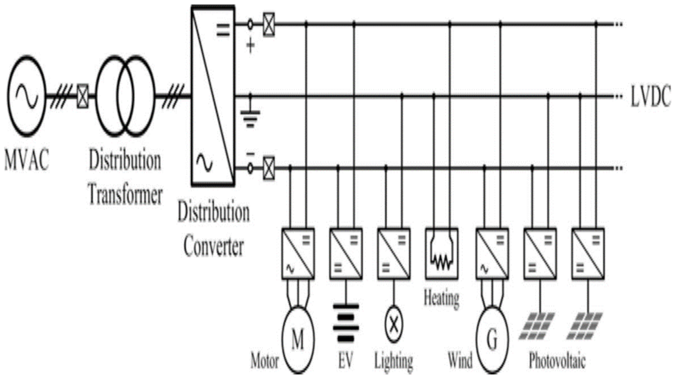


Fig.1.1.Bipolar LVDC power distribution system.

A typical LVDC grid is shown in Fig. 1. A distribution converter combined with a distribution transformer acts as the interface between the mid-voltage ac (MVAC) and LVDC grid. Just like the three-phase structure in ac power systems, a bipolar configuration can be adopted for the dc grid to provide two alternative voltage levels for DGs and loads with different voltage or power scales. The voltage between the positive and negative poles is similar to the line-line voltage in three-phase systems; while each pole is analogous to a single phase to provide a lower voltage for smaller equipment.

One of the major challenges for a bipolar dc grid is the asymmetrical operation caused by the uneven power distribution in the two poles. Such asymmetry may lead to voltage unbalance, and deteriorate power quality and voltage stability. To deal with this problem, a comprehensive investigation is needed in both the converter topology and the operation control strategy.

In this paper, the dc symmetrical component method is introduced for analysis and control of bipolar dc distribution systems. This approach uses a similar methodology and provides a similar benefit to that of the classical ac symmetrical component theory The asymmetrical voltage and current of each pole are decomposed into symmetrical. Components in common-mode and differential mode. Then the equivalent circuit for each mode can be derived, which turns out to be decoupled. Consequently, it provides an insightful view of the static and dynamic behavior of bipolar dc power systems, and simplifies the operation analysis and design.

As an application of the introduced method, an enhanced common-mode voltage regulation scheme is developed for a LVDC distribution system. It provides effective damping of the possible common-mode voltage oscillation, and offers tight voltage balance control by reducing the common-mode impedance.

The implemented technique is also suitable for more sophisticated bipolar dc distribution systems with multiple sources and complex grid structures. Moreover, the extensive research works initially targeted on a unipolar dc distribution grid can be readily migrated to a bipolar grid, taking advantage of the symmetrical component decomposition and decoupling.

The paper is organized as follows. Section II gives an introduction to the bipolar LVDC converter topologies, to lay the physical basis for the analysis throughout this paper. The dc symmetrical component method is described systematically in Section III. Based on this method, an enhanced common-mode regulation scheme by using SVPWM based controller is derived in Section IV to improve power quality and voltage stability. The Simulation results are presented in Section V to verify the theoretical conclusions. The last section summarizes the paper.

II. BIPOLAR LVDC DISTRIBUTION CONVERTER TOPOLOGIES

The distribution converter is the power hub of the entire LVDC grid. In this section, the converter topologies suitable for bipolar LVDC distribution are briefly summarized. They are the physical bases for the theoretical derivation in succeeding sections.

The most straightforward approach to build a converter with bipolar dc output is to use two cascaded voltage source converters (VSCs), as shown in Fig. 2. This topology essentially contains two independent voltage sources, and therefore permits independent operation of the positive and negative poles. However, two separated converters are needed in such a configuration, along with two isolated windings in the distribution transformer. This may result in increased size and cost. Bipolar dc voltage can also be acquired by a single VSC with some modifications. For example, the neutral line of the transformer can be connected to the mid-point of the dc output capacitors, as depicted in Fig. 3. The current in the neutral line can be regulated to balance the dc side voltage. Unfortunately, the neutral line current may contain significant dc component in this case, which should be strictly limited to prevent transformer saturation.

In order to prevent the neutral line dc current, an extra half bridge can be employed, which is dedicated to voltage balancing by actively redistributing the currents, as displayed in Fig. 4. This topology provides greater tolerance of unbalanced load currents than Fig. 3, and also has a simplified structure compared with Fig. 2.

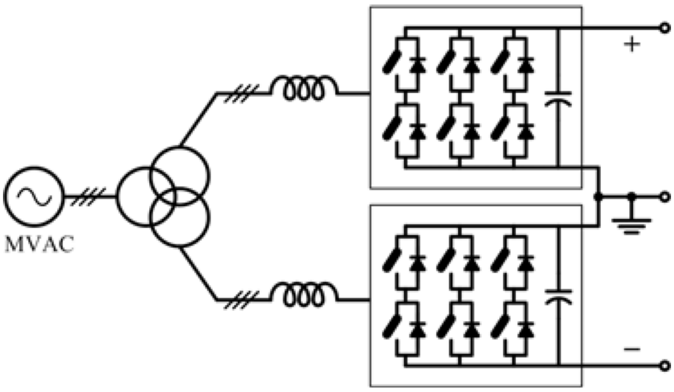


Fig. 2. Bipolar LVDC distribution converter with two cascaded VSCs.

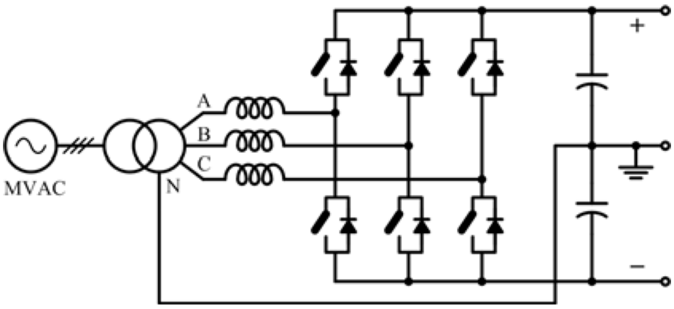


Fig. 3. VSC with neutral line connected to dc mid-point.

Therefore, it is adopted in this paper as the distribution converter to power the bipolar LVDC grid. In Fig. 4, the positive and negative poles are not independent, and therefore may induce the interaction between each pole. A method is needed to precisely model the possible inter-pole interference in bipolar dc systems. The dc symmetrical component method provides an effective solution to this problem, which is presented in the following section.

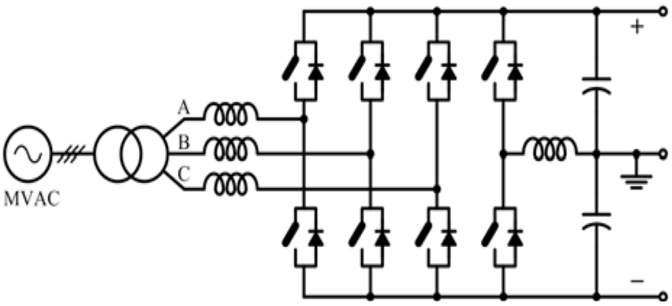


Fig. 4. VSC with extra voltage balancing half bridge.

III. DC SYMMETRICAL COMPONENT METHOD

In three-phase ac power system theories, the symmetrical component method provides a useful tool for analyzing asymmetrical phenomena. This approach can be extended to bipolar dc systems.

The symmetrical transformation in three-phase ac systems is defined by

$$\begin{bmatrix} x_0 \\ x_1 \\ x_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (1)$$

in which , are the phase variables, and are the symmetrical components in each sequence Essentially, a bipolar dc system can be viewed as a two-phase ac system with zero frequency. Therefore, a similar transformation can be derived from (1) by changing to and reducing the dimension to two. The resulted expression is

$$\begin{bmatrix} x_0 \\ x_1 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} x_p \\ x_n \end{bmatrix} \quad (2)$$

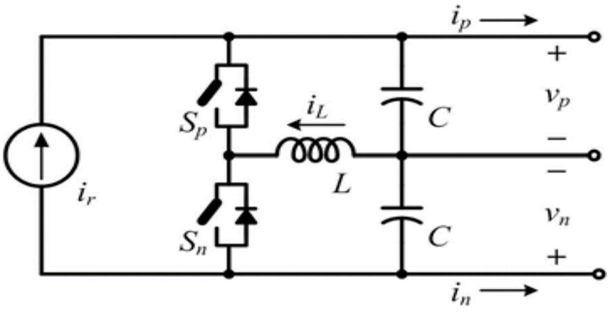


fig 5

Fig. 5. Simplified two-stage circuit for the converter in Fig. 4. in which are the values in the positive and negative poles respectively, while are the corresponding symmetrical components. The inverse transformation of (2) is

$$\begin{bmatrix} x_p \\ x_n \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \end{bmatrix} \quad (3)$$

It is interesting to observe that are essentially the common-mode and differential-mode components in analog electronics. They are named dc symmetrical components in this paper to highlight its relationship with the ac counterpart. The dc symmetrical components have many valuable properties. For example, there is a power conservation relationship in the transformation:

$$v_p \cdot i_p + v_n \cdot i_n = 2(v_1 \cdot i_1 + v_0 \cdot i_0) \quad (4)$$

If the voltages are balanced, and . In this case

$$v_p \cdot i_p + v_n \cdot i_n = 2v_1 \cdot i_1 \quad (5)$$

This implies that the differential-mode component represents the collective power transfer of the two poles, while the common-mode component describes the inter-pole interaction caused by unbalanced operation. More importantly, decoupled equivalent circuits can be derived for each mode. This enables simplified evaluation of the two modes independently, and provides a perceptive view of the static and dynamic behaviours of bipolar dc systems. Detailed procedures for obtaining the mode circuits for each segment of a bipolar LVDC grid, including the distribution converter, lines and loads, are discussed below. *A. Mode Circuits for Distribution Converter* The average state-space method is used to extract the mode circuits of a distribution converter. This approach is generally suitable for different converter topologies. We select the one in Fig. 4 as an example. To simplify the derivation, this converter can be divided into two stages, as displayed in Fig. 5. At the ac side is a three-phase VSC to rectify the ac power. Since the rectified current is independently controlled by the VSC, it is modelled as an independent current source . At the dc side is a half bridge converter, which redistributes the pole currents for voltage balancing.

IV . SVPWM TECHNIQUE:

A different approach to SPWM is based on the space vector representation of voltages in the d, q plane. The d, q components are found by Park transform, where the total power, as well as the impedance, remains unchanged. Fig:6. space vector shows 8 space vectors in according to 8 switching positions of inverter, V* is the phase-to-center voltage which is obtained by proper selection of adjacent vectors V1 and V2.

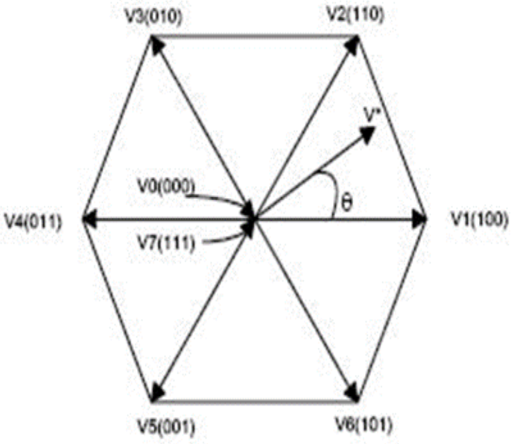


Fig 6: Inverter output voltage space vector

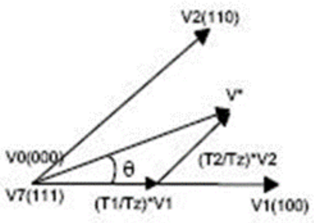


Fig:7 Determination of switching times

The reference space vector V* is given by Equation (6), where T1, T2 are the intervals of application of vector V1 and V2 respectively, and zero vectors V0 and V7 are selected for T0.

$V{*}Tz = V1{*}T1 + V2{*}T2 + V0{*}(T0/2) + V7{*}(T0/2)$.....(6)

Fig.8 below shows that the inverter switching state for the period T1 for vector V1 and for vector V2, resulting switching patterns of each phase of inverter are shown in Fig. pulse pattern of space vector PWM.

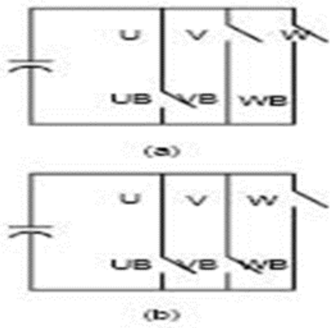


Fig 8:Inverter switching state for (a) V1, (b) V2

In Fig 10, U is the phase to- center voltage containing the triple order harmonics that are generated by space vector PWM, and U1 is the sinusoidal reference voltage. But the triple order harmonics are not appeared in the phase-to-phase voltage as well. This leads to the higher modulation index compared to the SPWM.

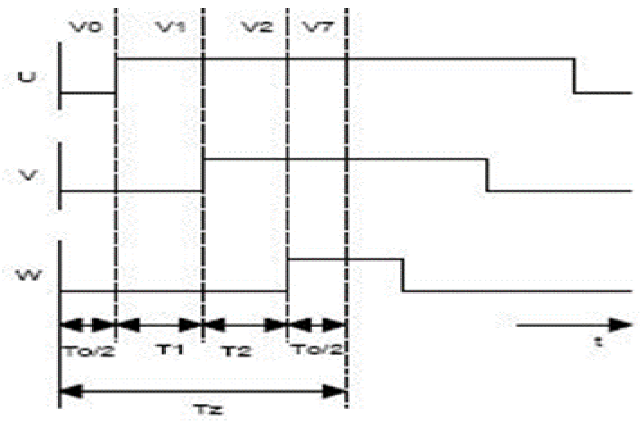


Fig 9: Pulse pattern of space vector PWM

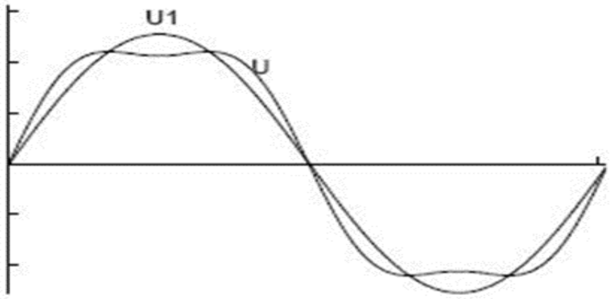


Fig 10: Comparison

Comparison of SPWM and Space Vector PWM

As mentioned above, SPWM only reaches to 78 percent of square wave operation, but the amplitude of maximum possible voltage is 90 percent of square-wave in the case of space vector PWM. The maximum phase-to-center voltage by sinusoidal and space vector PWM are respectively

$V_{max} = V_{dc}/2$: Sinusoidal PWM
$V_{max} = V_{dc}/\sqrt{3}$: Space Vector PWM
Where, Vdc is DC-Link voltage.

This means that Space Vector PWM can produce about 15 percent higher than Sinusoidal PWM in output voltage.

The typical values of the Distribution converter configuration and distribution line and load configuration are given in the table 1 table 2 given below.

SIMULINK RESULTS BY USING SVPWM TECHNIC

Fig.7.6.(a) Shows system response under bipolar load step change mode voltage graphs shown below

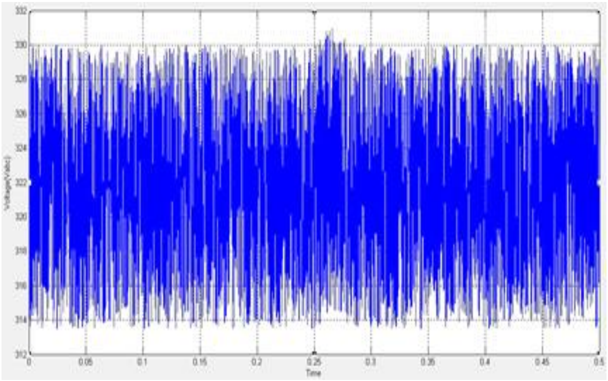


Fig.7.6.(a)input voltage (Vabc)

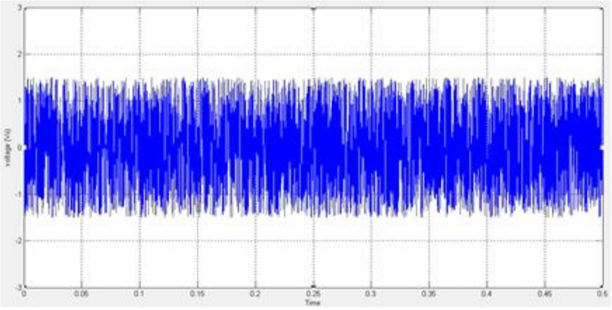


Fig.7.6.(a) Output voltage (Vo)

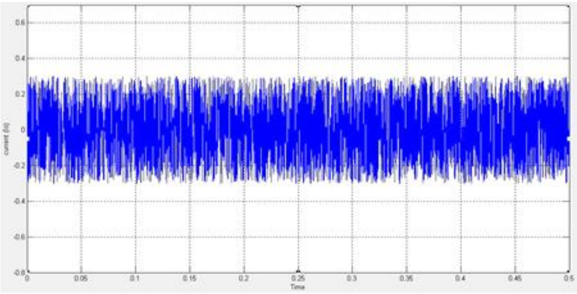


Fig.7.6.(b) Output current (Io)

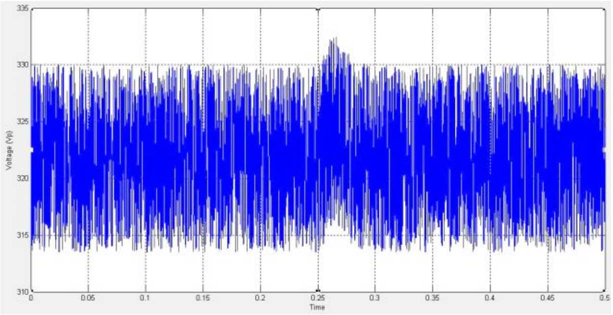


Fig.7.6.(c) Pole voltage (Vp)

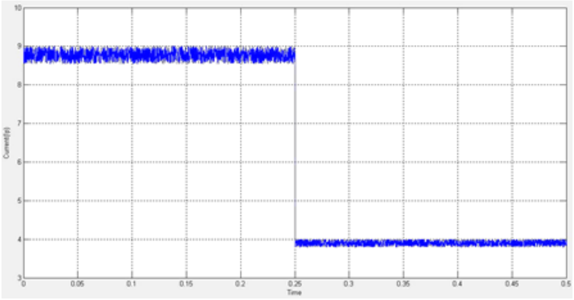


Fig.7.6.(d) Pole current (Ip)

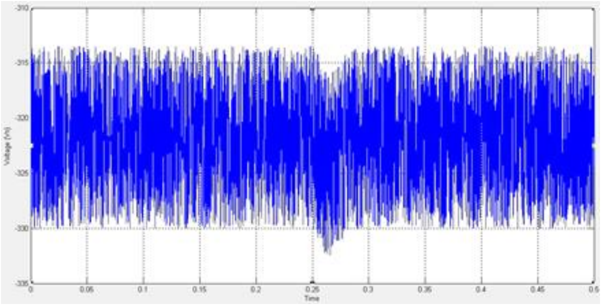


Fig.7.6.(c) Negative voltage(Vn)

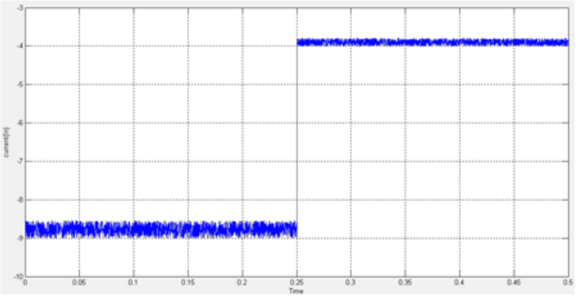


Fig.7.6.(d) negative current

Fig.7.6.(b) Shows system response under bipolar load step change current graphs shown below

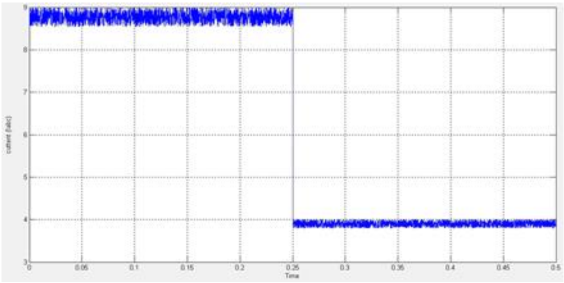
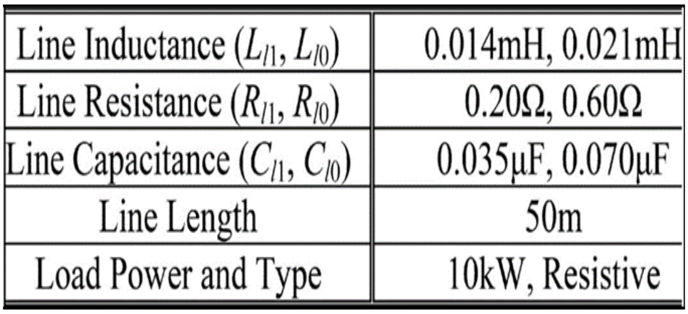


Fig.7.6.(b) input current (Iabc)

Rated Power	10kW	Switching Frequency	10kHz
AC Voltage	380V	Filter Inductor (L)	2.6mH
Bipolar DC Voltage	660V	Filter Capacitor (C)	1.5mF

Table 1. Distribution converter configuration



Line Inductance (L_{l1}, L_{l0})	0.014mH, 0.021mH
Line Resistance (R_{l1}, R_{l0})	0.20Ω, 0.60Ω
Line Capacitance (C_{l1}, C_{l0})	0.035μF, 0.070μF
Line Length	50m
Load Power and Type	10kW, Resistive

Table 2. Distribution line and load configuration

3. CONCLUSIONS

The dc symmetrical component method provides a useful tool for the analysis and control of bipolar LVDC distribution systems. It decomposes a bipolar dc grid into decoupled differential-mode and common-mode networks, thereby enabling separated and simplified investigation of each mode. Based on this method, the enhanced common-mode voltage regulation scheme shows advantageous performances in active damping by using SPVPMW based controller to improve power quality and voltage stability.

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