Research on the simulation of a new compensation strategy for dynamic voltage correction device

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Abstract. A new detection and compensation method for voltage sag is proposed. Dynamic voltage correction device (DVCD) is the most effective device to solve voltage sag. Based on the shortcomings of the traditional compensation strategy, the compensation characteristics of the compensation strategy are analyzed systematically. This paper proposes a new compensation method based on the traditional minimum energy compensation method, which uses different minimum energy methods for different sags, namely zero active power exchange and minimum energy exchange. Through Simulink to establish the simulation model of minimum energy method, and make simulation analysis. The simulation results show that the method can achieve the minimum output active power while ensuring the compensation effect, which proves the feasibility and effectiveness of the method. This method can make full use of energy storage of equipment and has high economic benefits.

1. Introduction
Voltage sag amplitude reflects the degree of voltage sag, and that is a very important parameter to describe voltage sag[1-2]. The drop amplitude is affected by the electrical distance from the fault point to the common connection point (PCC), system impedance, feeder impedance, transformer winding connection mode and whether there is sufficient power supply near the fault point[3-5]. Figure 1 shows the typical voltage sag waveform. The amplitude of voltage sag is the minimum effective value of voltage after sudden voltage drop, i.e. residual voltage. The residual voltage is usually expressed as a percentage of rated voltage:

\[ U_{re} = \frac{U_{sag}}{U_N} \times 100\% \] (1)

In (1), \( U_{re} \) is residual voltage, \( U_{sag} \) is the minimum effective value of voltage sag, \( U_N \) is rated voltage.

Voltage sag depth is also a parameter related to voltage sag amplitude[6-7]. It is the difference between rated voltage and minimum effective value of voltage[8]. The percentage of commonly used rated voltage is expressed as:

\[ \Delta U = \frac{U_N - U_{sag}}{U_N} \times 100\% \] (2)
In (2), \( \Delta U \) is the sag depth.

![Figure 1. shows the typical voltage sag waveform.](image)

**2. Dynamic voltage correction device and its compensation strategy**

**2.1. Dynamic voltage correction device topology**

The dynamic voltage correction device is connected in series between the system and the load, which can compensate the voltage sag to the normal value in millisecond. And the cost is lower than UPS, CVT and Mg, so it is the most effective compensation device to restrain voltage sag[9-10]. As shown in Figure 2-1, the main circuit topology of dynamic voltage correction device is shown in Figure 2.

![Figure 2. Topology diagram of dynamic voltage correction device](image)

**2.2. Minimum energy compensation strategy**

The minimum energy compensation method is to minimize the active power output of the device. From the point of view of energy flow, the compensation is realized by introducing reactive power and adopting a voltage injection with an appropriate phase lead to the grid voltage to reduce the active power output of the device[11]. The cost of the device is mainly considered in two aspects: the maximum value of the device output compensation voltage and the capacity of the DC energy storage unit[12]. Therefore, the research on compensation mode mainly considers how to maximize the amplitude of voltage sag compensation and how to obtain a longer compensation time for the device under the same DC energy storage unit. The phasor diagram of the system using the minimum energy compensation method is shown in Figure 3.
**Figure 3. Phasor diagram of minimum energy compensation method of the system**

$U_p$ is the system voltage before the drop, $U_S$ is the system voltage after the drop, $U_2$ is the target voltage, which is the system voltage after device compensation, and $U_C$ is the compensation voltage output by the device, $\alpha$ is the angle between $U_p$ and $U_2$, that is, the phase lead angle of the compensated voltage compared to the voltage before the drop, and $\delta$ is the angle between $U_p$ and $U_S$, which is the jump angle associated with the voltage sag.

In case of voltage sag, the active power of the system is as follows:

$$P_S = \sum_{j=1}^{3} U_j I_j \cos(\phi - \alpha + \delta), \phi \geq 0$$

$$P_S = \sum_{j=1}^{3} U_j I_j \cos(-\phi + \alpha + \delta), \phi < 0$$

The active power absorbed by the load after compensation is as follows:

$$P_{Load} = \sum_{j=1}^{2} U_j I_j \cos \phi$$

Assuming that DVCD ACTS on a three-phase balanced load system, the three-phase can be analyzed as a single phase, $I_{Lj} = I_L$, $U_{2j} = U_2$

$$P_C = \begin{cases} 
3U_2 I_L \cos \phi - \sum_{j=1}^{3} U_j I_j \cos(\phi - \alpha + \delta), \phi \geq 0 \\
3U_2 I_L \cos \phi - \sum_{j=1}^{3} U_j I_j \cos(-\phi + \alpha + \delta), \phi < 0 
\end{cases}$$

In (5), $P_C > 0$ means that the device emits active power, $P_C < 0$ means that the device absorbs active power, $P_C = 0$ indicates no active power exchange between the device and the outside world.

The phasor diagram of minimum energy compensation is shown in Figure 4. In the diagram, compensating phasor diagrams of resistive load, resistive and capacitive load, sags phase positive jump and sags phase negative jump are presented respectively.
Figure 4. Phasor diagram of minimum energy compensation strategy in four cases of sufficient compensation capacity

In Figure 4, when the load power factor angle $\phi$ is greater than 0, the reference voltage phasor should be rotated anticlockwise to the point with the minimum active power exchange based on the sag voltage phasor. On the contrary, when the load power factor angle $\phi$ is less than 0, the reference voltage phasor should be rotated clockwise to the minimum point of active power exchange based on the sag voltage phasor.

When the voltage sag is deep, it can not meet the requirements of $\sqrt{X^2 + Y^2} \geq 3U_2 \cos \phi$, so $P_C > 0$.

At this time, $\alpha$ is determined according to $\frac{dP_C}{d\alpha} = 0$, so that $P_C$ is the minimum when the voltage amplitude compensation requirement is met.

In this case, the load current is in phase with the sag voltage, that is, the compensating voltage phase of the device is:

$$\varphi_C = \begin{cases} 
\alpha + \arccos\left(\frac{U_C^2 + U_2^2 - U_S^2}{2U_C U_2}\right), & \phi \geq 0 \\
\alpha - \arccos\left(\frac{U_C^2 + U_2^2 - U_S^2}{2U_C U_2}\right), & \phi < 0
\end{cases} \quad (6)$$

3. Simulation analysis of minimum energy compensation method

Figure 5 shows the voltage sag of 40% in 0.04-0.16 s, and Figure 6 is the voltage diagram compensated by the device.
Figure 7 shows that the voltage of the system sags by 40% in the range of 0.04-0.16s, accompanied by the third harmonic of 20% phase voltage amplitude. Figure 8 shows the voltage diagram compensated by the device.

Figure 9 shows that the voltage of the system sags by 40% in the range of 0.04-0.16s, accompanied by the fifth harmonic of 20% phase voltage amplitude. Figure 8 shows the voltage diagram compensated by the device.

Figure 11 shows the waveform of active power consumed by the minimum energy method and in-phase voltage compensation method when the amplitude of system voltage sag by 40% in 0.04-0.16s. In the figure, the solid line part is compensated by the minimum energy method, and the dotted line part is compensated with full voltage.

In Figure 11, the solid line is the minimum energy method, and the dashed line is the in-phase voltage compensation method. It can be seen that the output active power of the minimum energy method is far less than that of the in-phase voltage compensation method.
The simulation results show that the simulation model of the dynamic voltage correction device based on the minimum energy method can be quickly and accurately compensated to the pre-sag level under three kinds of sags. Furthermore, through the comparison between the minimum energy method and the in-phase voltage compensation method, the output active power of the minimum energy method in the exposit-text is far less than that of the in-phase voltage compensation method. Therefore, this method can effectively minimize the compensation energy, relatively increase the capacity of the device, and extend the compensation time. Simulation results show the effectiveness and feasibility of the proposed method.

4. Conclusion
This paper proposes the minimum energy compensation in two cases, and different compensation methods are given according to different sag conditions. It can effectively reduce the demand for active power in the compensation process, maximize the compensable time of the dynamic voltage correction device without increasing the capacity of the energy storage device, and show good voltage compensation and harmonic suppression characteristics. The experimental results show that this method is effective in detecting compensation, and is superior to other methods under the same circumstances. It is effective and feasible, and satisfactory results are obtained.

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