Control Strategy and Application of Voltage Sag Compensation Based on UPQC

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Abstract. In order to solve the problem of voltage sags in low-voltage power grid, the control strategy and application of Unified Power Quality Controller (UPQC) are given. Based on the main circuit of UPQC, the method of Second-Order Generalized Integral (SOGI) is used to detect the voltage drop quickly and accurately, and the direct control method is used to compensate the voltage drop. The method is simulated by PSCAD/EMTDC, and the theoretical results are verified. TMS320F28335 controller is used to realize the algorithm, and a physical platform is built. The test waveform verifies the feasibility of the method.

1. Introduction

Low voltage station area refers to the area of low voltage (0.4kV) power supply affected by 35 (10) kV / 0.4kV distribution transformer. The electricity used in Taiwan is generally used by residents, and its quality directly affects residents’ lives. However, more and more distributed power sources are connected to the distribution network, which brings power quality problems such as voltage deviations, three-phase imbalances, and abnormal power factors at the assessment points to the distribution network, which will ultimately reduce system economics and threaten system security [1].

The Unified Power Quality Controller (UPQC) combines a parallel active filter and a series regulator to combine the advantages of current compensation and voltage compensation functions.

Voltage sag (Voltage Sag) is the most common electrical energy problem in the industrial field. The main cause is the system failure or internal switching operation of the system. The duration is about 5 to 30 cycles, which has a serious impact on sensitive loads.

For the method of voltage drop management, the domestic mostly adopts dynamic voltage regulator (DVR) solutions. The main principle is to use super capacitors and other components to store energy, and the output voltage of the full-power inverter. The main circuit power is switched to the inverter through a fast-cut switch.

DVR must be configured with power electronic devices and energy storage elements according to the full capacity of the load; energy storage elements with limited compensation time can generally last only 0.5S ~ 10S; for frequent voltage drops, frequent switching has to be performed, and the governance efficiency is not high; In addition, supercapacitor energy storage components may have voltage equalization problems after long-term charging and discharging [3].
In view of the above problems, this article uses UPQC as a control mechanism, which does not require energy storage components, and is especially suitable for occasions with frequent voltage sags. This topology compensation does not require full power, and is particularly suitable for large-capacity systems [1].

2. Principle and design
This article introduces the aspects of UPQC hardware topology, voltage drop detection method, and voltage drop compensation method.

2.1. UPQC topology

The adopted UPQC topology is shown in Figure 1. It mainly consists of series-side modules, isolated series transformers, and parallel-side modules. Both the parallel-side module and the series-side module adopt a three-level topology. The series-side module is connected to the primary side of the isolation transformer. The distribution transformer superimposes the voltage on the secondary side of the isolation transformer to achieve voltage regulation, and solves problems such as voltage sags, unbalanced voltages, and voltage fluctuations. The parallel side can realize three-phase four-wire current compensation. It can solve the problems of reactive power compensation, unbalanced current and harmonic current, and maintain the stability of the DC bus voltage in the case of grid fluctuations.

2.2. Voltage drop detection method

2.2.1. Basic principles of generalized second-order integrals. The generalized second-order integration method is that converters and rectifiers are often used to extract the fundamental wave for phase-locked loop calculation. The main advantage is that the positive sequence components are separated at the power frequency, which is accurate, fast in response, and has no phase shift [4]. The generalized second-order integrated signal generator schematic is shown in Figure 2.
The transfer function of SOGI is:

\[ D(s) = \frac{v'(s)}{v} = \frac{kw}{s^2 + kw s + w^2} \tag{1} \]

\[ Q(s) = \frac{qv'(s)}{v} = \frac{kw^2}{s^2 + kw s + w^2} \tag{2} \]

In equations (1) and (2): \( v \) is the input signal; \( v', qv' \) is a set of orthogonal output signals; \( k \) is the damping ratio; \( w \) is the centre angle of the filter; \( D(s) \) is the transfer function corresponding to \( v' \); \( Q(s) \) is the transfer function corresponding to \( qv' \).

Figures 3 and 4 show the Bode plots of \( D(s) \) and \( Q(s) \), respectively. It can be seen from the figure that \( D(s) \) is the band-pass filter transfer function and \( Q(s) \) is the low-pass transfer function; the frequency response of \( D(s) \) and \( Q(s) \), when the input signal frequency is at the centre angle of the filter, \( D(j\omega) = 0 \), \( Q(j\omega) = 0 \); indicates that the input signal follows the frequency transformation and the amplitude is guaranteed to remain unchanged.

When the system contains unexpected harmonic components of the fundamental wave, the attenuation is greater. The fundamental wave component is not affected, and its phase will not cause a phase shift with the filtering. The accuracy of the positive sequence and negative sequence of the fundamental wave can be guaranteed.

The bandwidth of \( D(s) \) and \( Q(s) \) can be adjusted through the damping ratio \( k \), and it will not be affected by the central angular frequency. A suitable angular frequency can ensure the filtering delay and response speed.
Figure 3. Bode of D (s).
2.2.2. Extraction of positive and negative sequence components of voltage.

The calculation method based on SOGI positive and negative sequence components is shown in Figure 5. The three-phase voltage is first obtained by Clark transformation, $U_\alpha$ and $U_\beta$ is used as an input quantity, and the positive sequence components $U_{d\_pos}$ and $U_{q\_pos}$, and the negative sequence components $U_{d\_neg}$ and $U_{q\_neg}$ are obtained through orthogonal decomposition.
In the normal phase-locked state, $U_{d,\text{pos}}$ represents the peak value of the fundamental wave, $U_{q,\text{pos}}$ is close to zero, and the negative sequence component $U_{d,\text{neg}}$ and $U_{q,\text{neg}}$ is also close to zero; when the voltage drops, the value of $U_{d,\text{pos}}$ also changes instantaneously. When single-phase or two-phase drop, negative sequence voltage will be generated, $U_{d,\text{neg}}$ and $U_{q,\text{neg}}$ will change instantaneously. When the relevant component triggers the threshold, a voltage sag event can be accurately detected.

2.3. Compensation method of voltage drop detection method

Figure 6 shows the series-side control strategy for UPQC voltage sag compensation.

![Diagram](image)

**Figure 6.** Control method of voltage sag compensation in series.

Voltage sag compensation is short-term operation, and the main considerations are response time and immunity.

The series-side inverter will generate a certain inrush current instantly. The inverter only uses the direct $U_{d,\text{ref}}$, voltage $U_{d,\text{ref}}$ and $U_{d,\text{pos}}$, closed-loop reference methods to speed up the response. With the current flowing into the module as the positive direction, $I_{\text{qigbt}_{-d}}$ and $I_{\text{qigbt}_{-q}}$ respectively, compensate the voltage drop of the series-side filter reactance. This control method discards the inner current loop, which will prevent the over-voltage and over-current caused by the sag moment, and it has certain requirements for sampling and calculation accuracy.

3. Experiment

In order to verify the usability of the method, PSCAD / EMTDC simulation experiments were first used, and actual verification was performed based on the simulation results.

The main parameters of UPQC are as follows: the UPQC series isolation transformer ratio is 1: 5, the impedance is 1%, the rated capacity of the parallel and series modules is 35kVA, the series reactor is 180uH, the switching frequency is 10kHz, and the DC control voltage is 750V.
3.1. Simulation verification

Figure 7. Waveform of voltage sag and load voltage.

Figure 8. Waveform of series side inverter voltage.

The simulation setting voltage drops from 400v to 320V. Figure 7 shows the comparison between the voltage drop and the compensated load voltage (AB line voltage). The blue line is the grid voltage and the red line is the load voltage. Figure 8 shows the output voltage of the UPQC series inverter when the voltage drops.

3.2. Practical verification

The UPQC controller uses TI's TMS320F28335 DSP with a switching frequency of 10kHz. The grid simulation uses a 100kVA variable frequency power supply with a voltage output of 400V and a frequency of 50Hz. The system load uses a 72A constant current source and a drop depth of 20% for testing.

It can be seen from Figures 9 to 12 that the voltage compensation on the series side of the UPQC is performed at the moment of the drop. The compensation effect is basically consistent with the simulation result, and fast and accurate compensation is achieved.
4. Conclusion
This paper aims at the unified power quality regulator as the control mechanism; the generalized second-order integration method is used to separate the positive and negative sequence components of the voltage to detect the voltage sag; and the direct control method is used to compensate the voltage sag. The actual test proves that the related method can solve the voltage drop problem well. Different from voltage sag management equipment that requires energy storage elements, the method provided in this article provides an economical solution to the problem of voltage sag.
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