The Control Strategy of Three-Phase Unbalance Load in Low Voltage Distribution Networks Based on SVG

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Abstract. For the three-phase imbalance management, this paper points out that the capacity of static var generator (SVG) can be configured based on smart meter measurement data, and the SVGs coordinated control strategy is used to compensate the three-phase imbalance load of the distribution network. Communication bus and coordinated control strategy are introduced in the proposed system. so that the SVG connected downstream of the low-voltage line can use the remaining capacity after compensating its downstream unbalanced current to sequentially compensate for the insufficient capacity of the upstream SVG. The low voltage problem of each node is further reduced by the reverse power flows from the downstream SVG to the upstream SVG. Simulations for actual effect evaluation of the proposed compensation system were done in Matlab/Simulink. Validity of the proposed system is confirmed by the simulation.

1. Introduction

In recent years, the power quality control of low-voltage distribution networks has become a key task. Among them, three-phase load imbalance has become one of the most important topics of concern. Complex load characteristics and low simultaneous power consumption have caused most distribution station areas to have varying degrees of three-phase load imbalance; due to the generation of negative and zero sequence components, unbalanced three-phase loads will cause adverse consequences such as large zero-line losses, increased power consumption, increased operating temperature, shortened equipment life and so on. Therefore, the three-phase imbalance is an important indicator of power quality. The management of three-phase imbalance has become an urgent problem to be solved.

The existing three-phase load imbalance control measures for low-voltage distribution networks mainly include three methods: manual adjustment of commutation, intelligent commutation, and use of passive / active compensation devices [1-4]. Compared with the other two measures, compensation devices are suitable for the situation where the user load is distributed. It has the advantages of dynamically balancing three-phase load currents, no short-term power failure, and long service life compared to commutation devices. As the best solution in the current reactive power compensation technology, SVG is more and more widely used in power distribution networks and it can play a good role in reactive power compensation for three-phase unbalanced loads and voltage compensation.

Affected by the concept of green economy and environmental protection, the power grid is continuously progressing towards intelligence. Smart meters are terminal devices for smart grids, establishing a communication bridge between the power sector and users. With the advantages of large storage capacity, high security levels, and strong stability, smart meters can provide real-time
measurements of three-phase active and reactive power, voltage and current amplitudes of low-voltage user terminals, thus bringing new opportunities for low-voltage distribution network state estimation.

This article proposes that SVG capacity can be configured using smart meter measurement data, and SVG coordinated control strategies are used to compensate for the three-phase unbalanced load on the distribution network. In order to verify the correctness of the compensation system, this paper based on Matlab/Simulink digital simulation software to simulate the effect of three-phase unbalanced load compensation on the proposed compensation system.

2. Three-phase imbalance
If the component parameters of the three-phase system are asymmetric, the three-phase voltage or current will run in an unbalanced state for a long time. When the three-phase voltage or current of the system is no longer symmetrical in the positive sequence, such as the phase angle is no longer 120° with each other and the amplitude is no longer equal, it is called a three-phase unbalanced system.

The three-phase unbalance factor is an important power quality parameter. The internationally defined three-phase voltage imbalance is expressed as equations (1) and (2).

\[
\varepsilon_{U0} = \frac{U_0}{U_2} \times 100\% \quad (1)
\]
\[
\varepsilon_{U2} = \frac{U_2}{U_1} \times 100\% \quad (2)
\]

Where \(\varepsilon_{U0}\) and \(\varepsilon_{U2}\) are the zero-sequence and negative-sequence imbalance factor of three-phase voltage. Where \(U_0\), \(U_1\) and \(U_2\) are the zero-sequence, positive-sequence and negative-sequence component of three-phase voltage, respectively.

For three-phase systems without zero-sequence components, the instantaneous values of the three-phase voltage or current phasor are A, B, and C. The negative-sequence imbalance factor is expressed as in equation (3) and (4).

\[
\varepsilon_2 = \left[\frac{1-(3-6L)^{1/2}}{1+(3-6L)^{1/2}}\right]^{1/2} \times 100\% \quad (3)
\]
\[
L = (A^4 + B^4 + C^4)/(A^2 + B^2 + C^2)^2 \quad (4)
\]

During normal operation of the power grid, the negative-sequence voltage imbalance factor doesn’t exceed 2% and mustn’t exceed 4% for a short time; the allowable value of the negative-sequence voltage imbalance factor at this point caused by each user connected to point of common coupling is generally 1.3% and mustn’t exceed 2.6% for a short time. The allowable value can be appropriately changed according to the load condition of the connection point and the requirements for the safe operation of nearby generators, relay protection and automatic devices [5].

3. SVG capacity configuration based on smart meter data
With the development of flexible AC transmission technology, SVG based on power electronic converters has appeared. It is widely used in power transmission systems and can play a good role in reactive power compensation for three-phase unbalanced loads and voltage compensation. When configuring SVG, you need to determine the capacity of SVG and its capacity refers to the maximum reactive power it can emit. According to different requirements, the calculation of reactive power compensation capacity is different, and the system parameters to be collected are also different.

The three-phase imbalance condition is generally monitored by devices such as smart meters, power distribution terminals that automatically collect three-phase currents and zero-sequence currents in real time. With the development of AMI (advanced metering infrastructure), smart meters [2,3], as the core equipment of AMI, have begun to be widely used in low-voltage distribution networks. Smart meters can provide real-time measurement of three-phase active and reactive power, voltage and current amplitude of low-voltage user terminals. Power quality monitoring is one of the important functions of smart meters, which can monitor the three-phase voltage imbalance factor. [7-10]

Reference [6] aimed to minimize the three-phase imbalance of the system after compensation, and used a nonlinear constraint optimization algorithm to calculate the optimal compensation capacity...
configuration. Governing the three-phase unbalanced capacity allocation is an overall optimization process. After the optimization, the optimal unbalanced management goal should be reached without overfilling, while taking into account the improvement of the system power factor. The optimized objective function is to achieve the minimum three-phase imbalance of the system after compensation and meet the specified imbalance. The constraint process of system compensation optimization is that the system cannot be over-compensated after compensation. At the same time, no active power can appear in the three-phase system after compensation. It is a negative phenomenon. Constraints should also consider increasing the power factor of the system while adjusting the three-phase imbalance, so that the power factor after the system compensation reaches the regulation.

From the above, smart meters can provide real-time measurement of three-phase active and reactive power, voltage and current amplitudes of low-voltage user terminals, and monitor the three-phase imbalance factor. For the network equipped with a smart meter, first the three-phase imbalance factor can be obtained based on the data, and then the SVG capacity can be figured based on the three-phase imbalance factor.

4. Coordinated control of SVGs
Based on the distributed access SVG compensation system, the communication bus between SVGs is increased. The downstream SVG can use it to compensate the remaining capacity after the downstream unbalanced current, and based on the insufficient capacity and distance of the upstream SVG obtained by communication, the upstream SVG can be compensated in turn. This compensation system can make full use of capacity of each SVG, while the downstream SVG compensates for the insufficient capacity of the upstream SVG to form a reverse flow, which can further reduce the low voltage problem of each node. In the SVG control algorithm, the implementation of control loops and the calculation of the compensation capacity use dq transformation, which effectively improves the coordinated control speed of each SVG. The compensation system based on coordinated control SVGs is shown in Figure 1.

![SVG compensation system based on coordinated control](image)

In order to realize the full use of the capacity of each SVG, and the comprehensive compensation of the compensation system for unbalanced current, node low voltage and other issues, the SVG in the compensation system uses a coordinated control strategy. These include coordinated control modules, negative sequence current loop, zero sequence current loop, DC voltage loop, grid voltage feedforward control, and SPWM modulation. The SVG control strategy is shown in Figure 2.
Among them, downstream three-phase current at the k-th access point $i_{Ak}$, $i_{Bk}$, and $i_{Ck}$ are based on the negative-order dq transformation to obtain $i_{d2k}$ and $i_{q2k}$, as in equation (5). The rest of the dq transformations in the control strategy are the same.

$$\begin{align*}
\begin{bmatrix}
i_{d2k} \\
i_{q2k}
\end{bmatrix} &= \frac{1}{3} \begin{bmatrix}
\cos \omega t & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \\
\sin \omega t & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3})
\end{bmatrix} \begin{bmatrix}
i_{Ak} \\
i_{Bk} \\
i_{Ck}
\end{bmatrix}
\end{align*}$$

(5)

5. Simulation analysis

In order to verify the accuracy of the compensation system and control strategy proposed in this paper, a low-voltage distribution network structure as shown in figure 1 is designed: the effective value of the secondary voltage of the distribution transformer is 400V; the other three loads except load 2 are zero, and load 2 is the current source. The negative sequence component has an effective value of 400A and the zero-sequence component has an effective value of 200A. SVGs are connected in parallel to access points 1 to 4 respectively. Using the coordinated control strategy proposed in this paper, the effective value of the maximum compensation current is 150A; the line impedance between the access points is equal to 0.025Ω. Based on this structure circuit, simulations were done in Matlab / Simulink.

Figure 3 shows the compensation current waveforms of each SVG. Because the coordinated control strategy is used, even if SVG3 and SVG4 are downstream of the line 2 access point of load 2, the unbalanced current generated by reverse flow compensation load 2 can be generated. Since the unbalanced current of load 2 reaches the total capacity of the SVG compensation system, all 4 SVGs are fully compensated. It can be seen that the compensation currents of SVG1 to SVG4 are the same, and the phase A current reaches its maximum compensation current.

It can be seen from Figure 4 that the unbalance component of the current of load 2 is large and the secondary current of the distribution transformer contains only very small zero-sequence components and harmonic components. It can be seen that the compensation system has a good compensation effect on the three-phase unbalanced load current.
Figure 5 shows the voltage of each access point. As can be seen from the figure, the maximum phase voltage drop of 30V (phase A 600A current drop across two 0.025Ω line impedances) may occur. Due to the reverse flow of some SVGs in the compensation system, the unbalanced current is effectively absorbed, so no obvious phase voltage drop is found in the access point voltage.

The feasibility of the compensation system proposed in this paper in comprehensively solving the three-phase current imbalance on the secondary side of the low-voltage distribution network distribution transformer and the low voltage of the node is verified by simulation.

6. Conclusion
Low-voltage distribution network three-phase imbalance will cause many problems, such as low utilization of transformers in the distribution network, increased line losses, etc., resulting in reduced operating economics, and even serious accidents such as equipment burnout, which will pose a threat to the safe and stable operation of the power grid. At present, SVG-based compensation devices can effectively compensate unbalanced active power and reactive power.

Based on the related concepts of three-phase imbalance and the power quality detection function of smart meters, this article points out that SVG capacity can be configured based on smart meter data, and focuses on the three-phase load imbalance comprehensive compensation system for low-voltage
distribution networks based on coordinated control of SVG. The simulation results under Matlab / Simulink digital simulation software show the use effect of the compensation system proposed in this paper, and prove the feasibility of the compensation system.

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