Characteristics of Reactive Power Compensation for Islanded Microgrids Based on Synchronized Current Phasor Control

Jiaxin Jin¹, Qianhong Shi¹, Zhijun Wang* and Lei Ding¹

¹ School of Electrical Engineering, Shandong University, Jinan, Shandong, 250061, China
*Corresponding author’s e-mail: wangzhijun@sdu.edu.cn

Abstract. Synchronized Current Phasor Control (SCPC) is a new control method proposed recently for islanded microgrids. This paper firstly investigates the reactive power compensation characteristics of the SCPC islanded microgrid with I-V droop control, then analyzes the influence of the droop coefficient on it. Through this study, we find that the traditional reactive power compensation strategies are no longer adapted to SCPC islanded microgrids, since their characteristics of reactive power compensation are different from the traditional grid or other islanded microgrids controlled by the typical methods.

1. Introduction

New energy power generation is an effective method to solve the energy and environmental crisis. As the main technology to exploit the distributed renewable energy, microgrids have been paid widespread attention all over the world[1]. The microgrid is a new type of network structure, which uses the control system to integrate distributed energy resources (DERs) and loads and then form a single controllable unit. The core of the microgrid is ‘network mutual aid and island autonomy’. In other words, the microgrid can realize normal power exchange with the grid at the networked mode, and it can also shield various influences of the grid and operate independently and stably at the islanded mode[2].

For the islanded microgrid, there are several main control strategies[3-6]: the centralized control, the master-slave control and the peer-to-peer control. However, they generally have the problems of power angle and frequency stability. In order to completely solve the frequency problem, a fixed frequency voltage control strategy is proposed[7-10], using GPS to achieve the same internal potential frequency and initial phase of all distributed power sources. Through the V-I droop control, the power dispatch problem of the power grid is converted into a current dispatch problem. However, long-distance power transmission cannot be achieved, since the initial phase of the internal potential of all distributed power sources is the same. In view of the inherent shortcomings of the fixed-frequency voltage control strategy, an innovative fixed-frequency current control strategy is proposed based on the Synchronous Current Phasor Control (SCPC)[11]. The microgrid can establish a unified reference frame for each DER, based on GPS timing signals. DER then generates the output current phasors of the same initial phase and the fixed frequency through vector control. Moreover, the I-V droop control strategy is used to adjust the output current amplitude to achieve the voltage stability and the power balance of the islanded microgrid.

On the other hand, more reactive power output of a source will decrease its maximum active power output capacity due to the limited power capacity. In addition, the reactive power loss on the
transmission line will cause the load voltage to decrease. Therefore, a suitable reactive power compensation strategy will greatly improve the operating efficiency of the power grid [12]. The islanded microgrids based on SCPC with I-V droop control are quite different from the traditional power grids or the islanded microgrids under typical control strategies, so their reactive power compensation control strategies also need to be re-examined. The above-mentioned differences are mainly manifested in the property of the source. The source of the SCPC islanded microgrid is a current source with the fixed frequency and the same initial phase, and controlled by I-V droop curve, which is called ‘I-V current source’. Its characteristics are different from the constant voltage source or the constant current source. Therefore, this paper investigates the characteristics of reactive power compensation under I-V current source. In the future, an adaptive reactive power compensation control strategy will be proposed based on this investigation.

2. Basic principle of SCPC and I-V droop control

A uniform 50Hz reference frame is established based on the synchronous clock of GPS for the entire microgrid. According to this uniform reference frame, all DERs can generate the current phasors with the same phase and fixed frequency through vector control. Hence, each DER based on SCPC can be regarded as a controllable current source. The frequency $f$ of each current source is fixed at the power frequency, the phase $\delta$ is the same (generally set $\delta=0$), and the amplitude is regulated according to terminal voltage through I-V droop curve.

The principle diagram of the SCPC strategy is shown in figure 1. The terminal voltage is measured for calculation of the reference output current. Then the difference between the reference current and the actual current is fed into the PI regulator to generate the PWM modulation signal. The I-V droop curve is shown in figure 2.

![Figure 1. The principle diagram of the synchronized current phasor control strategy.](image)

![Figure 2. I-V droop curve characteristic.](image)

A simple system of dual power supply and single load is shown in figure 3.

![Figure 3. A simple system of dual power supply and single load.](image)

Under the SCPC strategy, DER 1 and DER 2 output current phasors with fixed frequency in the same phase, as shown in equation (1).

$$\hat{I}_1 = I_1 \angle 0^\circ, \quad \hat{I}_2 = I_2 \angle 0^\circ$$

Hence, the amplitude of the voltage at PCC is:
The amplitude of $U_{PCC}$ shows a linear relationship with the algebraic sum of the DERs output currents and the phase angle of $U_{PCC}$ equals the load impedance angle.

Assumed that the load voltage is the rated value. At a certain moment, the active or reactive load increases. If both DERs do not adjust their output currents, the load voltage will drop and the terminal voltages of both DERs will also decrease accordingly. Similarly, if the active or reactive load is reduced, the whole network voltage will rise.

Actually, DER will adjust the respective output current amplitude according to the I-V droop curve once the terminal voltage amplitude changes. For example, if the load increases, the voltages of both supplies will drop. According to the I-V droop curve shown in figure 2, both DERs will immediately increase the output currents, which can raise the microgrid voltage close to the rated value.

It can be noticed that the operating mechanism of the islanded microgrid based on SCPC is simple but with unique advantages. Some of the advantages of using the proposed SCPC over existing methods are as follows:

• The unified frequency of the entire network completely solves the problem of frequency stability.
• The I-V droop control strategy converts the power dispatch problem to the current distribution problem.
• SCPC is based on a distributed droop control, which only needs local information without any centralized calculation and communication.
• SCPC is a plug-and-play control strategy and it’s simpler to add the newly DER to the network.
• The load change in SCPC islanded microgrid will only cause the voltage change, which has a wider acceptable fluctuation range than the frequency. Therefore, SCPC enhances the robustness of the islanded microgrid.

To sum up, SCPC has obvious advantages over existing methods and has both theoretical and practical significance to the islanded microgrid.

3. Reactive power compensation characteristics of SCPC islanded microgrid

The source of the islanded microgrid based on SCPC is an I-V current source, which differs from a constant voltage source or a constant current source. As a result, the reactive power compensation characteristics under the I-V current source is analyzed by comparison with the constant voltage source and the constant current source.

For the investigation of the reactive power compensation characteristics under I-V current source, a single-source-single-load model is used, as shown in figure 4.
Table 1. Parameters of model.

| Nominal Grid Voltage | Source Rated Output | Rated Load | Feeder Impedance |
|----------------------|---------------------|------------|------------------|
| 0.38kV               | 60kW                | 60kW+20kVar (0.05+j0.05) Ω |

In addition, the output voltage amplitude $U_1$ of constant voltage source, the output current amplitude $I_1$ of the constant current source, and the droop coefficients $k$ and $b$ of I-V current source need to meet the certain conditions that the reactive power compensation is zero and the load voltages $U_2$ under three different sources are equal.

With the increase of the reactive power compensation, the load power-factor angle accordingly increases from negative to positive. The change trends of the load voltages $U_2$ under the three different sources and their relationship are shown in figure 5.

Figure 5. Reactive power compensation characteristics under three different sources.

Figure 6. Influence of $b$ on the reactive power compensation characteristic.

According to figure 5, with the increase of the reactive power compensation, the load voltages $U_2$ under the three sources exhibit different variation tendencies. There is an equilibrium point of the three curves and the relationship between the three curves will change at this point. Before the point, the curve of constant current source is on the top and the curve of constant voltage source is at the bottom. It means that with the same reactive power compensation, the voltage support effect under constant current source is strongest, while it under constant voltage source is weakest. After the point, the two are reversed. However, the curve of I-V current source is always between the constant voltage source and the constant current source. Therefore, the reactive power compensation characteristic under I-V current source is always between the constant voltage source and the constant current source.

4. Influence of I-V droop coefficients

The I-V current source is controlled by the I-V droop curve, which is determined by the droop coefficients $k$ and $b$, as shown in figure 2. Note that $k$ is negative and $b$ is positive.

With the example model mentioned above, the value of $k$ is changed to show its influence on the reactive power compensation characteristic.

Table 2. Droop coefficient $k$ of I-V current source.

| I-V Current Source | #1 | #2 | #3 | #4 | #5 | #6 | #7 |
|--------------------|----|----|----|----|----|----|----|
| Value of $k$       | -1 | -9 | -9.9 | -10 | -10.1 | -11 | -100 |

As the value of $k$ changes according to table 2, the reactive power compensation characteristic curve under I-V current source changes, as shown in figure 7.
Figure 7. Influence of $k$ on the reactive power compensation characteristic.

As the value of $|k|$ decreases, the reactive power compensation characteristic curve under I-V current source gradually approaches the constant current source, and the voltage support effect becomes stronger; as the value of $|k|$ increases, the reactive power compensation characteristic curve under I-V current source will close to the constant voltage source, and the voltage support effect is getting weaker.

Then, the value of $b$ is changed to show its influence on the reactive power compensation characteristic.

Table 3. Droop coefficient $b$ of I-V current source.

| I-V Current Source | #8  | #9  | #10 |
|--------------------|-----|-----|-----|
| Value of $b$       | 10.9| 11  | 11.1|

As the value of $b$ changes according to table 3, the reactive power compensation characteristic curve under I-V current source changes, as shown in figure 6. The change of $b$ would bring an overall change to the value of load voltage, but has no influence on the variation tendency of the load voltage. Therefore, the droop coefficient $b$ has no influence on the reactive power compensation characteristic.

5. Conclusion

The reactive power compensation characteristic of the islanded microgrid based on SCPC is different from the traditional grid or typical microgrids. The reactive power compensation characteristic under I-V current source is between the constant voltage source and the constant current source, that is, with the same reactive power compensation capacity, the voltage support effect under I-V current source is between the constant voltage source and the constant current source. In addition, the reactive power compensation characteristic under I-V current source is affected by the droop coefficient $k$. The larger $|k|$ is, the closer it is to the reactive power compensation characteristic under the constant voltage source; the smaller $|k|$ is, the closer it is to the reactive power compensation characteristic under the constant current source. And the droop coefficient $b$ has no influence on the reactive power compensation characteristic.

Therefore, traditional reactive power compensation strategies may not be appropriate to the SCPC islanded microgrids due to their different characteristics from the traditional grid. In the future, new adaptive reactive power compensation strategy will be studied based on this investigation.
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