Research of Metering Scheme for Self-provided Power Plants Based on Synchronized Clock Signals

Yihang Yang  
School of Electrical Engineering  
Zhengzhou University  
Zhengzhou, China

Yuanrong Xu, Wenzhe Duan, Yuehao Yan  
State Grid Henan Electric Power Company Zhengzhou Power Supply Company  
Zhengzhou, China  
yanyuehao@163.com

Yiwei Zhai  
School of Electrical Engineering  
Shandong University  
Jinan, China

Abstract—Influenced by their loads and operation states, self-provided power plants may get power from the grid or supply power to the grid. It is necessary to measure the on-grid energy and the off-grid energy respectively because of the difference between the on-grid price and the off-grid price. When a self-provided power plant is connected with two or more substations in the power grid, ride-through flow may be generated due to the influence of grid operating states. It is crucial for accurate metering to eliminate ride-through energy when measuring on-grid energy and off-grid energy. A novel method to judge the power state of self-provided power plants is put forward in this paper by analyzing the phenomenon that ride-through flow may be generated when transmission lines is connected with the grid. On this basis, a scheme for measuring on-grid energy and off-grid energy of self-provided power plants based on synchronized clock signal is presented by introducing a clock synchronization system. The accuracy of the proposed scheme is verified by comparing against approximate measurement data.

Index Terms—self-provided power plants; electric energy metering; ride-through flow; synchronized clock signals

I. INTRODUCTION

Influenced by their loads and operation states, self-provided power plants[1], which generate electricity for their own use or supply their surplus electricity to the grid, may get power from the grid or supply power to the grid. Because of the difference between the on-grid price and the off-grid price, normally, the total on-grid energy and off-grid energy are needed to be calculated respectively for settlement.

In practice, self-provided power plants may connect their single or multiple lines with one or more substations in the grid. When a self-provided power plant is connected with only one substation in the grid, the on-grid energy and off-grid energy can be directly available through forward and reverse watt-hour meters at the metering point [2][3][4].

When a self-provided power plant is connected with two or more substations, some flow in the grid will run through the bus of the self-provided power plant and get other positions of the grid. That is to say, ride-through flow may occur between substations and the self-provided power plant. In this case, the readings on forward and reverse watt-hour meters are not accurate on-grid energy and off-grid energy. Instead, the read energy contains ride-through energy which is generated when ride-through flow passes the metering point of the power plant. If ride-through energy cannot be excluded in the energy metering system, the accuracy of energy settlement will be greatly influenced.

Attempts were made to solve this problem. A metering scheme is put forward that moving the settlement threshold metering point down to the high side of main transformer and thus the forward active energy of the high side is on-grid energy and the reverse active energy of the high side is off-grid energy[5]. However, when self-provided power plants adopt bus connection and public utility units supply electricity to power plants through the bus, the forward active energy of the high side will be less than on-grid energy. Another scheme is to measure on-grid and off-grid energy in separated period of time according to the flow direction by modifying the metering point set-up and improving metering devices[6]. But that scheme fails to take into account the influence of synchronous collection on flow direction.

When power assets cut-off point is at a side of the plant, transmission lines of two or more substations can be merged into one line and real-time measurement of on-grid and off-grid energy can be directly conducted by means of “sum current”. However, in the circumstances discussed in this paper, metering points are located in substations and are difficult to be measured by means of “sum current” due to long distances.

The reference value of power should be subject to Smart Grid Operation Supporting System (D5000). D5000 system platform develops independently power middle-wares with complete independent property rights, dispatching plan application and dispatching management application systems. The functions of real-time control, online stability analysis and dispatching business management are realized in the grid operation. The subsystems of D5000 include: energy management system, dynamic and steady management...
system, wide-area phasor measurement system, power planning management system, dispatcher training simulation system, powerhouse scheduling automation system, relay protection and fault information management system, etc.[7]

This paper put forward a judging method of power supply of self-provided power plants based on instantaneous active flow by analyzing different kinds of ride-through flow. On this basis, a scheme for measuring on-grid energy and off-grid energy of self-provided power plants based on synchronized clock signal is presented by introducing a clock synchronization system. The accuracy of the proposed scheme is verified by comparing against approximate measurement data.

II. OUTLINE OF RIDE-THROUGH ENERGY OF A SELF-PROVIDED POWER PLANT

Picture 1 shows the connection diagram of a unified management self-provided plant which has three units: #1, #2, #3. Its installed capacity is 900,000 kilowatts with a self-provided load of 800,000 kilowatts. Among its three units, #1 and #3 are self-provided units and #2 is a public unit. The power plant builds a 220kV single-bus step-up substation which is connected with substations A and B of the grid respectively by two lines. According to the assets cut-off principle and the power supply agreement between the grid company and the plant, the metering points shall be in substations A and B.

According to relevant price standard, the unit price for the off-grid energy of the plant is 0.5712 RMB/kWh. The off-grid energy of #1 and #3 should not be settled for they are self-provided units. The settlement price for the on-grid energy of #1 and #3 should not be settled for they are self-provided units. The readings "A L1P-AL2N" on the meters at the metering points in the corresponding time period indicate off-grid energy of the power plant in the said time period.

Case 1: The direction of ride-through flow is: substation A → self-provided power plants → substation B. When ΔP=PL1P−PL2N>0 (we specify that the substation-to-bus direction is positive and PL1P refers to the active power in Line 1 within a time period and PL2N refers to the negative active power in Line 2 within a time period. The same below), the active power runs into the bus of the power plant is larger than that runs out of the bus of the power plant, which is the state that the grid supply electricity to power plants. So the readings “A L1P-AL2N” on the meters at the metering points in the corresponding time period indicate off-grid energy of the power plant in the said time period.

Case 2: The direction of ride-through flow is: substation A →self-provided power plants → substation B. When ΔP=PL1P−PL2N<0, it is in the state that power plants supply electricity to the grid. The readings “A L1P-AL2N” at the metering points in the corresponding time period indicate on-grid energy of the power plant in the said time period.

Case 3: The direction of ride-through flow is: substation B → self-provided power plants → substation A. When ΔP=AL1P−AL2N<0, it is in the state that power plants supply electricity to the grid. The readings “AL1P-AL2N” at the metering points in the corresponding time period indicate on-grid energy of the power plant in the said time period.

Case 4: The direction of ride-through flow is: substation B → self-provided power plants → substation A. When ΔP=AL1P−AL2N>0, it is in the state that the grid supply electricity to power plants. The readings “AL1P-AL2N” at the metering points in the corresponding time period indicate off-grid energy of the power plant in the said time period.

To sum up the above 4 states, the formula can be concluded as follows:

\[ \Delta P = PL1P + PL2P - PL1N - PL2N \]  

(1)

The state of power supply can be determined according to formula (1).

Take Case 1 for example, when the direction of ride-through flow is substation A → self-provided power plants → substation B, the values of PL2P and PL1N are zero. Formula (1) can be simplified as \( \Delta P = PL1P - PL2N \), which is consistent with the formula of Case 1. Similarly, the same conclusion can be reached by verifying Cases 2, 3 and 4.

According to the above analysis, for a self-provided power plant which is connected with several substations, the judgment formula of its state of power supply should be:

\[ \Delta P = PL1P + PL2P + ... + PLnP - PL1N - PL2N - ... - PLnN \]  

(2)
When ΔP>0, it is in the state that the grid supplies electricity to power plants and ΔP indicates the off-grid energy of power plants in the corresponding time period. When ΔP<0, it is in the state that power plants supply electricity to the grid and ΔP indicates the on-grid energy of power plants in the corresponding time period.

Accurate off-grid and on-grid energy in the corresponding metering period can be calculated by judging the state of power supply according to formula (2) and by summing up the off-grid energy and on-grid energy in different time periods respectively.

IV. POWER METERING SCHEME BASED ON SYNCHRONIZED CLOCK SIGNAL

The state of power supply between the grid and power plants can be accurately identified by means of formula (2), provided that the active power in the said formula and the synchronic collection of electricity data must be in the same time period. In order to realize accurate measurement of off-grid energy and on-grid energy of power plants in the condition of ride-through power, synchronized clock signals in the station are connected with the metering device to realize synchronous measurement.

According to the above analysis, there are two problems to be solved in order to improve the metering scheme of power plants. One is the synchronous collection of metering signals. Non-synchronous data of active power may cause misjudgment of the state of power supply. The other is the realization of computational formulas. The novel scheme in this paper is shown in Figure 2.

According to the above analysis, there are two problems to be solved in order to improve the metering scheme of power plants. One is the synchronous collection of metering signals. Non-synchronous data of active power may cause misjudgment of the state of power supply. The other is the realization of computational formulas. The novel scheme in this paper is shown in Figure 2.

A. Synchronous Satellite Clock System

In the power system, synchronous satellite clock system are mainly used for time correction for computers and automatic devices. Time synchronization server obtains standard clock signals (with a timing accuracy of about 10μs) from Beidou Satellite (or GPS) and transmit the signals to devices (such as computers, protection devices, fault recorders, SOE recorders, automatic safety devices, RTU equipments, etc.) which need time information in automation systems via various interfaces, so time synchronization of the whole system can be realized.

At present, most 220kV substations and unified management plants in China are installed with synchronized clock devices, which offers precise timing service to other devices through network.

B. Metering Scheme of On-grid and Off-grid Energy

1) Metering Scheme of Off-grid Energy

Put the values of active power on the 4 threshold meters at the same time into Formula (2), and, if ΔP>0, it is in the state that the grid supplies electricity to the power plant. In the duration of “ΔP>0”, calculate “the difference between the sum of forward energy and the sum of reverse energy” for the 4 threshold meters, and the result is the off-grid energy in the duration of “ΔP>0”.

2) Metering Scheme of On-grid Energy

(1) Put the values of active power on the 4 threshold meters at the same time into Formula (2), and, if ΔP<0, it is in the state that the power plant supplies electricity to the grid. In the duration of “ΔP<0”, calculate “the difference between the sum of reverse energy and the sum of forward energy” for the 4 threshold meters, and the result is the on-grid energy in the duration of “ΔP<0”.

(2) Compare the on-grid energy of #2 with the total on-grid energy in the metering period, and, when the on-grid energy of #2>the total on-grid energy, the settlement shall be on the total on-grid energy; otherwise, the settlement shall be on the on-grid energy of #2.

(3) The total off-grid energy and total on-grid energy in the metering period can be obtained by calculating the off-grid energy and on-grid energy in each metering period.

C. Scheme Flow

The basic flow of the metering scheme is as follows:

(1) Network signals allow communication between related threshold meters and the synchronous clock device in the station so that the clock synchronization function can be realized and the demands for time synchronization in this scheme can be satisfied.

(2) The active power and other data with time scales on the threshold meters are sent to the collector and site backup device in as short intervals as possible (within 5 seconds), then the collector sends the related data to the main metering station.

(3) The main metering station conducts analysis on the received data in the same period on the 4 threshold meters.

Figure 2 Schematic Diagram of the Novel Metering Scheme
In this paper, the metering data is verified based on the reference value which is subject to Smart Grid Operation Supporting System (D5000) and its inbuilt district energy analysis module. Through monitoring the real-time active power of connection lines and public units of the self-provided power plant, measurement of on-grid and off-grid energy of the self-provided plant is conducted by means of corresponding sum formula.

As for the self-provided power plant shown in Figure 1, in the original scheme, two sets of forward and reverse watt-hour meters are installed at the assets cut-off points of Lines L1 and L2 of the power supply company. By the end of each month, energy is calculated for each meter. The off-grid energy equals the difference between the sum of forward energy and the sum of reverse energy and the on-grid energy of the plant equals the reverse energy of L1. Influenced by the grid operation mode, L2 is closed from January to March, 2016 and resumes normal in April at the requirement of district operation in the grid.

The following Table 1 shows the comparison result of off-grid energy of the original scheme, the novel scheme in the paper and D5000 system from January to July, 2016 (In January, #1 is stopped for maintenance). The following Table 2 shows the corresponding comparison result of on-grid energy.

<table>
<thead>
<tr>
<th>Month</th>
<th>D5000 power</th>
<th>Original scheme</th>
<th>Relative error (%)</th>
<th>Current scheme</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>113,787,321</td>
<td>114,785,498</td>
<td>0.87</td>
<td>113,065,228</td>
<td>0.64</td>
</tr>
<tr>
<td>February</td>
<td>545,178</td>
<td>550,310</td>
<td>0.93</td>
<td>549,637</td>
<td>0.81</td>
</tr>
<tr>
<td>March</td>
<td>783,016</td>
<td>790,126</td>
<td>0.90</td>
<td>776,245</td>
<td>0.87</td>
</tr>
<tr>
<td>April</td>
<td>727,470</td>
<td>657,371</td>
<td>10.66</td>
<td>722,085</td>
<td>0.75</td>
</tr>
<tr>
<td>May</td>
<td>647,085</td>
<td>568,953</td>
<td>13.73</td>
<td>640,289</td>
<td>1.06</td>
</tr>
<tr>
<td>June</td>
<td>716,726</td>
<td>660,671</td>
<td>8.48</td>
<td>712,376</td>
<td>0.61</td>
</tr>
<tr>
<td>July</td>
<td>690,742</td>
<td>620,498</td>
<td>11.32</td>
<td>683,742</td>
<td>1.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Month</th>
<th>D5000 power</th>
<th>Original scheme</th>
<th>Relative error (%)</th>
<th>Current scheme</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>5,636,785</td>
<td>5,586,829</td>
<td>0.89</td>
<td>5,717,282</td>
<td>1.41</td>
</tr>
<tr>
<td>February</td>
<td>35,980,051</td>
<td>36,383,581</td>
<td>1.11</td>
<td>36,378,392</td>
<td>1.09</td>
</tr>
<tr>
<td>March</td>
<td>33,781,579</td>
<td>34,082,720</td>
<td>0.88</td>
<td>34,218,345</td>
<td>1.28</td>
</tr>
<tr>
<td>April</td>
<td>44,580,665</td>
<td>40,842,967</td>
<td>9.15</td>
<td>44,278,533</td>
<td>0.68</td>
</tr>
<tr>
<td>May</td>
<td>37,858,915</td>
<td>32,874,780</td>
<td>15.16</td>
<td>37,372,682</td>
<td>1.30</td>
</tr>
<tr>
<td>June</td>
<td>40,860,121</td>
<td>34,577,828</td>
<td>18.17</td>
<td>41,428,303</td>
<td>1.37</td>
</tr>
<tr>
<td>July</td>
<td>42,683,084</td>
<td>38,375,321</td>
<td>11.23</td>
<td>42,937,744</td>
<td>0.59</td>
</tr>
</tbody>
</table>
Through the data comparison of Figures 4 and 5, it is easy to find that, from January to March, ride-through flow does not occur because the self-provided power plant is connected with the system by a single line. Therefore, compared with the result measured by D5000 system, the relative errors of both the results calculated by the original metering scheme and the novel metering scheme in this paper is around 1%. From April to July, ride-through flow occurs due to the operation of the other line. Consequently, the relative error between the result of the original metering scheme and D5000 measurement result reaches 10% and above. Whereas the relative error between the result of the novel metering scheme in this paper and D5000 measurement result remains around 1%. So the novel metering scheme has higher precision. (D5000 belongs to the grid operation monitoring system whose measurement error is relatively bigger than that of metering systems. The metering data listed in this paper comes from real metering system and has high precision. The relative error of 1% is normal.)

VI. CONCLUSION

This paper analyses the phenomenon that ride-through flow may be generated when transmission lines of power plants is connected with the grid and puts forward a method judging power supply state of self-provided power plants based on instantaneous active power flow. On this basis, a novel scheme for measuring on-grid energy and off-grid energy of self-provided power plants based on synchronized clock signal is presented by introducing a clock synchronization system.

The novel scheme in this paper is applicable to self-provided power plants which have multiple connection lines. It can effectively eliminate the influence of ride-through flow and achieve accurate calculation of on-grid energy and off-grid energy, which ensures the economic interests of the grid and power plants.

REFERENCES