Analysis and Research on 500kV Bus Power Imbalance in Dispatching End UHV near Zone

H Jiang¹,², M J Yuan¹,³, Q Li¹, Z H Wang² and H Y Liu²

¹ CYG SUNRI CO., LTD, Shenzhen 518057, Guangdong Province, China
² Shanghai Electricity Company, Shanghai 200000, China

E-mail: yuannj@sznari.com, jianghao@sznari.com

Abstract. As a result of long distance of UHV AC transmission power transmission and fluctuations of tie-line power, large fluctuations exist in UHV near zone 500kV trend line, which seriously affects the calculation and assessment of bus efficiency in smart grid. In order to enhance the quality of the station fundamental data, through the research on sending the remote measurement acquisition principle, we found that measurement accuracy and Telemetry sent out of sync are main reasons. Combining with the current technology situation, it describes the basic ideas and implementation process of the two schemes, and points out the advantages and disadvantages of each scheme at the same time. For the traditional substation, it puts forward the Bay Control Unit (BCU) and Remote terminal units (RTU) reconstruction scheme based on GPS synchronization acquisition. BCU accepts GPS signal, sends the change telemetry data, RTU supports packing and sending important telemetry data under normal circumstances. When the BCU is abnormal or the synchronization is abnormal, RTU No packaging, only sends change telemetry data. So, important telemetry is fully synchronized under normal conditions, while data from abnormal BCU can also be effectively reflected in the SCADA. For new generation of smart substation, it raises a synchronous acquisition implementation based on Cluster Bay Control Unit (CBCU), the CBCU accept all SV message from the same bus, which can ensure bus power calculations and sent at the same time regardless of change trigger mode. Finally, it takes the UHV substation as a simulation model, the 500kV bus telemetry values as the basic data, finishes the bus imbalance simulation to verify the effectiveness of the scheme.

1. Introduction
In recent years, all the countries in the world carried out research work of smart grid as global energy issues become increasingly severe [1]. The ultimate goal of smart grid is to build a real-time system which covers covering the entire electricity system production process, including power generation, transmission, substation, distribution, electricity and scheduling and other panoramic. Real-time panoramic data acquisition, transmission and storage, and the accumulation of huge amounts of data fast analysis is the foundation for smart grid security, self-healing, green, strong as well as the cumulative mass rapid analysis of multi-source data [2-4].

UHV power grid is the strong backbone of Chinese smart grid, while the strong power grid which coordinats different voltage level is the basis of it. As a result of long distance of UHV AC transmission power transmission and fluctuations of tie-line power [5-7], large fluctuations exist in UHV near zone 500kV trend line, which seriously affects the calculation and assessment of bus efficiency in SCADA. Grid company attaches great importance to the quality of the underlying data, requires improving the
quality of the underlying data station end and want to solve the adverse effects on all aspects of the send data. This paper analyzed the scheduling affect balance in all aspects of the bus terminal, proposed corresponding technical indicators and solutions, and verified The technical indicators and the feasibility of the scheme through simulation finally.

2. The typical structure of smart substation automation system

Substation Automation is the basis for grid to achieve power measurement and control, it realized automatic monitoring of substation equipment, measurement, control, and communications and scheduling integrated automation through modern information, communication and control technology. Substation automation equipment comprises BCU, RTU, intelligent terminal, the merging unit, phasor measurement unit (PMU), clock synchronization, Ethernet switches, integrated monitoring system, the typical structure is shown below.

![Figure 1. The typical structure of substation automation](image)

3. Analysis of influence factors of unbalanced bus dispatching

3.1. Telemetry information flow

According to automation system telemetry information flow shown in figure 1, from electrical to dispatch master data applications, the remote measurement went through the following process:

1. Electrical transmission: Voltage transformer converts the high voltage to low voltage, current transformer converts high current to small current.

2. Analog to digital conversion: convert the small voltage, low current analog to digital conversion.

For traditional substation, analog to digital conversion is completed inside BCU; for smart substation, analog-to-digital conversion is done by merging units.

3. Remote Computing: BCU receives real-time sampling values, calculated and sent to the telemetry values.

4. Telemetry sent: I zone data gateway machine receives and re-post the telemetry data.

5. Scheduling: Scheduling master station terminals accept the data, complete the assessment and advanced applications.

3.2. Factors of unbalanced scheduling bus terminal

Ignore the power loss of bus, the inlet and outlet of the power should be zero. Under normal conditions, the bus power is balanced. In project application, affected by the accuracy of data synchronization, mutual supply and other factors, there are some imbalance of power dispatching.

1. Accuracy error
   - The amplitude and phase error of transformer.
   - The second small PT, small CT amplitude and phase angle error.
   - AD conversion error. For more than 14 bit AD, it can be ignored.
   - Telemetry dead zone.
   - Calculation rounding errors. Normally rounding error is small, it can be ignored.
(2) Data sync

The master scheduler adopts real-time data of the latest section to evaluate and calculate. However, because of inconsistencies from internal BCU and RTU sending data, telemetry data used to calculate the master is often not at the same time cross-section. For the substation which has rapid fluctuations of trend, the affect of data synchronization of the master scheduler data analysis is particularly evident.

4. Solution

For dispatching bus unbalanced factors, in addition to PT and CT accuracy problems involving the transformation of the physical characteristics of the device, the telemetry dead zone, telemetry calculation error, telemetry sent out of sync and other factors may be considered to be eliminated by internal implementation. The basic idea of this solution is: eliminate the influence of the dead zone telemetry, acquisition and delivery the sync datas which are on the same bus.

4.1. General Substation Solution

Considering the engineering practicality, the general substation solutions do not involve hardware changes, only to do a software upgrade involves two types of devices: BCU, RTU.

4.1.1 Upgrade package of BCU. The BCU adds cycle send on the basis of change send, the delivery cycle time less than one second. The realization of reconstruction BCU is shown in figure 2.

Two keys upgrade for the BCU s are iterative calculation and cycle send.

(1) Iterative calculation

Telemetry is calculated by the method of iteration calculation instead of cycle calculation, ensure that the send queue can always get the latest telemetry.

- RMS

\[
X_k = \sqrt{N \times X_{k-1}^2 + x(k)^2 - x(k-N)^2} \quad (1)
\]

Where: \(X_k\) is the current time rms; \(X_{k-1}\) is the previous time rms; \(N\) is the number of samples per cycle; \(x(k)\) is the current time sample values; \(x(k-N)\) is one cycle wavefront samples.

- Active power

\[
P_k = P_{k-1} + u(k) \times i(k) - u(k-N) \times i(k-N) \quad (2)
\]

Where: \(P_k\) is current time active; \(P_{k-1}\) is previous time active power; \(u(k)\) is the current sampling time voltage value; \(u(k-N)\) is one cycle wavefront voltage samples; \(i(k)\) is the current time current sampling value; \(i(k-N)\) is one cycle before the current wave samples.

- Reactive power

About reactive power according to IEEE definition:

\[
Q = \sum_{k=1}^{\infty} U_k \times I_k \sin \phi_k \quad (3)
\]

Fourier method is one of the commonly used power algorithm, it has no theoretical error, but it is not suitable for real-time computing because of intensive computation and long calculation period. If the voltage of the single frequency signal is delayed \(T/4\), i.e., phase shifted 90°, product signal and current signal obtained in a period \(T\) is integrated and averaged, then it can get the required reactive power. In this paper, fundamental and all harmonic voltage signals are phase-shifted relative to the current 90° by the Hilbert [8-12] digital filtering algorithms, ensure that measurements are various reactive power of the fundamental and harmonic.

Reactive power base on Hilbert is calculated as follows,

\[
Q_k = Q_{k-1} + u_{HF1}(k) \times i_{HF1}(k-N) + u_{HF2}(k) \times i_{HF2}(k-N) \quad (4)
\]
Compared to other methods obtained Hilbert filter, the Half-band IIR filter type filter has advantages of lower order, smaller amount of computation and data storage capacity. The expression of its complex frequency domain for \( H_{F1}(Z) / H_{F2}(Z) \), refer to the following formula.

\[
H_{F1}(z) = \prod \left( 1 - \frac{a_i}{a_i z^{-2}} \right)
\]

\[
H_{F2}(z) = \prod \left( \frac{1 - a_i z^{-2}}{a_i - z^{-2}} \right)
\]

Which, \( H_{F1}(z) \) is the voltage digital phase frequency domain filter expression, \( H_{F2}(z) \) is the current digital phase frequency domain filter expression.

Where: \( Q \) is reactive power; \( U_k \) is \( k \)-harmonic voltage rms; \( I_k \) is the \( k \)-harmonic current rms; \( Q_k \) is the \( k \)-harmonic voltage and current phase; \( Q_{k-1} \) is previous time reactive power value; \( U_{HF1}(k) \) is the current time voltage value by Hilbert transform; \( U_{HF1}(k-1) \) is previous time voltage value by Hilbert transform; \( i_{HF1}(k) \) is current time current value by the Hilbert transform; \( i_{HF1}(k-1) \) is previous time current value by the Hilbert transform.

(2) Telemetry cycle send

The BCU can take second period of time as a starting point to send, when the devices have unified clock source. It can send telemetry data on regular intervals according to the cycle value.

\[\text{Start} \]
\[\text{telemetry computation} \]
\[\text{whether } \text{Telemetry period } \text{send is put into} \]
\[\text{whether Beyond the dead zone} \]
\[\text{Added to the IEC61850/103 to send queue} \]
\[\text{Wait for interrupt} \]

**Figure 2.** The telemetry realization flow chart of BCU

4.1.2 RTU upgrade program. RTU transmit data to the master through the data frame. If the telemetry data in the same bus was not in one frame, dispatching will appear remote data synchronization. To solve this problem, the paper propose the concept of important telemetry packet sending. It means to arrange the same telemetry data in one bus in the same frame, RTU package the interval telemetry data telemetry data of this bus in the same frame and send them.

The realization flow chart of RTU is shown as figure 3. Two major upgrade in RTU are as follows:

- Process of cycle sending: extract the same time telemetry data by sampling time alignment or label alignment.
- Important telemetry packet send: achieving configured telemetry channel data sent on the same frame.
**5. New generation smart substation solutions**

One important goal of this project is to solve the problem of telemetry data out-sync. Drawing bus protection ideological, taking the bus as a unit, retaining the original configuration of BCU, it adds cluster bay control unit. Cluster bay control unit receives all line telemetry data of the bus, sends the Information redundancy to RTU. then the RTU select only the telemetry data of cluster bay control unit to scheduling.

Cluster bay control unit: Cluster bay control unit belongs to secondary equipment. It can run 15 to 20 online virtual BCU. Each virtual device has full functionality of the current bay control unit, similar configuration parameters and methods with physical device, which has an independent operation and maintenance interface and a soft cast back plate.

New generation smart substation automation system has features of compact structure, functional integration, information integration, cluster bay control unit consistent with the direction of development of new generation smart substation. On one hand, cluster bay control unit enhance the scheduling side bus balance. On the other hand, it solves the problem that smart substation BCU s has no backup device, improves reliability of the BCU.

**6. Scheme comparison**

The traditional substation upgrade scheme based on cycle sending and the smart substation upgrade scheme based on cluster bay control unit can effectively improve the balance of UHV near area on dispatch end, two options have their advantages and disadvantages.

(1) Traditional substation reconstruction scheme

Advantages: only software upgrade, lower costs.

Disadvantages: Telemetry information depends on the GPS signal, the telemetry values may no longer synchronized when the GPS signal is abnormal.

(2) Smart substation reconstruction scheme

Advantages: it does not affect the normal operation of the existing BCU and RTU, with less risk; it can ensure the same bus telemetry collect and sent at the same time; it can be used as an alternate interval BCU which improves substation reliability.

Disadvantages: New device will increase costs.

**7. Simulations**

Simulate a 500kV UHV substation, primary connection diagram see the figure 4. Among them, ChengYi, ChengEr are parallel double circuit line, ChangYi, ChangEr, ChangSan are parallel multi circuit transmission lines.

---

**Figure 3.** The realization flow chart of I district data communication gateway
The UHV substation has tide fluctuations and rapidly power changes. Take Medium voltage side of main transformer as an example, the power fluctuation is up to 787MW in one day, active power fluctuations peaked at 175MW within five seconds.

The measured bus power in master is imbalance, in order to ensure simulation data with balance power, the main transformer medium voltage side, ChangYi, ChangEr, ChangSan take the real measure data. According to computing base on bus power balance equation, ChengYi and ChengEr have the same power.

The parameters before reconstruction: telemetry dead zone is 0.5%, PT, CT accuracy is class 0.2, telemetry sent time is 3 seconds.

The parameters after reconstruction: PT, CT accuracy is class 0.2, synchronous acquisition and transmission, not affected by the dead zone and telemetry unsynchronized send.

The determination method for 500kV bus power balance is: active power unbalance is less than 20MW, reactive power unbalance is less than 30MVar.

The simulation results shown in Table 1, active error before and after reconstruction are shown as figure 5 (this figure is only part of the data interception).

**Table 1. The simulation results of power balance**

| Simulation case                  | Max unbalance power/MW | Qualified rate/% |
|----------------------------------|------------------------|------------------|
| Before reform: active power      | 78.6                   | 83.6             |
| After reform: active power       | 5.8                    | 100              |
| Before reform: reactive power    | 38.3                   | 98.8             |
| After reform: reactive power     | 23.4                   | 100              |

**8. Conclusions**

Affect by UHV rapid fluctuations, SCADA UHV near zone has low qualification rate of bus balance. Through analysis to the whole process of acquisition, calculation and transmission. This paper points out that the loss of precision and telemetry send sync are the causes of bus unbalanced on scheduling terminal. From the thought of bus protection, proposed that using the reformation scheme of all intervals simultaneous acquisition and sending in the same bus, eliminates telemetry dead zone, reduces total power plus error on dispatching. For traditional substation, through changing the existing software realization of BCU and RTU, adding new function of cycle sending and sending functionally important.
telemetry packets, it ensures the scheduling receives the same time interval BCU data. For smart substation, it proposes the use of cluster bay control unit to achieve synchronous acquisition on delivery, not only solves the problem of bus unbalanced on scheduling terminal, but also become to an backup for interval BCU, improves substation reliability. Finally, it takes a special high-voltage substation as a model, takes the real measured data as simulation data, simulation results shows the effectiveness of the proposed scheme.

Acknowledgements
Project supported by Science and Technology Project of SGCC (520900160006), Research on Key Technologies of Centralized Redundant Backup Measurement And Control Device For Smart Substation.

References
[1] Xi F, Satyajayant M, Xue G L et al 2012 Smart Grid, the new and improved power grid: a survey IEEE Communications Surveys and Tutorials (COMST) 12 944-80
[2] Song Y Q, Zhou G L, Zhu Y L 2013 Present Status and Challenges of Big Data Processing in Smart Grid Power Syst. Technol. 37 927-34
[3] Zhang W L, Tang G F, Zha K P et al 2010 Application of advanced power electronics in smart grid Proceedings of the CSEE 30 1-7
[4] Niu D X, Gu Z H, Xing M et al 2006 Study on forecasting approach to short-term load of SVM based on data mining P. CSEE 26 6-12
[5] Tang Y, He J, Sun H D et al 2012 AC tie-line stochastic power fluctuation mechanism and amplitude estimation for two-area interconnected power systems P. CSEE 32 30-5
[6] Liu Z C, Wang C M, He Y B 2009 Analysis of power control of 1000kV Changzhi-Nanyang-Jingmen UHV tie-line Central China Electric Power 22 5-8
[7] Zeng Q Y 2012 Study on power transmission capability of 1000kV ultra high voltage transmission system Power Syst. Technol. 36 1-6
[8] Johansson H, Wanhhammer L 1998 Digital Hilbert Transformers Composed of Identical Allpass Subfilters Proceedings of the 1998 IEEE International Symposium on Circuits and Systems (California, USA) 437-40
[9] Ansari R 1987 IIR Discrete-time Hilbert Transformers IEEE Trans on Acoustics, Speech, Signal Processing 35 1116-9
[10] Ansari R 1985 Elliptic Filter Design for a Class of Generalized Halfband Filters IEEE Trans on Acoustics, Speech, Signal Processing 33 1146-50
[11] Zu Quxiao, Pang Hao 2003 A Method of Reactive Power Measurement Based on Hilbert Digital Filter in Power System Automation 27 50-2
[12] Xue Y D, Xu B Y, Feng Z R 2004 Average and instantaneous reactive power of non-sinusoidal circuit based on Hilbert transformation Power Syst. Autom. 28 35-9